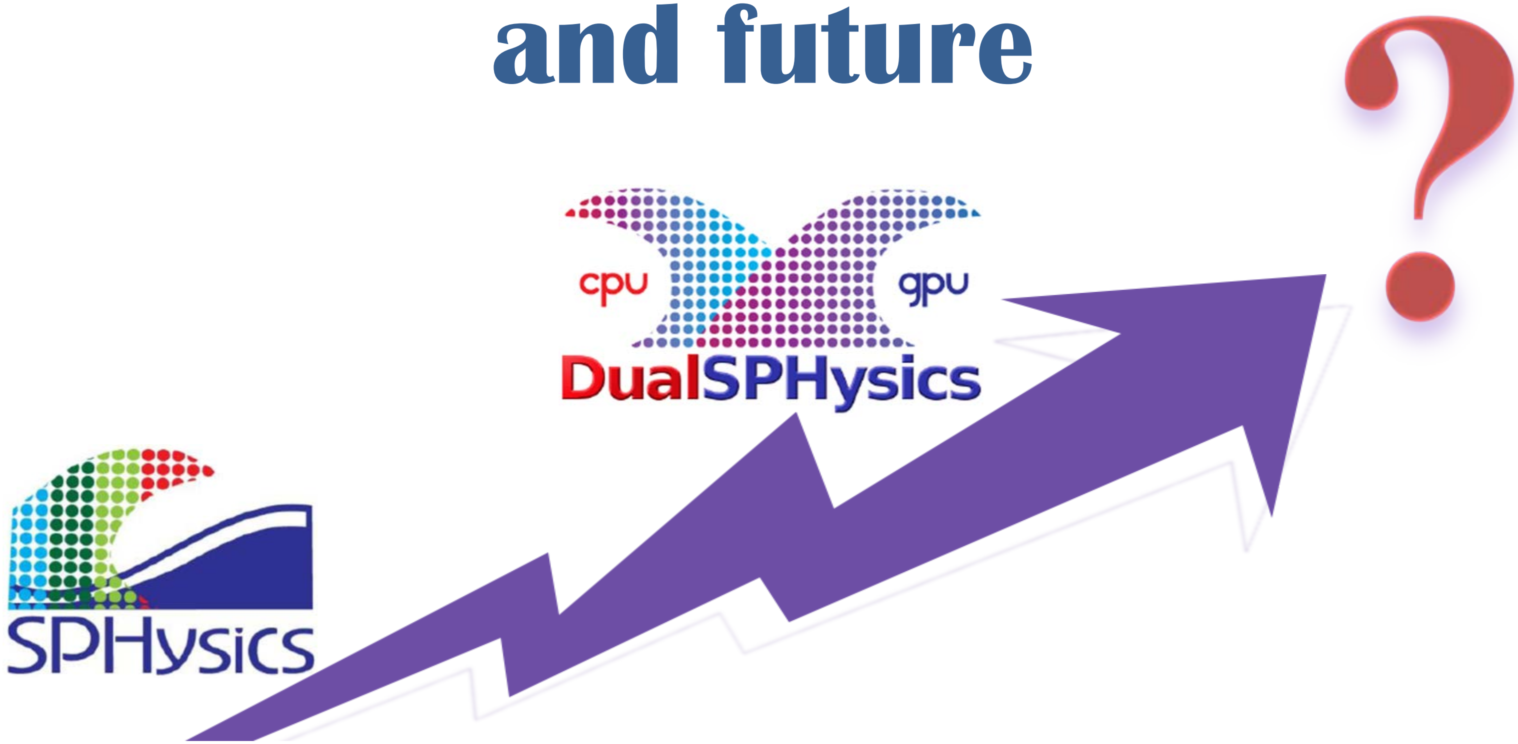
DualSPHysics: past, present and future



J.M. Domínguez, A.J.C. Crespo, A. Barreiro, O. García-Feal,
M. Gómez-Gesteira, Ricardo Canelas, C. Altomare,

jmdominguez@uvigo.es

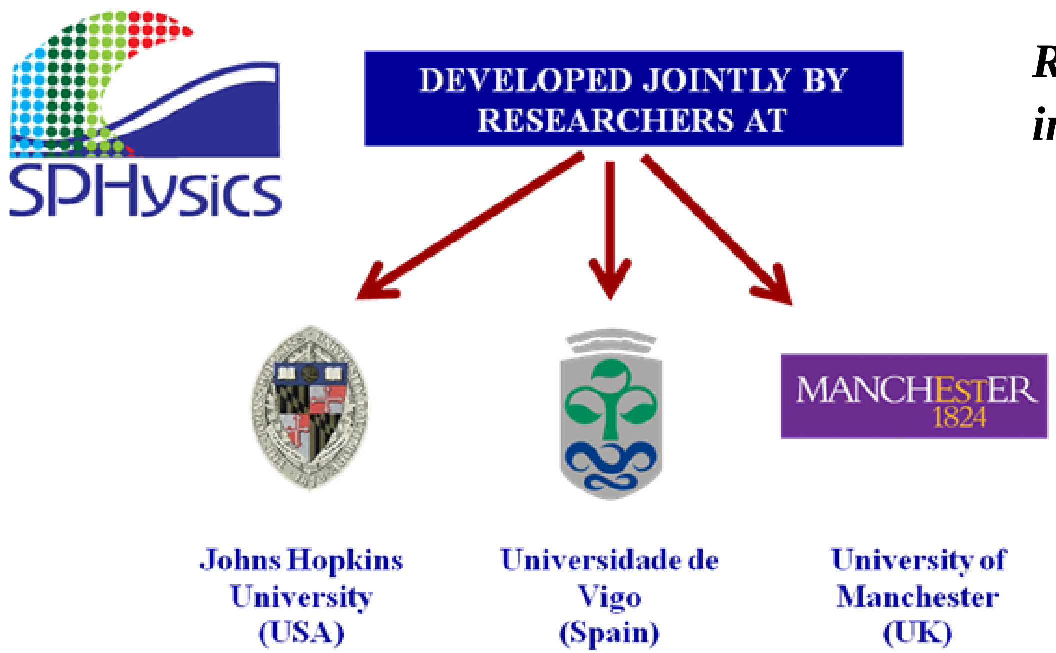
NVIDIA CUDA CENTER OF EXCELLENCE
Universida de Vigo
MANCHESTER 1824 The University of Manchester
flanders HYDRAULICS RESEARCH
TÉCNICO LISBOA
UNIVERSITÀ DEGLI STUDI DI PARMA
UNIVERSITEIT GENT
UNIVERSIDAD DE GUANAJUATO

Outline

1. **Birth of DualSPHysics**
   - **1.1. Origin of DualSPHysics**
   - **1.2. Why GPUs?**
   - **1.3. DualSPHysics project**
2. Stages of evolution
   - 2.1. Optimisations to maximize speed
   - 2.2. Multi-GPU to maximize the size
   - 2.3. Developing new capabilities
3. Future of DualSPHysics
   - 3.1. Next release
   - 3.2. Ongoing work

1.1. Origin of DualSPHysics

The DualSPHysics code was created starting from SPHysics.



Release in 2007

SPHysics is a numerical model SPH developed for the study of free-surface problems.

It is a code written in Fortran90 with numerous options (different kernels, several boundary conditions,…), which had already demonstrated **high accuracy** in several validations with experimental results… but it is **too slow** to apply to large domains.

1.1. Origin of DualSPHysics

The problem:

- SPH PRESENTS A HIGH COMPUTATIONAL COST THAT INCREASES WHEN INCREASING THE NUMBER OF PARTICLES
- THE SIMULATION OF REAL PROBLEMS REQUIRES A HIGH RESOLUTION WHICH IMPLIES SIMULATING MILLIONS OF PARTICLES

IT WAS NECESSARY TO INCREASE THE VELOCITY OF THE CODE A FACTOR 100x

IT WAS NECESSARY TO USE HPC TECHNIQUES

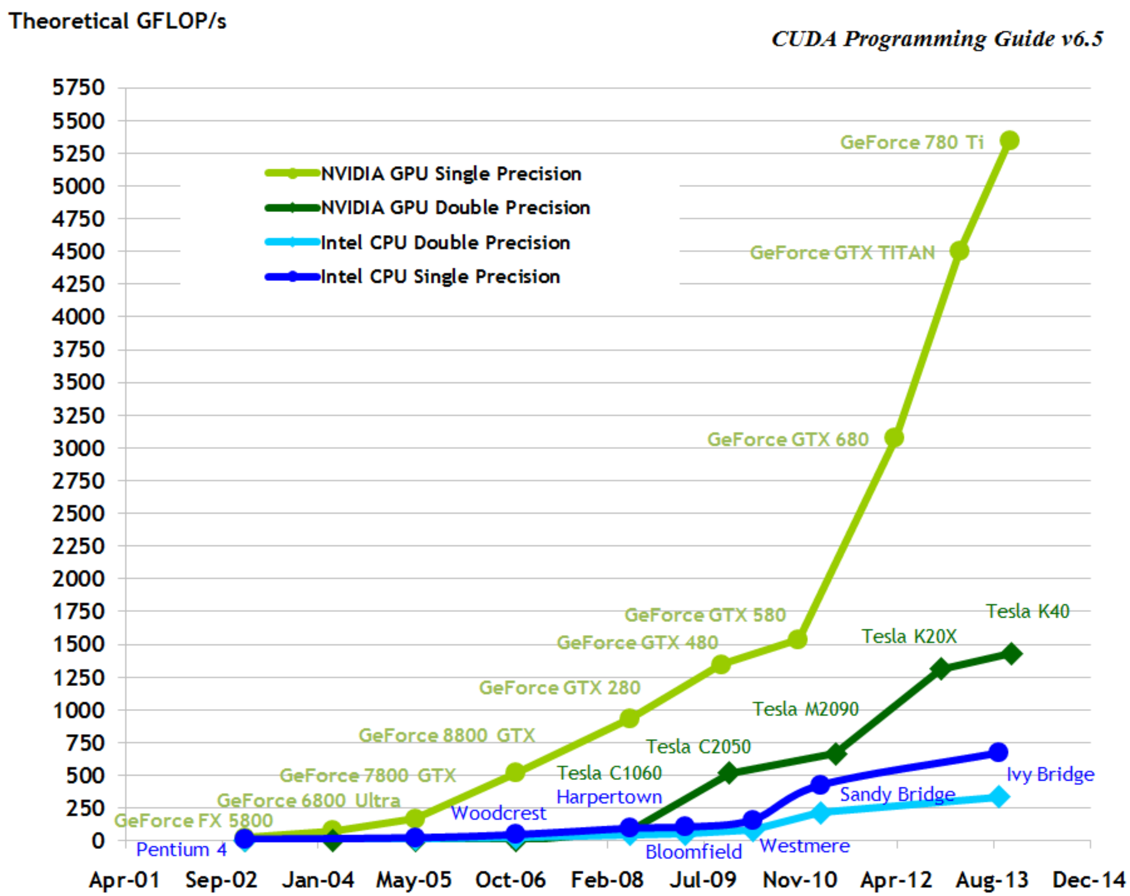
Classic options:

- **OpenMP:** Distribute the workload among all CPU cores (≈4x)
- **MPI:** Combines the power of multiple machines connected via network (high cost).

New option:

- **GPU:** Graphics cards with a high parallel computing power (cheap and accessible).

1.4. Graphics Processing Units (GPUs)



Graphics Processing Units (GPUs)

- powerful parallel processors
- designed for graphics rendering
- their computing power has increased much faster than CPUs.

Advantages: GPUs provide the necessary power with very low cost and without expensive infrastructures.

Drawbacks: An efficient and full use of the capabilities of the GPUs is not straightforward.

1.3. DualSPHysics project

First version in late 2009.

It includes **two implementations**:

- **CPU**: C++ and OpenMP.
- **GPU**: CUDA.

Both options optimized for the best performance of each architecture.

Why two implementations?

This code can be used on machines with GPU and without GPU.

It allows us to make a fair and realistic comparison between CPU and GPU.

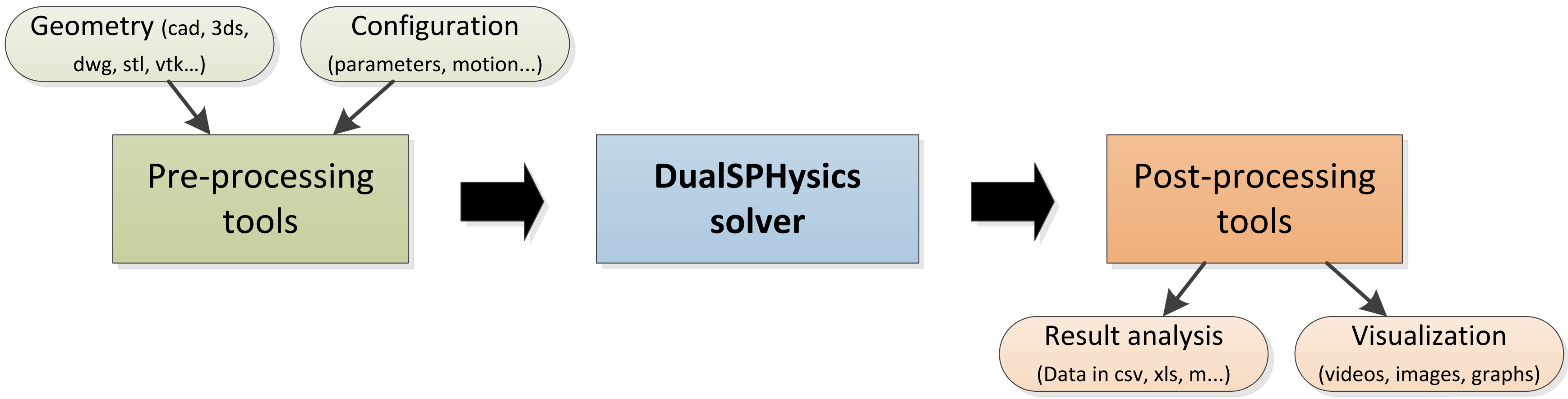
Some algorithms are complex and it is easy to make errors difficult to detect. So they are implemented twice and we can compare results.

It is easier to understand the code in CUDA when you can see the same code in C++.

Drawback: It is necessary to implement and to maintain two different codes.

1.3. DualSPHysics project

DSPH project includes:



Pre-processing tools:

- Converts geometry into particles.
- Provides configuration for simulation.

DualSPHysics solver:

- Runs simulation using SPH particles.
- Obtains data simulation for time intervals.

Post-processing tools:

- Calculates magnitudes using particle data.
- Generates images and videos starting form SPH particles.

1.5. DualSPHysics project

cpu gpu DualSPHysics

DEVELOPED JOINTLY BY RESEARCHERS AT

and many contributors

MANCHESTER 1824

Universidade de Vigo (Spain)

University of Manchester (UK)

Dr Benedict Rogers
Dr Georgios Fourtakas
Dr Athanasios Mokos
Dr Stephen Longshaw
Abouzied Nasar
Prof. Peter Stansby

Prof. Moncho Gómez Gesteira
Dr Alejandro J. C. Crespo
Dr José Domínguez Alonso
Dr Anxo Barreiro Aller
Orlando García Feal

Prof. Rui Ferreira
Dr Ricardo Canelas

Dr Corrado Altomare
Dr Tomohiro Suzuki

Dr Renato Vacondio
Prof. Paolo Mignosa

Dr Xavier Gironella
Andrea Marzeddu

www.dual.sphysics.org

Outline

1. Birth of DualSPHysics

    1.1. Origin of DualSPHysics

    1.2. Why GPUs?

    1.3. DualSPHysics project

2. **Stages of evolution**

    2.1. Optimisations to maximize speed

    2.2. Multi-GPU to maximize the size

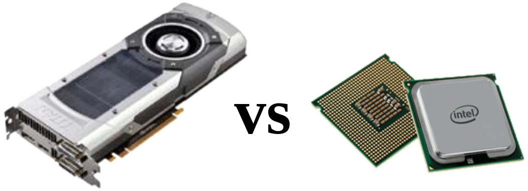
    2.3. Developing new capabilities

3. Future of DualSPHysics

    3.1. Next release

    3.2. Ongoing work

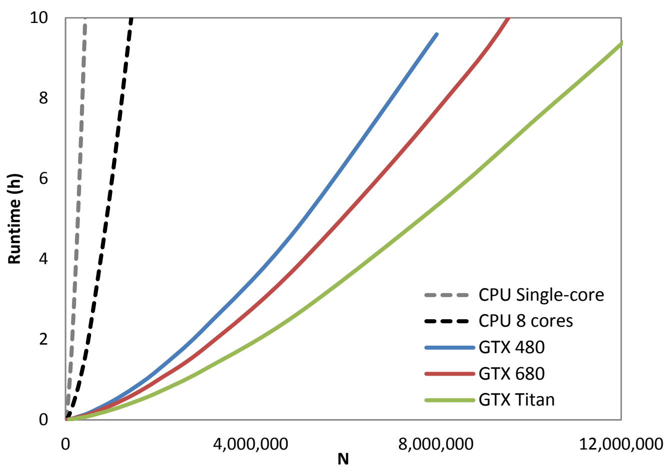
2.1. Optimisations to maximize speed



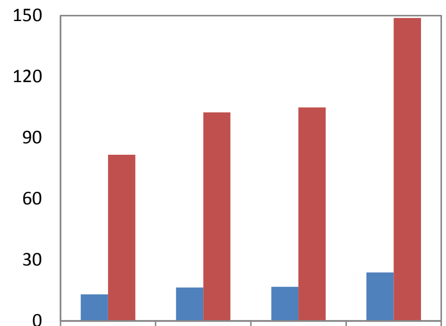
The main objectives were:

- To maximize the speedup of GPU against CPU.
- To maximize the performance on CPU and GPU.

Runtime for CPU and different GPU cards.



Speedups of GPU against CPU simulating 1 million particles.



	GTX 480	GTX 680	Tesla K20	GTX Titan
vs CPU 8 cores	13	16	17	24
vs CPU Single-core	82	102	105	149

After optimising the performance of DualSPHysics on CPU and GPU...

The most powerful GPU (**GTX Titan**) is **149 times faster** than CPU (single core execution) and **24 times faster** than the CPU using all 8 cores.

Domínguez JM, Crespo AJC, Gómez-Gesteira M. Optimization strategies for CPU and GPU implementations of a smoothed particle hydrodynamics method. Computer Physics Communications, 184(3): 617-627, **2013**.

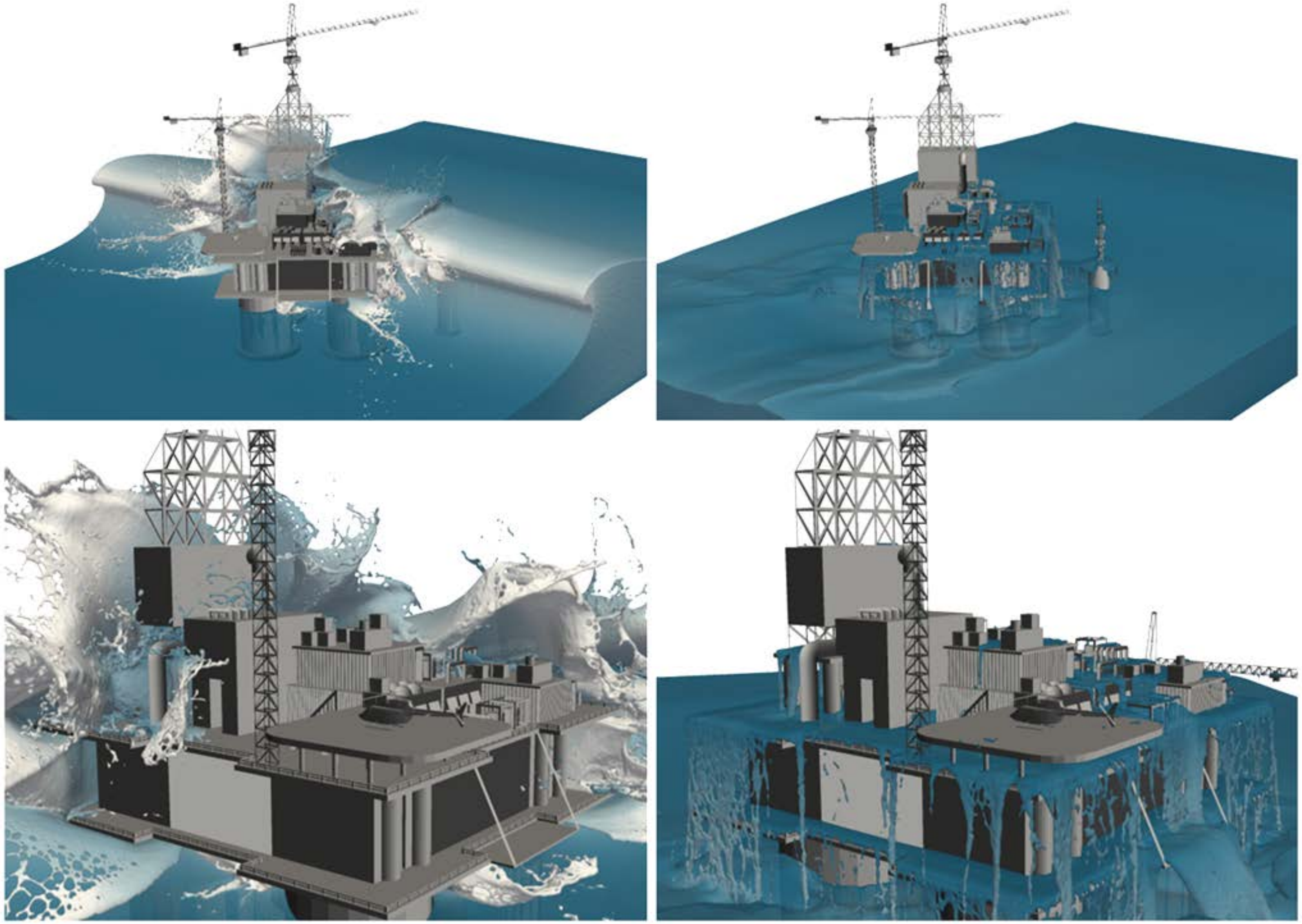
Domínguez JM, Crespo AJC, Gómez-Gesteira M, Marongiu JC. Neighbour lists in Smoothed Particle Hydrodynamics. International Journal For Numerical Methods in Fluids, 67(12): 2026-2042, **2011**.

2.2. Multi-GPU to maximize the size

64×

Simulation of 1 billion SPH particles using 64 GPUs Tesla

Large wave interaction with oil rig using 10^9 particles



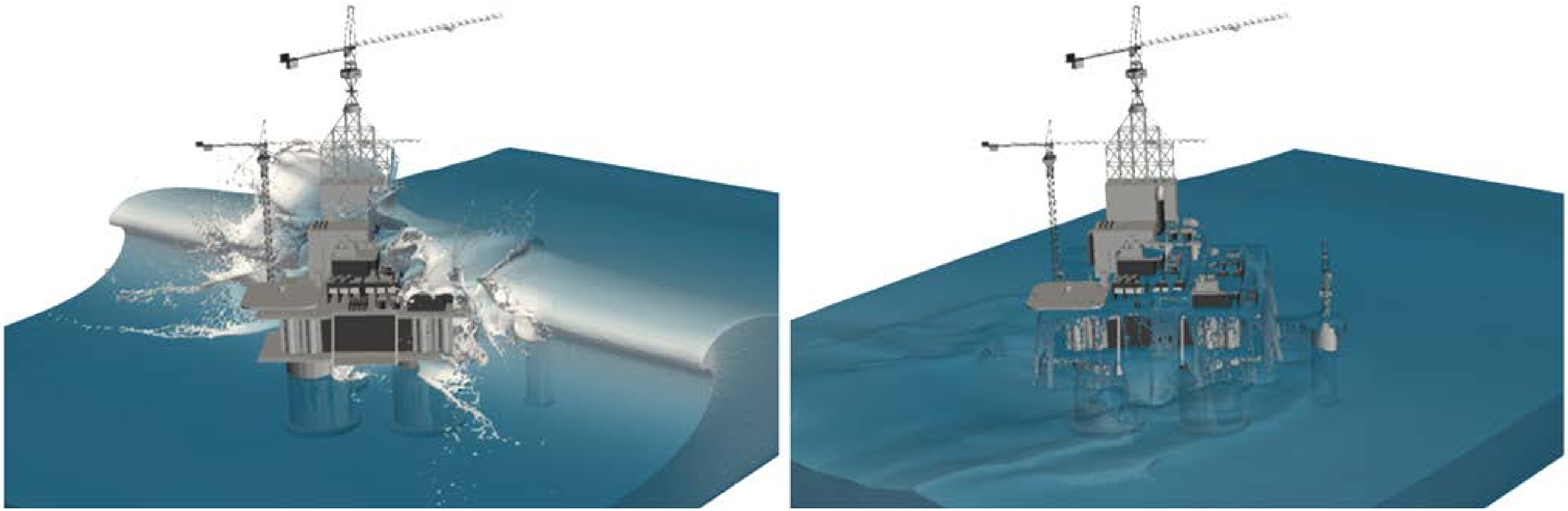
Domínguez JM, Crespo AJC, Valdez-Balderas D, Rogers BD, Gómez-Gesteira M. New multi-GPU implementation for Smoothed Particle Hydrodynamics on heterogeneous clusters. Computer Physics Communications, 184: 1848-1860, **2013**.

2.2. Multi-GPU to maximize the size

64×


Simulation of 1 billion SPH particles using 64 GPUs Tesla

Large wave interaction with oil rig using 10^9 particles



Domínguez JM, Crespo AJC, Valdez-Balderas D, Rogers BD, Gómez-Gesteira M. New multi-GPU implementation for Smoothed Particle Hydrodynamics on heterogeneous clusters. Computer Physics Communications, 184: 1848-1860, **2013**.

But, is it useful?

A lot of resources are necessary

Complicated pre-processing and post-processing

2.3. Developing new capabilities

Now, the objectives are:

- Maintaining a balance between maximizing the performance and code complexity.
- Developing new capabilities to increase the usefulness of DualSPHysics on real problems.

UniversidadeVigo

Wave-structure interaction
Coastal protection
Buoyancy of floating objects
Interaction with rigid objects
Simulation of debris flows
Dispersion in porous media
Design of wave energy devices
High Performance Computing
Advanced visualisation

MANCHESTER 1824
The University of Manchester

Multiphase air-water
Multiphase soil-water
Fuel-tank sloshing
ISPH development

UniversidadeVigo + MANCHESTER 1824 The University of Manchester

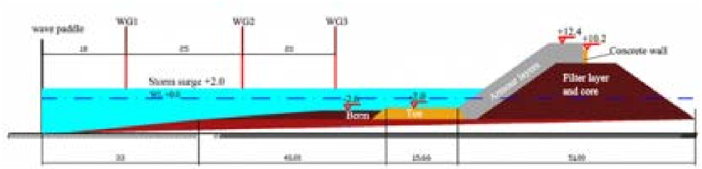
New boundary conditions in SPH
Dynamic refinement – variable resolution in SPH
Development of DualSPHysics & RELEASES

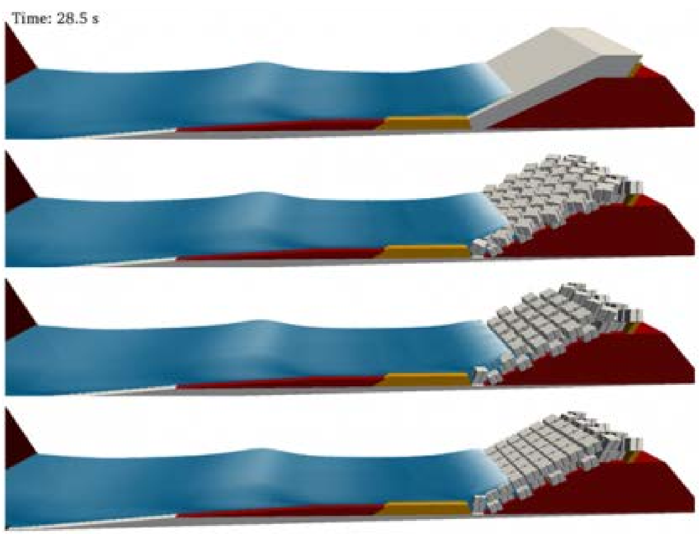
2.3.1. New capabilities for coastal protection

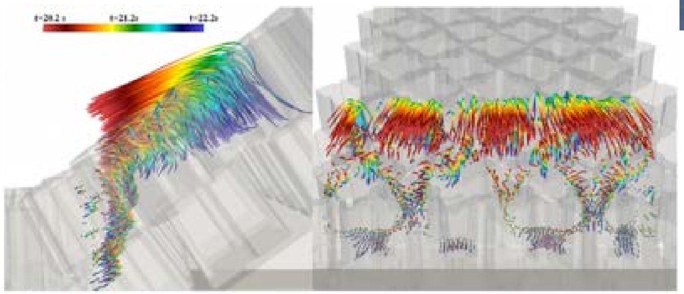
The problems we are interested on:

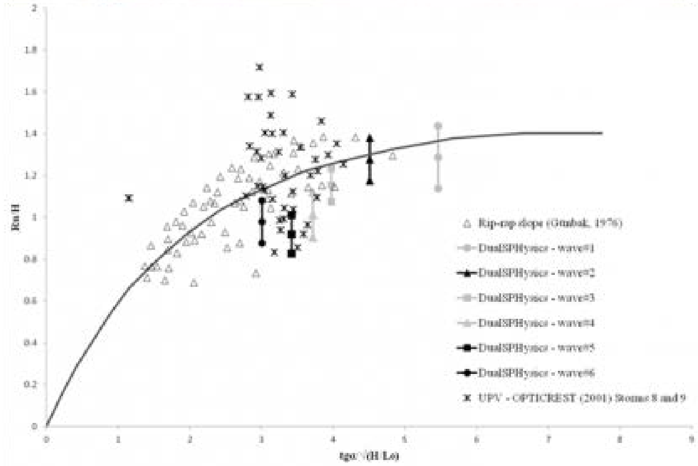
2.3.1. New capabilities for coastal protection

Study of the run-up in an existing armour block sea breakwater









Barreiro A, Crespo AJC, Domínguez JM and Gómez-Gesteira M. Smoothed Particle Hydrodynamics for coastal engineering problems. Computers and Structures, 120(15): 96-106, **2013**.

Altomare C, Crespo AJC, Rogers BD, Domínguez JM, Gironella X, Gómez-Gesteira M. Numerical modelling of armour block sea breakwater with Smoothed Particle Hydrodynamics. Computers and Structures, 130: 34-45, **2014**.

Altomare C, Crespo AJC, Domínguez JM, Gómez-Gesteira M, Suzuki T, Verwaest T. Applicability of Smoothed Particle Hydrodynamics for estimation of sea wave impact on coastal structures. Coastal Engineering, 96: 1-12, **2015**.

2.3.1. New capabilities for coastal protection

Wave generation

- Wave generation starting from parameters of the waves: H, T, depth, piston type…
- Wave generation using theory of 1st and 2nd order
- Regular waves and irregular waves (JONSWAP and Pierson Moskowitz spectrums)
- Analytical results to compare elevation and fluid velocity

Wave absorption

- Passive absorption: Sponge layer and beach dissipation
- Active absorption: System AWAS to avoid wave reflection on piston

Altomare C, Domínguez JM, Crespo AJC, Barreiro A, Suzuki T, Gómez-Gesteira M., Troch P. Wave Generation and absorption in SPH-based model…

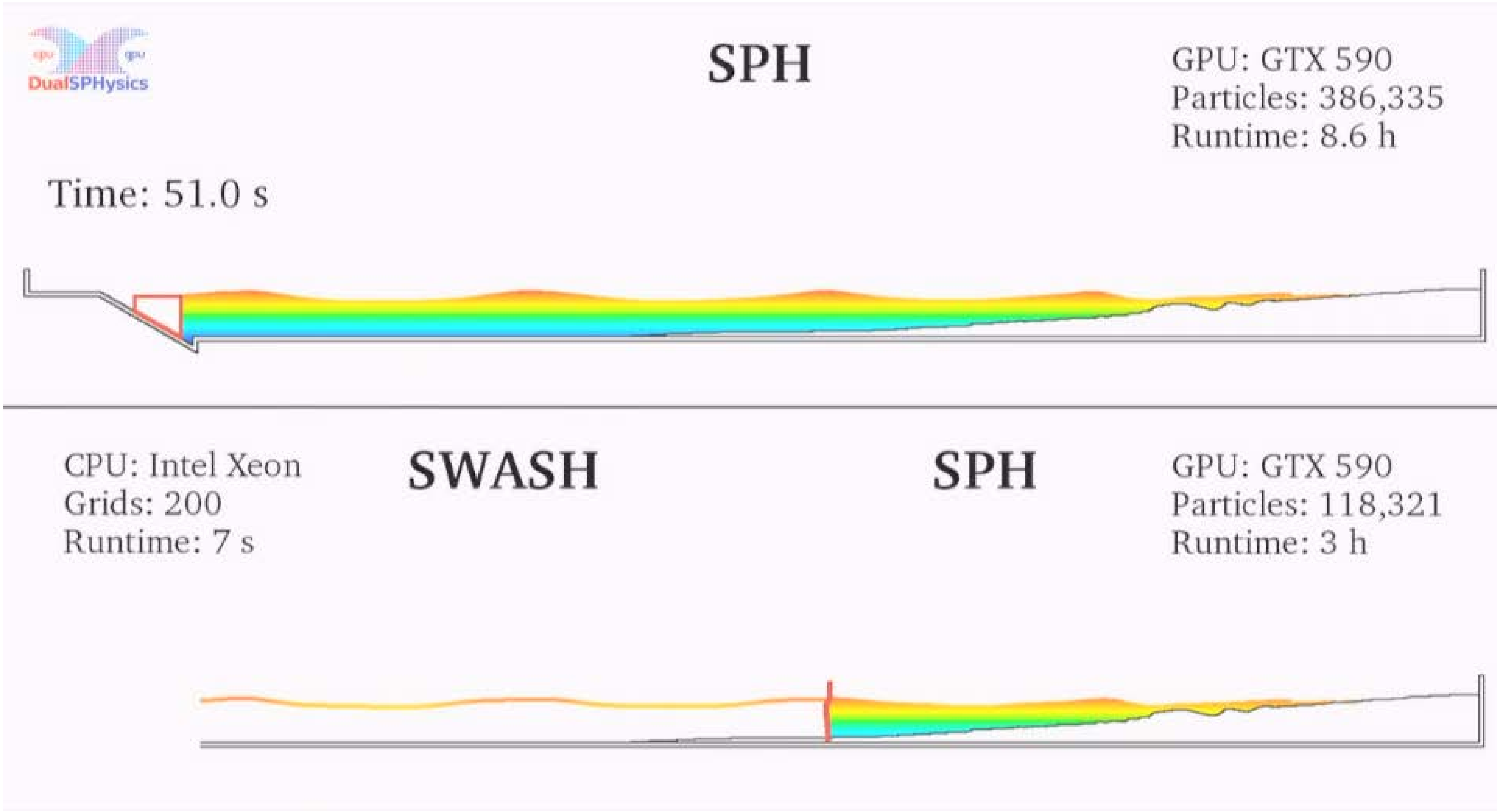
IN PREPARATION

2.3.2. Coupling with other models

Altomare C, Domínguez JM, Crespo AJC, Suzuki T, Cáceres I, Gómez-Gesteira M. Hybridisation of the wave propagation model SWASH and the meshfree particle method SPH for real coastal applications. Coastal Engineering Journal.

UNDER REVIEW

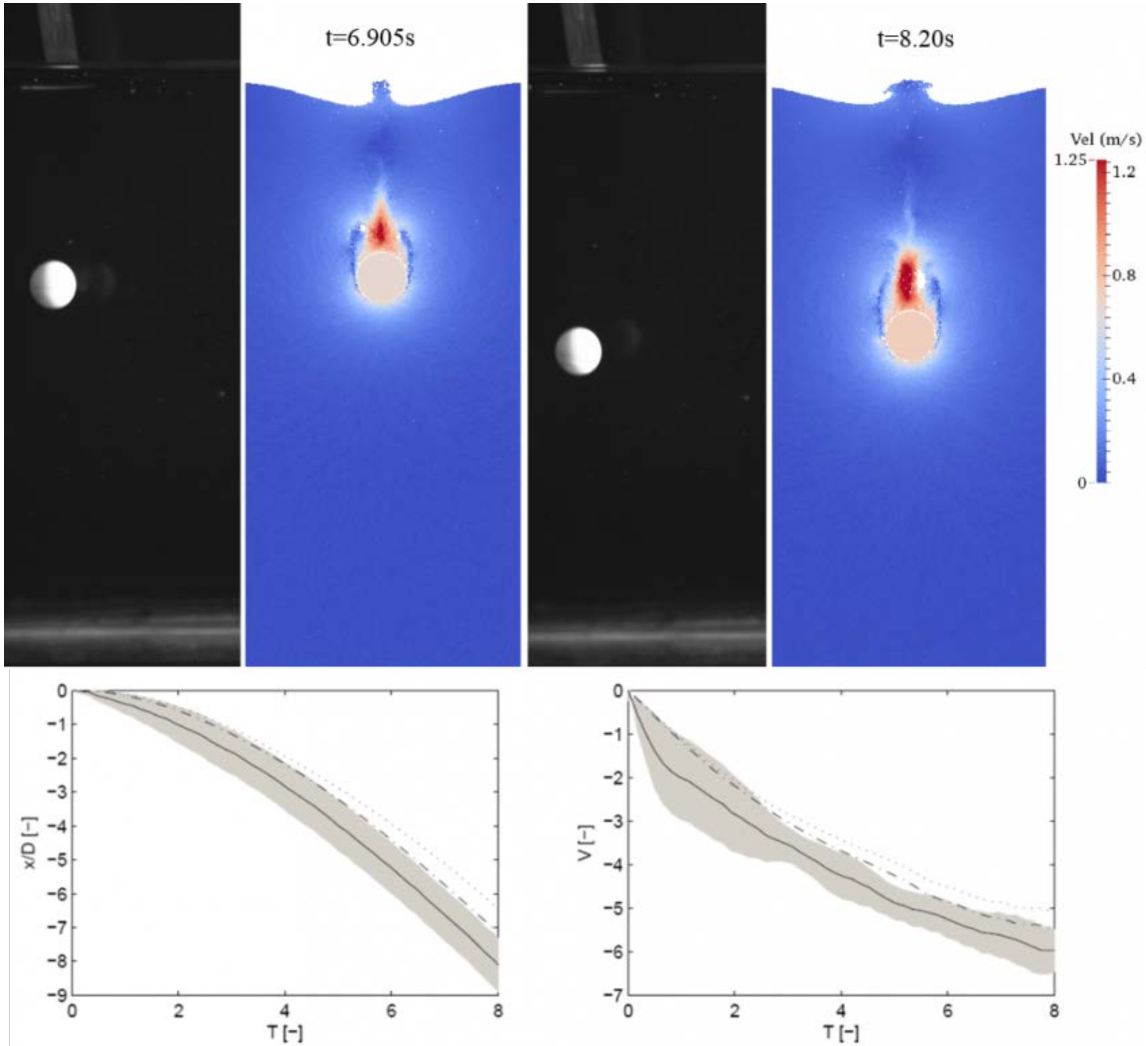
Coupling with wave propagation model SWASH



2.3.3. Floating objects

Canelas RB, Domínguez JM, Crespo AJC, Gómez-Gesteira M, Ferreira RML. A Smooth Particle Hydrodynamics discretization for the modelling of free surface flows and rigid body dynamics. International Journal for Numerical Methods in Fluids, 78: 581-593, **2015**.

Buoyancy of floating objects



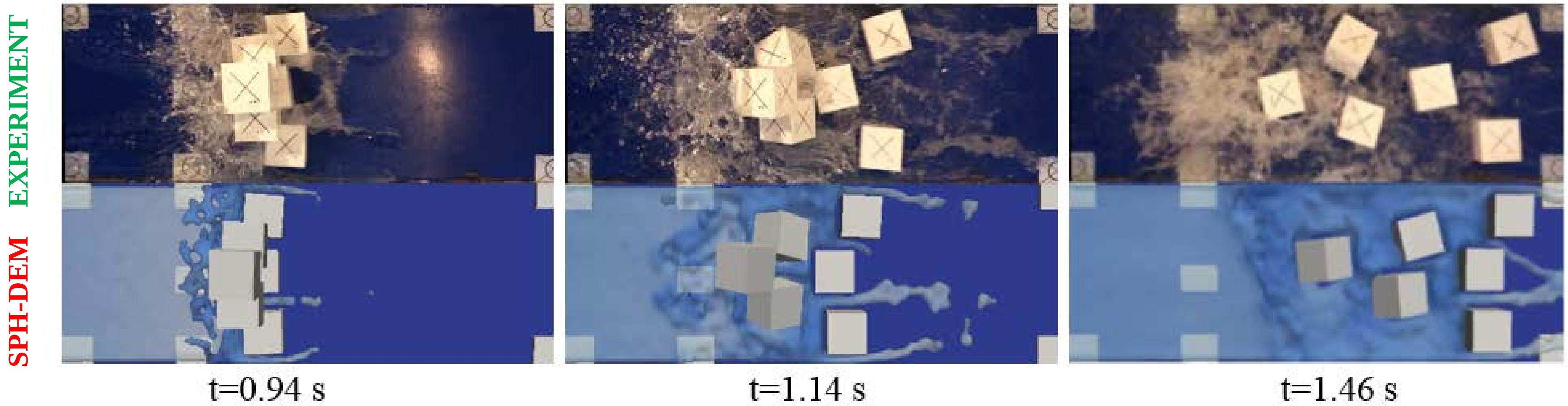
Sinking sphere with $\rho = 2.54\rho_w$. Experimental(-), experimental error region (shaded gray), DualSPHysics $D/dx = 20$ $(\cdots)$ $D/dx = 50$ $(-\cdot-)$

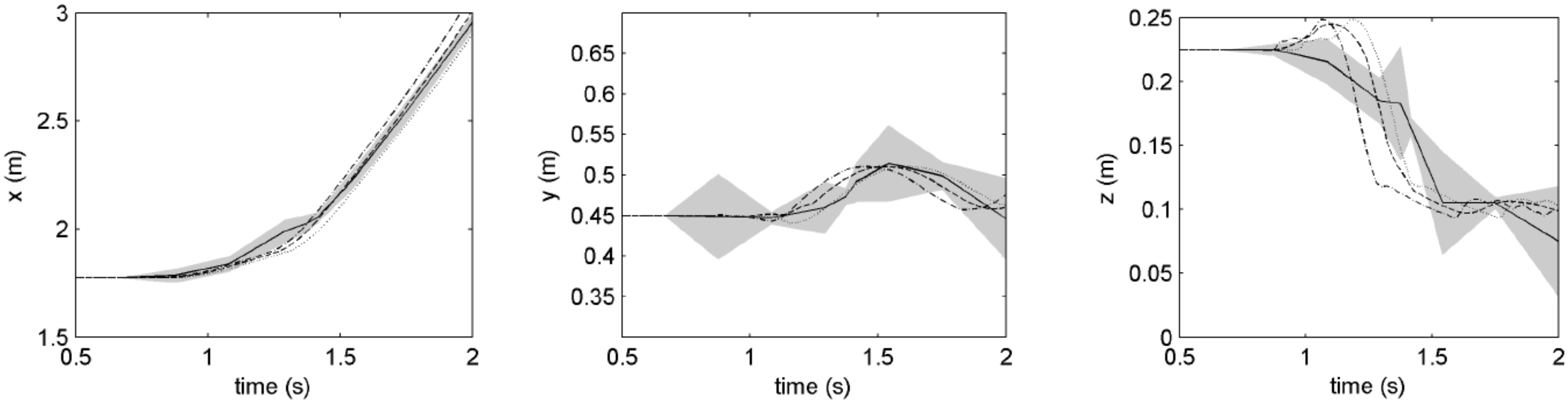
2.3.4. Rigid objects using DEM

Canelas RB, Crespo AJC, Domínguez JM, Ferreira RML, Gómez-Gesteira M. SPH-DCDEM model for arbitrary geometries in free surface solid-fluid flows. Computer Physics Communications, **2015**.

Interaction with rigid objects

Validation of SPH-DEM





Top left cube: Experimental (-), DualSPHysics L/Dp = 15(--), L/Dp = 10(-.-), L/Dp = 45(…)

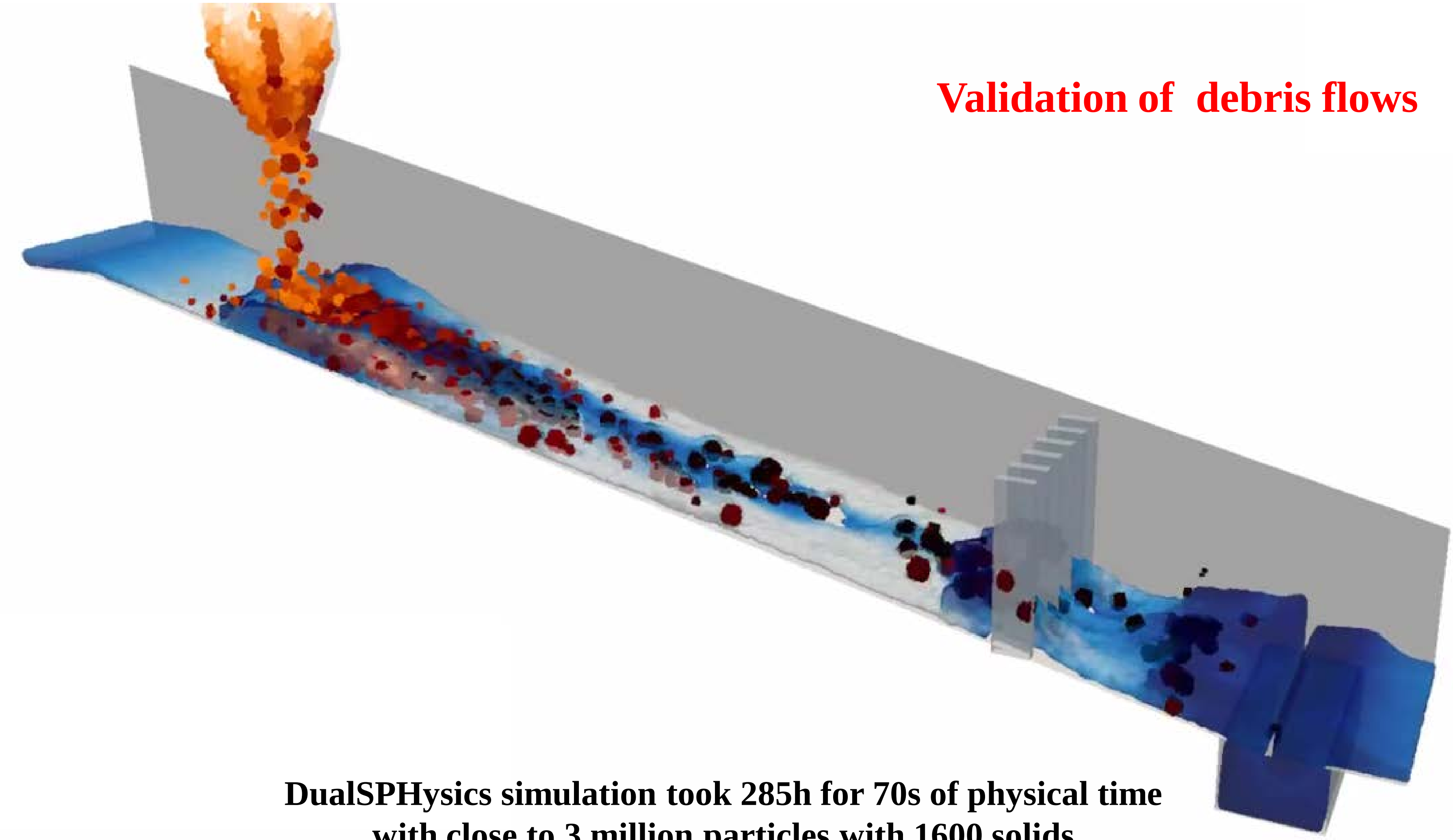
2.3.4. Rigid objects using DEM

Canelas RB, Domínguez JM, Crespo AJC, Ferreira RML. Resolved simulation of a granular-fluid flow with a coupled SPH-DCDEM model. Journal of Hydraulic Engineering.

UNDER REVIEW

Simulation of debris flows

Validation of debris flows

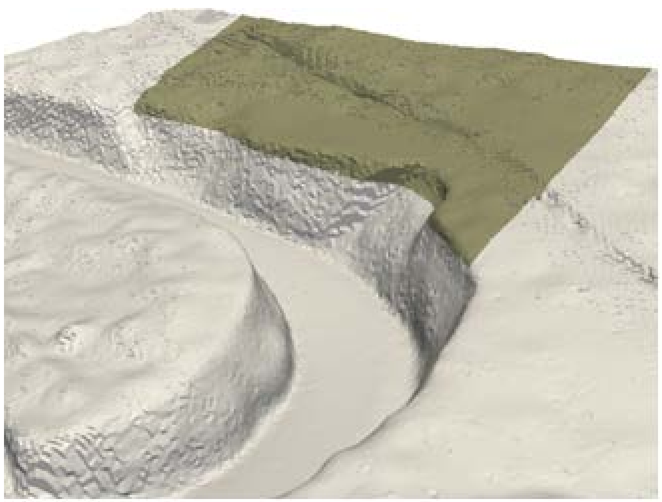


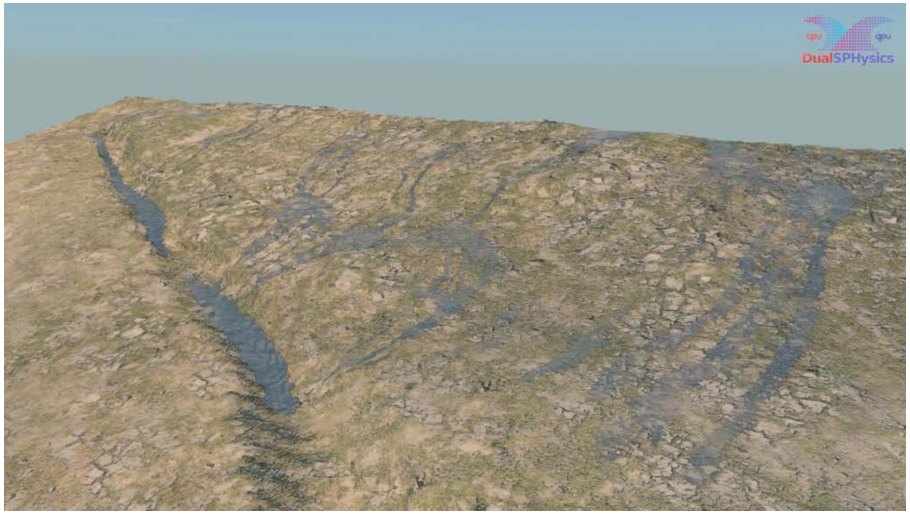
DualSPHysics simulation took 285h for 70s of physical time with close to 3 million particles with 1600 solids

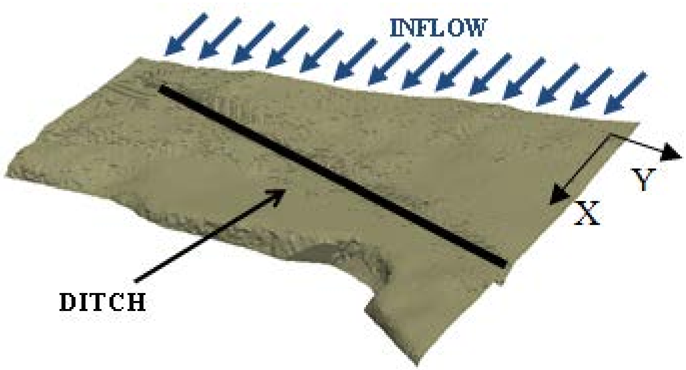
2.3.5. Inlet conditions

Barreiro A, Domínguez JM, Crespo AJC, González-Jorge H, Roca D, Gómez-Gesteira M. Integration of UAV photogrammetry and SPH modelling of fluids to study runoff on real terrains. PLoS ONE, 9(11): e111031, **2014**.

Study of runoff on real terrains





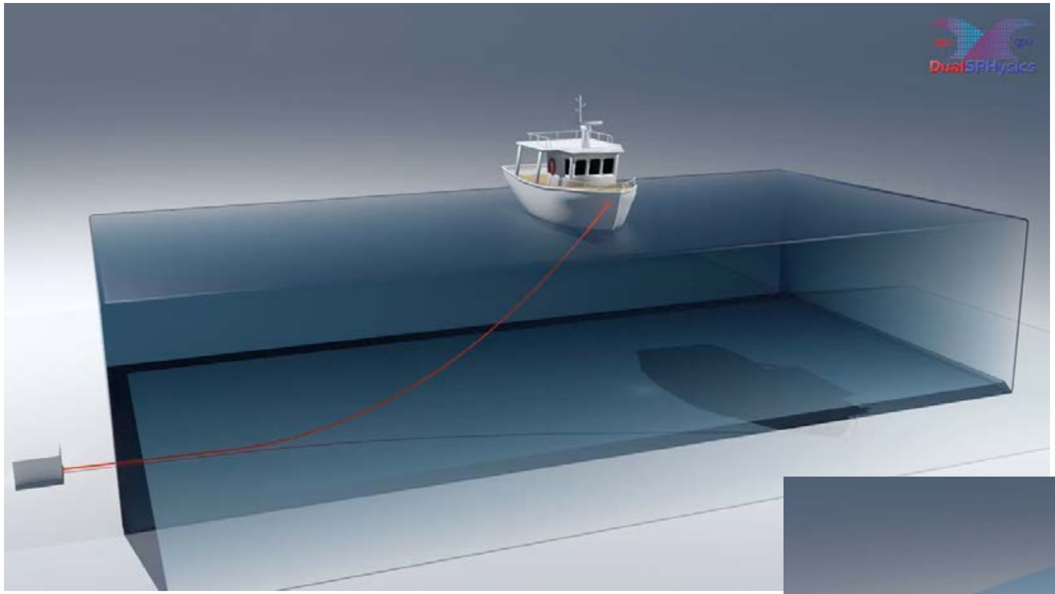


2.3.6. Moorings implementation

Barreiro A, Domínguez JM, Crespo AJC, García-Feal O, Zabala I, Gómez-Gesteira M. Quasi-Static Mooring solver implemented in SPH. Journal of Ocean Engineering and Marine Energy.

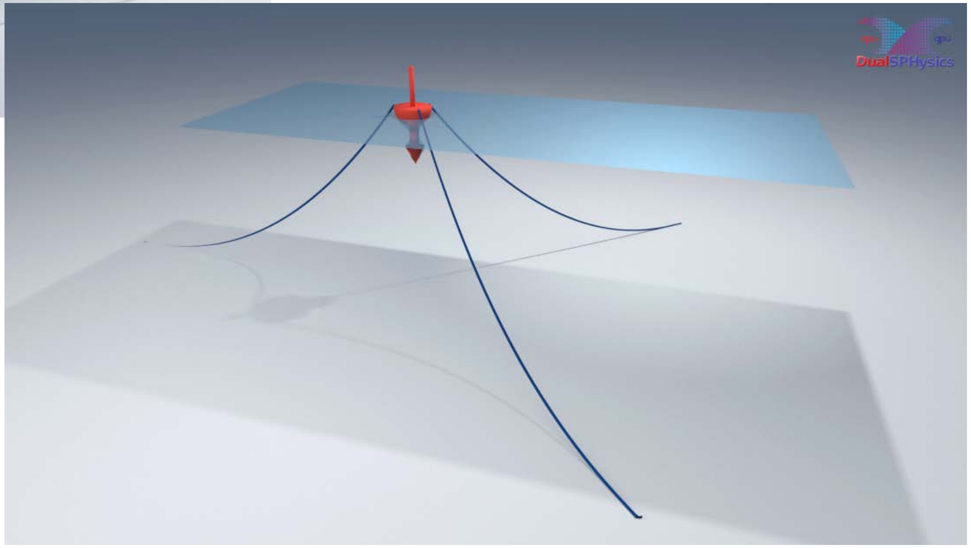
UNDER REVIEW

Moorings implementation



Ship moored

Buoy with several moorings

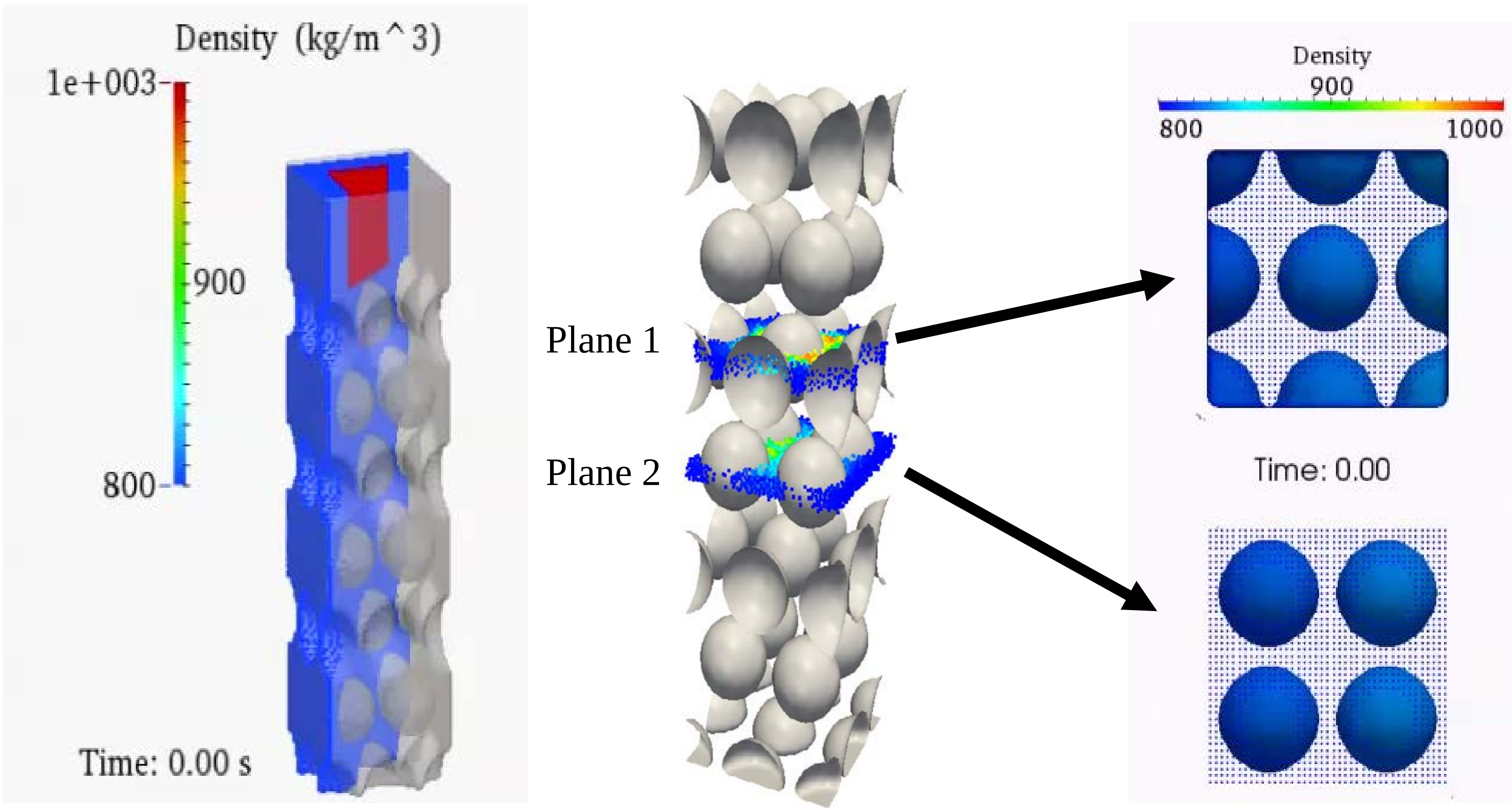


2.3.7. Multiphase flows

Alvarado-Rodríguez C, Barreiro A, Domínguez JM, Gómez-Castro FI, Klapp J, Gómez-Gesteira M. Applications of the shifting algorithm and the variable smoothing length in multiphase simulations…

IN PREPARATION

Dispersion in porous media with multiphase flows

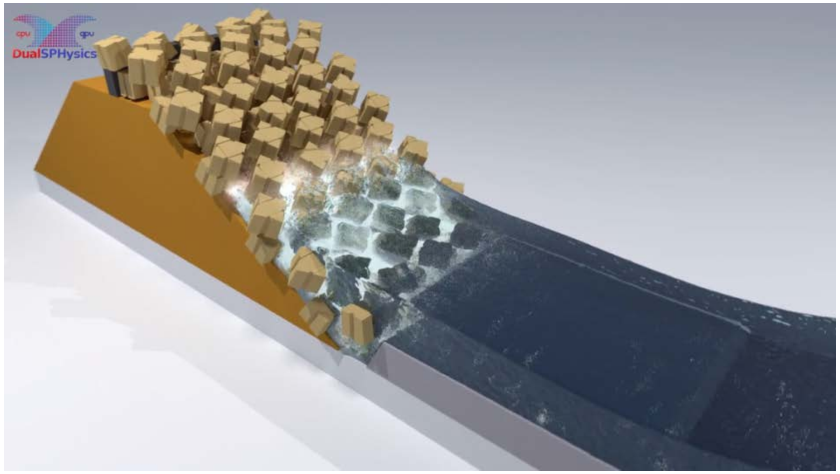


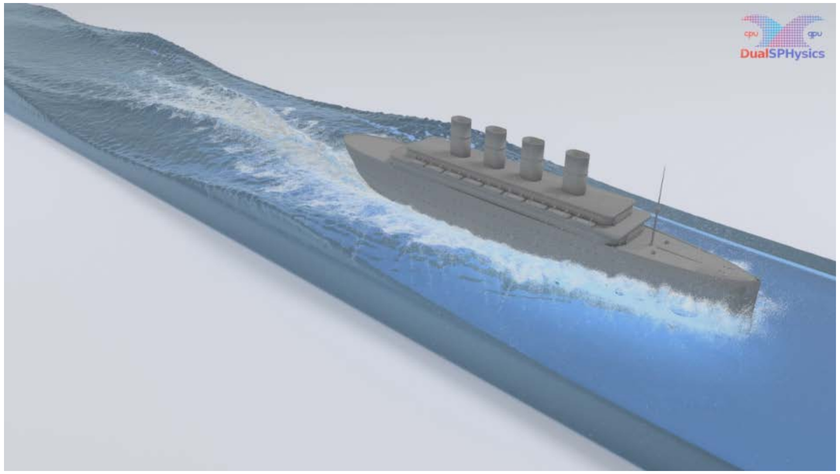
2.3.8. Realistic visualization

García-Feal O, Crespo AJC, Domínguez JM, Barreiro A, Gómez-Gesteira M. Open-source software for realistic visualisation of validated fluid simulations …

IN PREPARATION

Advanced visualization using Blender

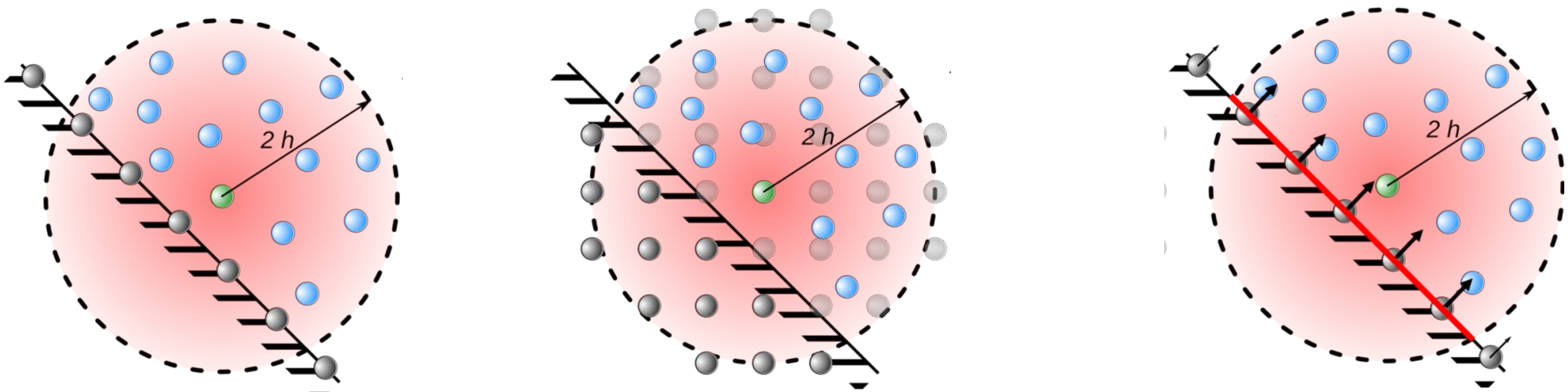




2.3.9. New boundary conditions

Three main categories:
(i) Boundary repulsive forces
(ii) Fluid extensions to the solid boundary
(iii) Boundary integral representation terms preservation

Dynamic boundaries (DBC) from group (i-ii)	Local Uniform STencil (LUST) from group (ii)	Boundary Integral (INTEGRAL) from group (iii)



(a) (b) (c)

cpu gpu DualSPHysics **To be included in next releases**

2.3.9. New boundary conditions

SPHERIC Benchmark Test Case #10

Dynamic boundaries (DBC)

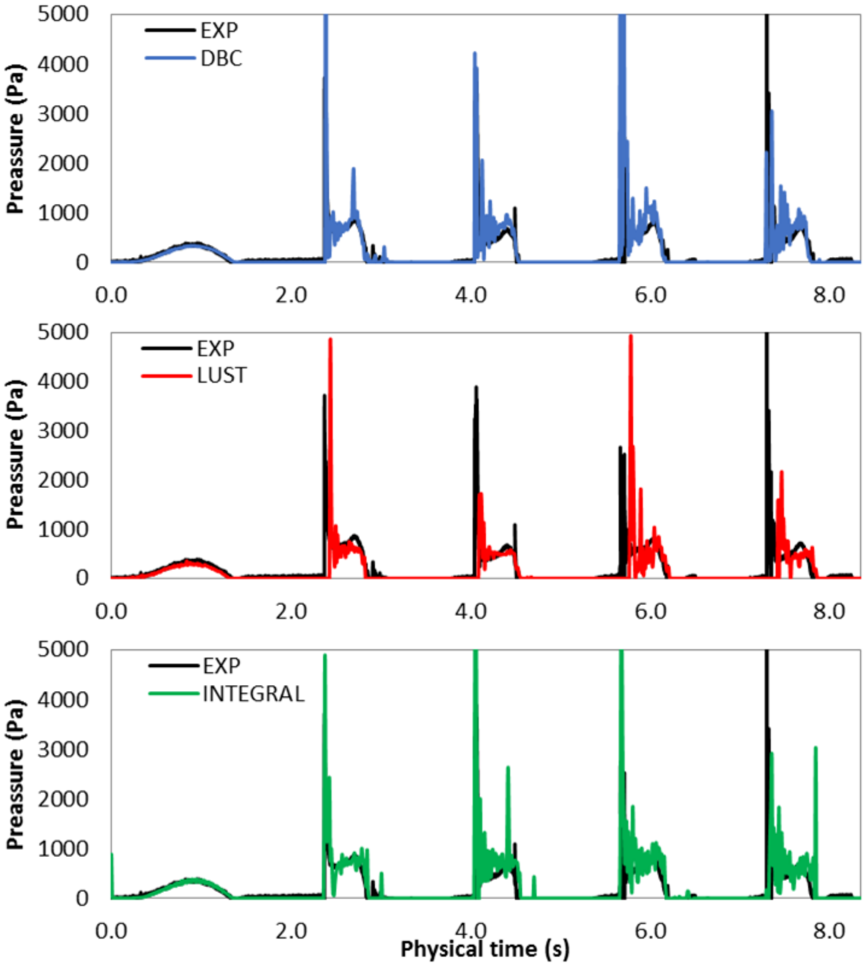
h/dp=1.3

Local Uniform STencil (LUST)

h/dp=1.3

Boundary Integral (INTEGRAL)

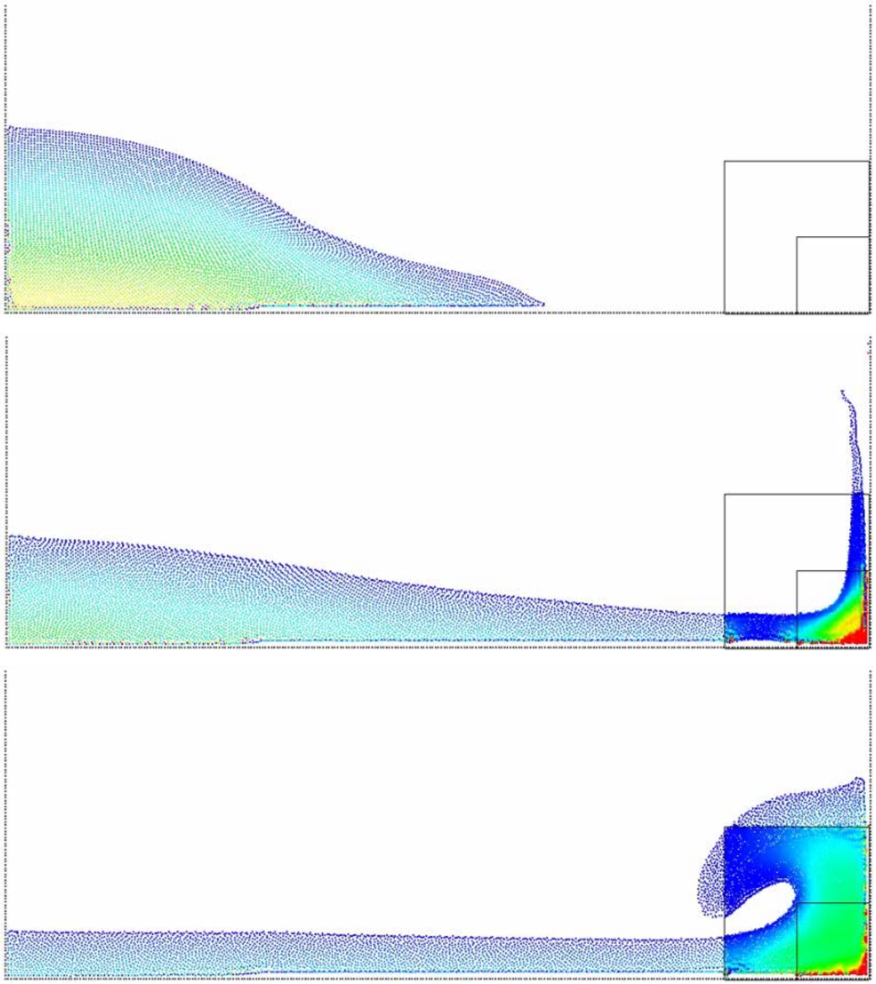
h/dp=4.0



Experimental and numerical pressures measured at the sensor P1

2.3.10. Variable resolution

Dynamic refinement with particles with different sizes by means of particle splitting and coalescing procedures.



Two levels of splitting/coalescing

Outline

3.1. Next release

Current formulation (DualSPHysics v3):

- Time integration scheme:
    - Verlet [*Verlet, 1967*]
    - Symplectic [*Leimkhuler, 1996*]
- Variable time step [*Monaghan & Kos, 1999*]
- Kernel functions:
    - Cubic Spline kernel [*Monagham & Lattanzio, 1985*]
    - Quintic Wendland kernel [*Wendland, 1995*]
- Density filter:
    - Shepard filter [Panizzo, 2004]
    - Delta-SPH formulation [*Molteni & Colagrossi, 2009*]
- Viscosity treatments:
    - Artificial viscosity [*Monaghan, 1992*]
    - Laminar viscosity + SPS turbulence model [*Dalrymple & Rogers, 2006*]
- Weakly compressible approach using Equation of State
- Dynamic boundary conditions [*Crespo et al., 2007*]
- Floating objects [*Monaghan et al., 2003*]
- Periodic open boundaries
- Coupling with Dicrete Element Method

3.1. Next release

DualSPHysics v4.0 (End of 2015):

- New CPU structure that mimics the GPU threads.
- New GPU structure with to help the user to follow and modify the code.
- Double precision implementation.
- Shifting algorithm.
- Floating bodies formulation were corrected.
- New wave generation (regular, irregular by given H/Hs, T/Tp and depth).
- Source code of the coupling with Discrete Element Method (DEM).

DualSPHysics v4.2 (Spring 2016):

- MultiGPU code with OpenMP.
- New BCs (LUST, Integral, Ghost particles).

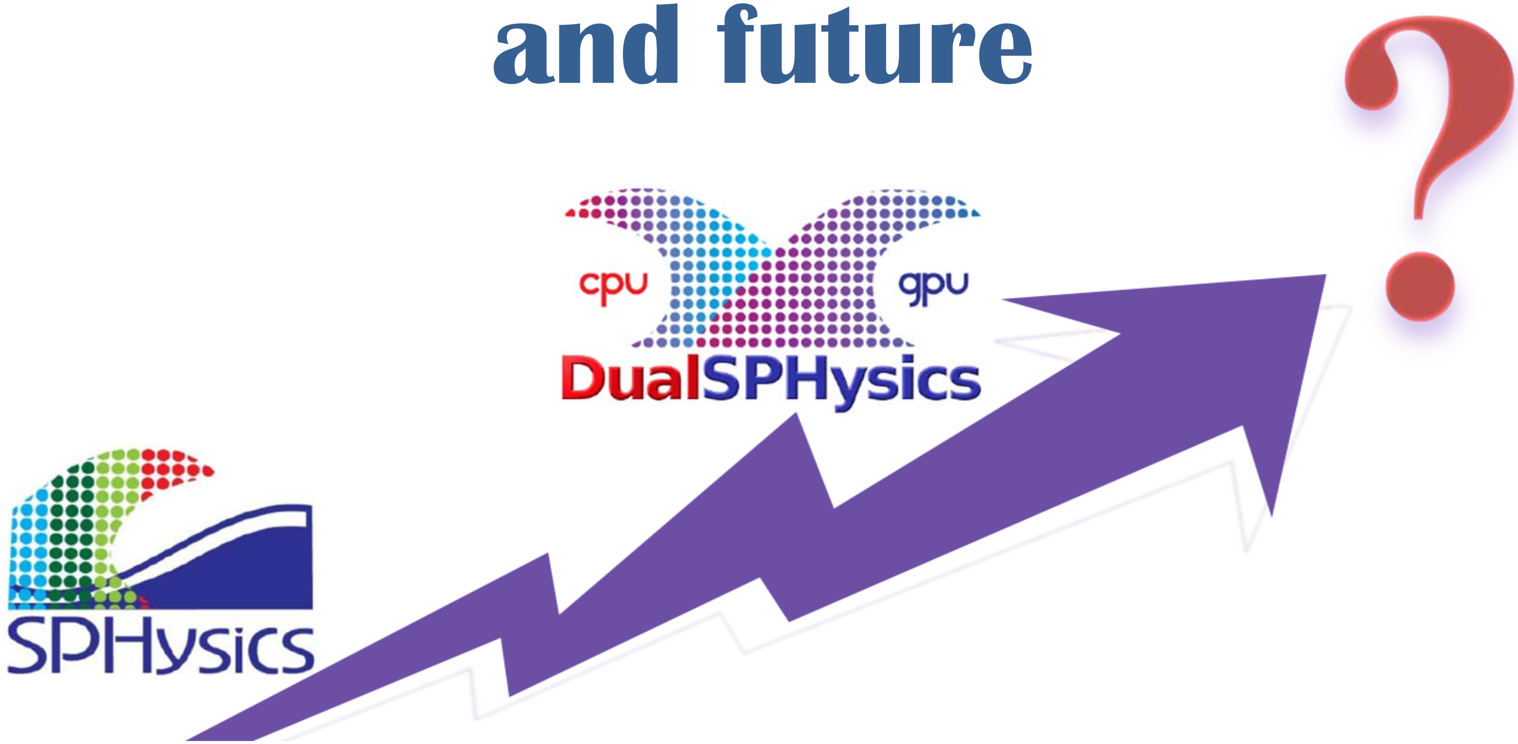
3.2. Ongoing work

DualSPHysics solver:
- Variable resolution.
- Advanced inlet conditions.
- Improved Multi-GPU version for huge number of GPUs.

Pre-processing tools:
- New GenCase for other boundary conditions.
- Particle generation without mesh.
- Drawing particles adapted for variable resolution.

Post-processing tools:
- Recognition of data arrays defined by user.
- New tools for other functionalities.

DualSPHysics: past, present and future



J.M. Domínguez, A.J.C. Crespo, A. Barreiro, O. García-Feal,
M. Gómez-Gesteira, Ricardo Canelas, C. Altomare,

jmdominguez@uvigo.es

Universidade Vigo

MANCHESTER 1824 The University of Manchester

flanders HYDRAULICS RESEARCH

TÉCNICO LISBOA

UNIVERSITÀ DEGLI STUDI DI PARMA

UNIVERSITEIT GENT

UNIVERSIDAD DE GUANAJUATO