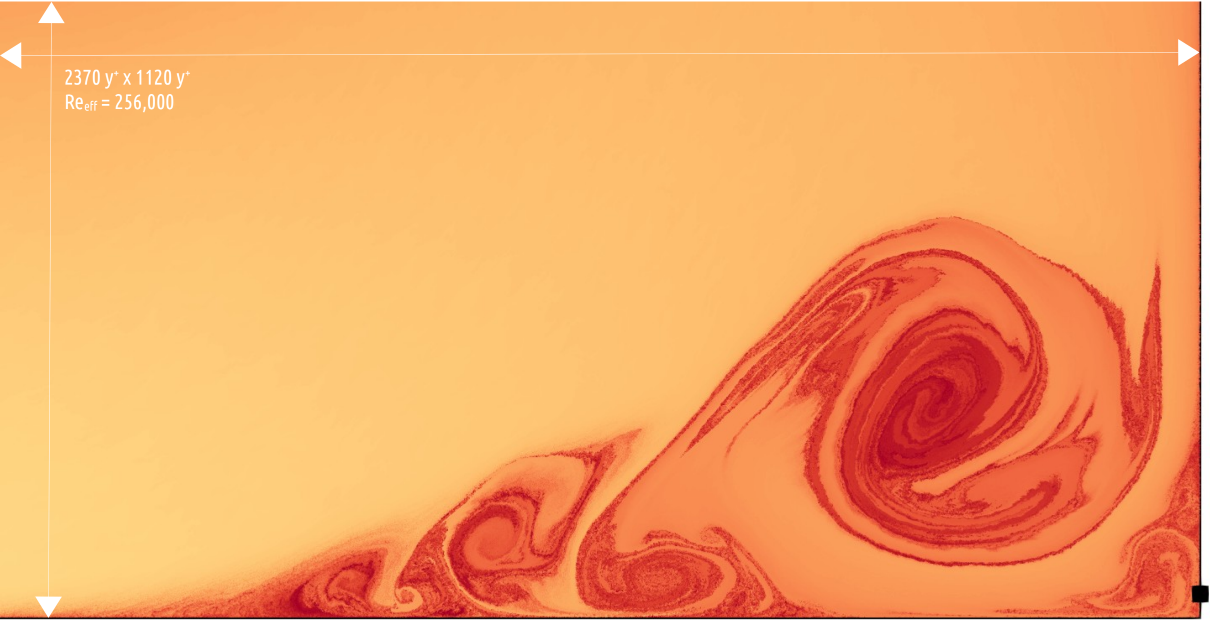
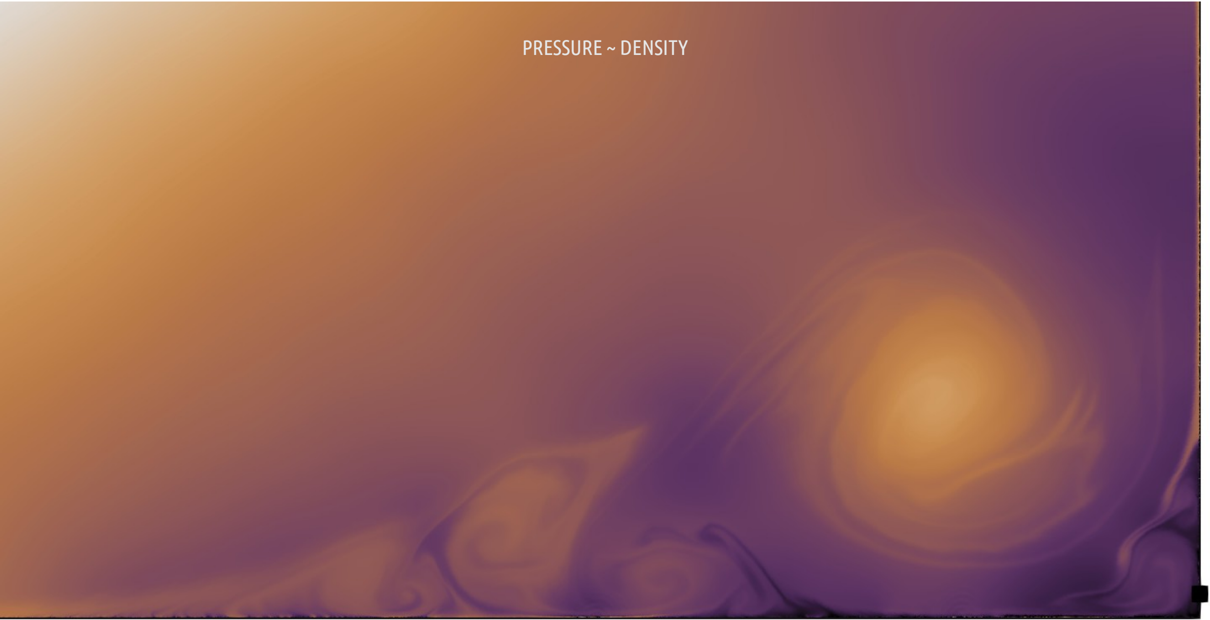
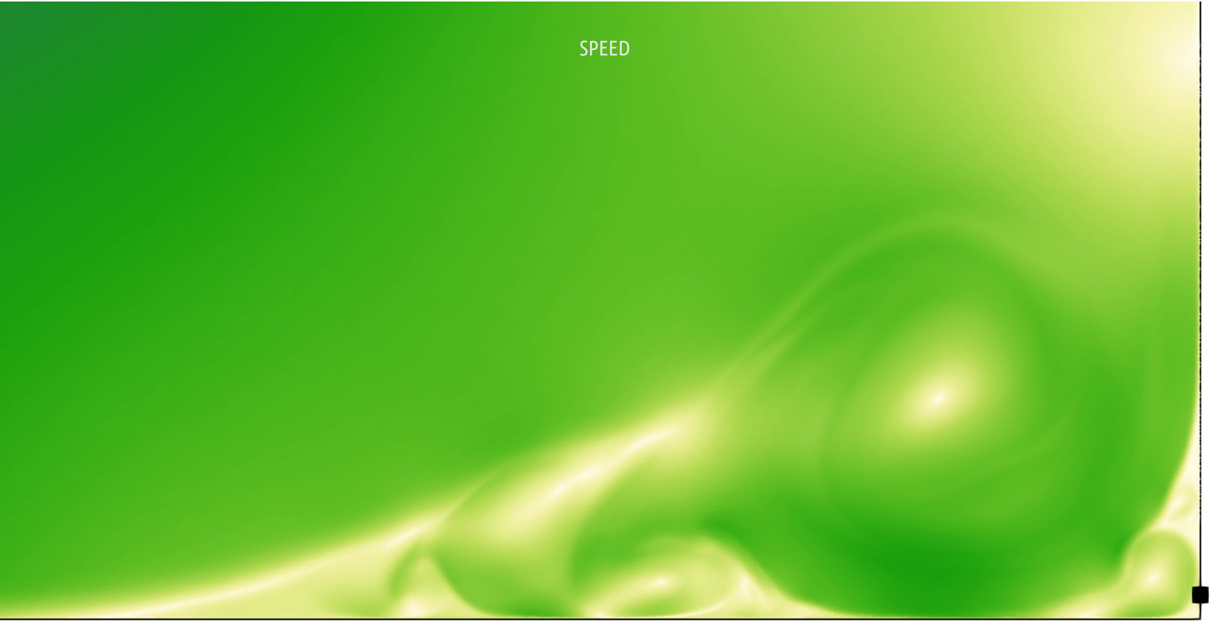

$2370\ y^+ \times 1120\ y^+$
$Re_{eff} = 256{,}000$


PRESSURE ~ DENSITY


SPEED

1. vision

"We hope to motivate the fellow fluid dynamicists to become architects of their own data workflows. Shared results make the simulations outlive the research projects for the benefit of the wider community of practice"

2. available materials

4TU.ResearchData

High-resolution SPH simulations of a 2D dam-break flow against a vertical wall

1 collection, 4 datasets, 735 GB, 1650 files https://doi.org/10.4121/c.5353691

YouTube, animations playlist https://youtu.be/mJCVCAVID-w

SPHERIC 22 Dam Break Flow Benchmarks: Quo Vadis? https://doi.org/10.5281/zenodo.6391457

SPHERIC 25 The pressure signal in weakly compressible SPH https://doi.org/10.5281/zenodo.14674511

Burgers Symposium 2025 this presentation **https://doi.org/10.5281/zenodo.15486157**

3. history and acknowledgements

Nov 2020 – Apr 2021 tail to project `GPU acceleration and numerical optimization for SPH` 2018-2020

Delft Institute of Applied Mathematics, TU Delft sponsor of compute resources ← GPU Nvidia Quadro GP100

Roel Janssen, 4TU.ResearchData Netherlands deposit metadata

4. dam-break benchmark

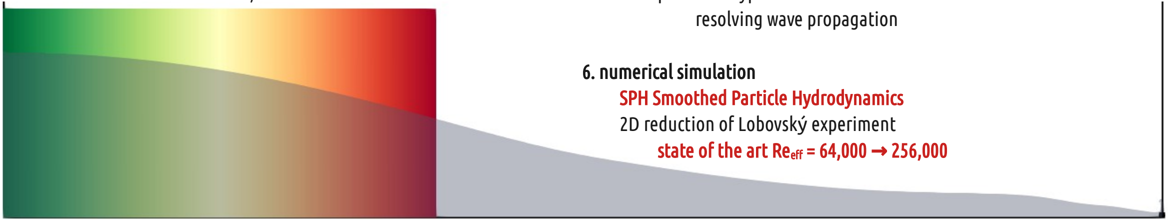
- *Dammbruch* (Ritter 1892)
- free-surface flows
  - shallow-water equations
  - non-hydrostatic pressure
  - bores in open channels
  - collapse of retaining structures
  - impacts on structures
    - **experiment Lobovský et al 2013**
      - dry floor, impact on vertical wall
      - Re = 516,000

5. modelling approach

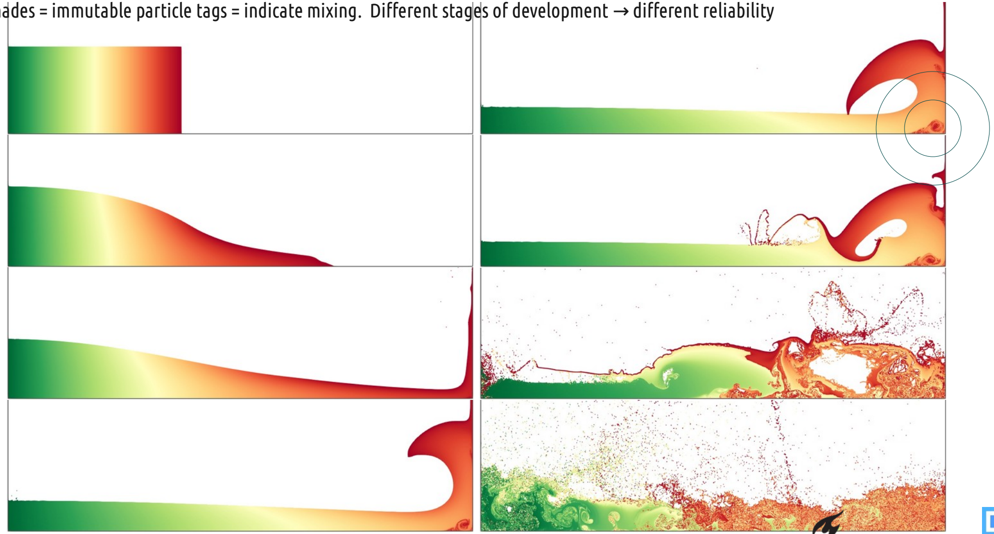
- single-phase system
  - without air → blank = nothing
- no surface tension
  - the deformed free surface is not stabilised
- weakly compressible fluid
  - constant artificial (low) speed of sound
    - being the celerity of compression/rarefaction waves
  - linear equation of state
    - pressure ~ density
  - parabolic-hyperbolic PDEs
    - resolving wave propagation

6. numerical simulation

- SPH Smoothed Particle Hydrodynamics
- 2D reduction of Lobovský experiment
  - state of the art Re_{eff} = 64,000 → 256,000



Colour shades = immutable particle tags = indicate mixing. Different stages of development → different reliability



SPH → the forces on each travelling computational node are smoothed interactions with other node flowing by within a radius

7. particles for meshless numerical integration

computational nodes with mass → not material particles, let alone `smoothed` ones
travelling → not pinned to a stencil
→ do not confuse mass density and number density!

8. hydrodynamics

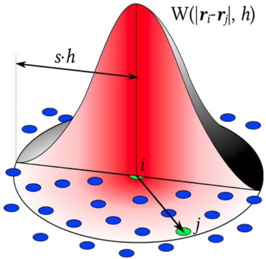
Newtonian mechanics → not Lagrangian mechanics, yet consistent with it
continuum approximation
Navier-Stokes equations → also solid mechanics
Lagrangian material derivative → non-linearity is implicit

9. smoothing for spatial integration

convolution with a well-behaved **kernel** function, supported within a set radius of influence
for gradient operators → integral → action of force terms inside the kernel support
computational nodes → numerical quadrature → summations

10. assumed you all the physics is in order, SPH is reliable so long as particles really follow the underlying flow

- clumps and voids → coverage grows uneven → mitigation
- no/few particles in the kernel → interfaces and boundaries → mitigation
- weakly compressible fluid → numerical rounding-off causes waves → noise → mitigation



drawing by Jlcercos, Wikipedia

11. simulation = 2D reduction of Lobovský experiment

state of the art Re_{eff} = 64,000 → Re_{eff} = 256,000

brute-force approach...

- 6400 particles per water column (H/dx) → the fluid is made of **82 million** particles
  → estimated viscous sublayer: 4 particles per y^+ → DNS-like at Re_{eff}
- density, velocity, particle tag → 3 quantities of interest + 2 coordinates
- single-precision variables (FP32) → 4B
- size of the problem → **984 MB** per time level

...and a bit of convergence analysis → likewise for H/dx = 800, 1600, 3200 → 1, 5, 20 million particles

12. explicit time integration

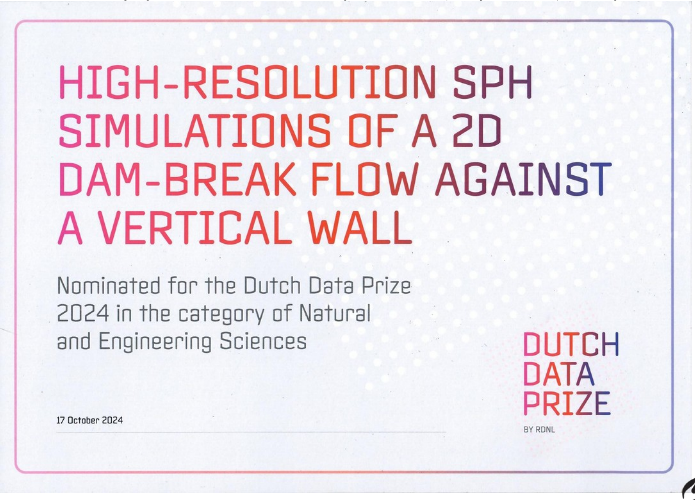
- compute-bound, embarrassingly parallel task → number crunching on GPUs ← **solver** DualSPHysics 5.0 https://dual.sphysics.org/
- stability criterion → increase particle spacing → reduce the time step
  → variable, based on the fastest particle (strict) ← $\Delta t = C \min_i \dfrac{1}{\frac{c_0}{h} + \max_j \frac{|\mathbf{u}_{ij} \cdot \mathbf{r}_{ij}|}{\mathbf{r}_{ij}^2}}$
- 82 million particles → **11,743,221** time levels $O(10^7)$ → average time step $O(10^{-6})$
- 20 seconds of simulated flow → **54'** runtime to simulate 1 physical second (2021)
  → **19,2 PB** (10^{15}) worth of information processed ← **1TB storage at 4TU.ResearchData**

13. performance

- 2021 GPU Nvidia GP100 (3,584 cores, ...) → 20M particles **138 hours**, 82M particles **45 days**
- 2025 GPU Nvidia H100 (16,896 cores, ...) → 20M particles 40 hours ← courtesy SURF / EUROCC

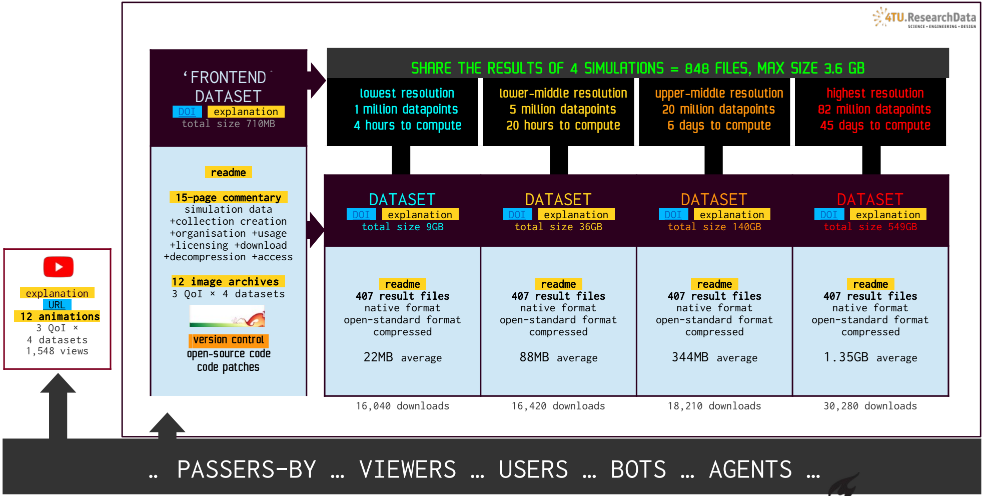
14. FAIR data findable accessible interoperable reproducible

2024 Dutch Data Prize ← jury-nominated finalist → only nominee in (computational) fluid dynamics

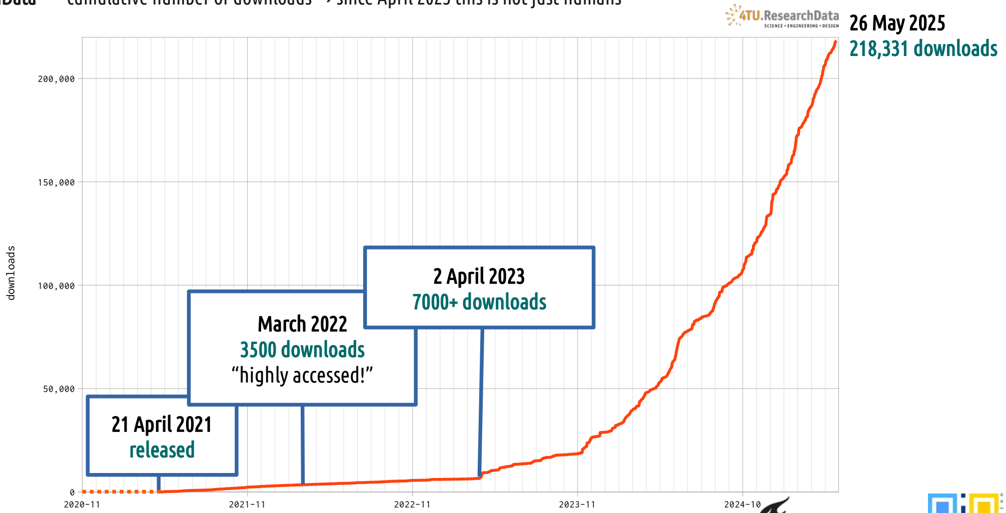


15. FAIR upscale challenge

4 simulations **1650 files** 750 GB → how to make exploration inviting for viewers? → https://doi.org/10.4121/c.5353691



16. 4TU.ResearchData cumulative number of downloads → since April 2023 this is not just humans

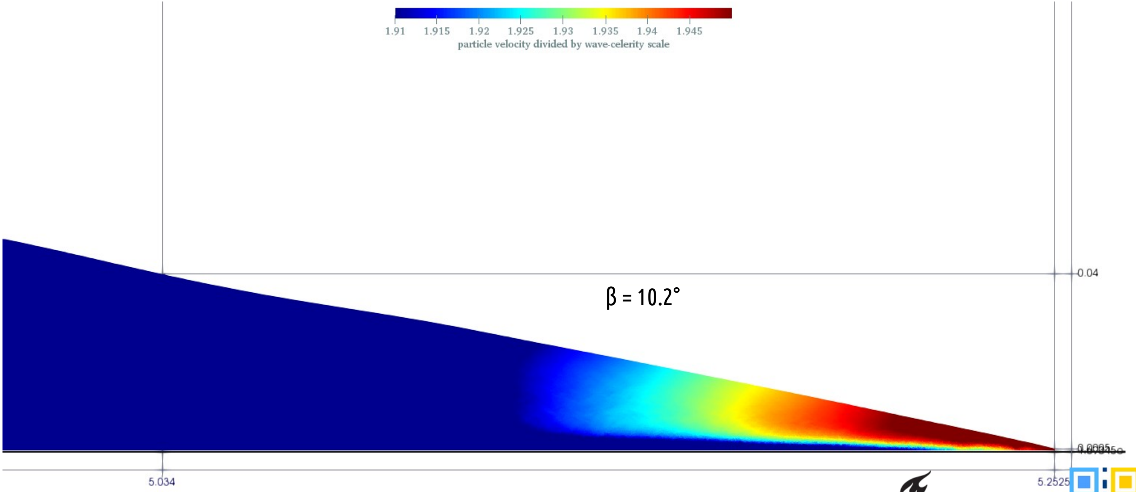


We hope to motivate the fellow fluid dynamicists to become architects of their own data workflows

Shared results make the simulations outlive the research projects for the benefit of the wider community of practice

this presentation

18. extra slope angle and velocity distribution in the surge toe ← presented at SPHERIC 22 https://doi.org/10.5281/zenodo.6391457



19. extra simulated impact pressure at four resolutions versus measurements by Lobovský ← SPHERIC 22 https://doi.org/10.5281/zenodo.6391457