Simulation et Optimisation pour les Energies Marines Renouvelables

10-12 janv. 2018 Paris

Simulation numérique 3D du mouvement d'éoliennes flottantes par méthode de pénalisation

Frédéric Golay

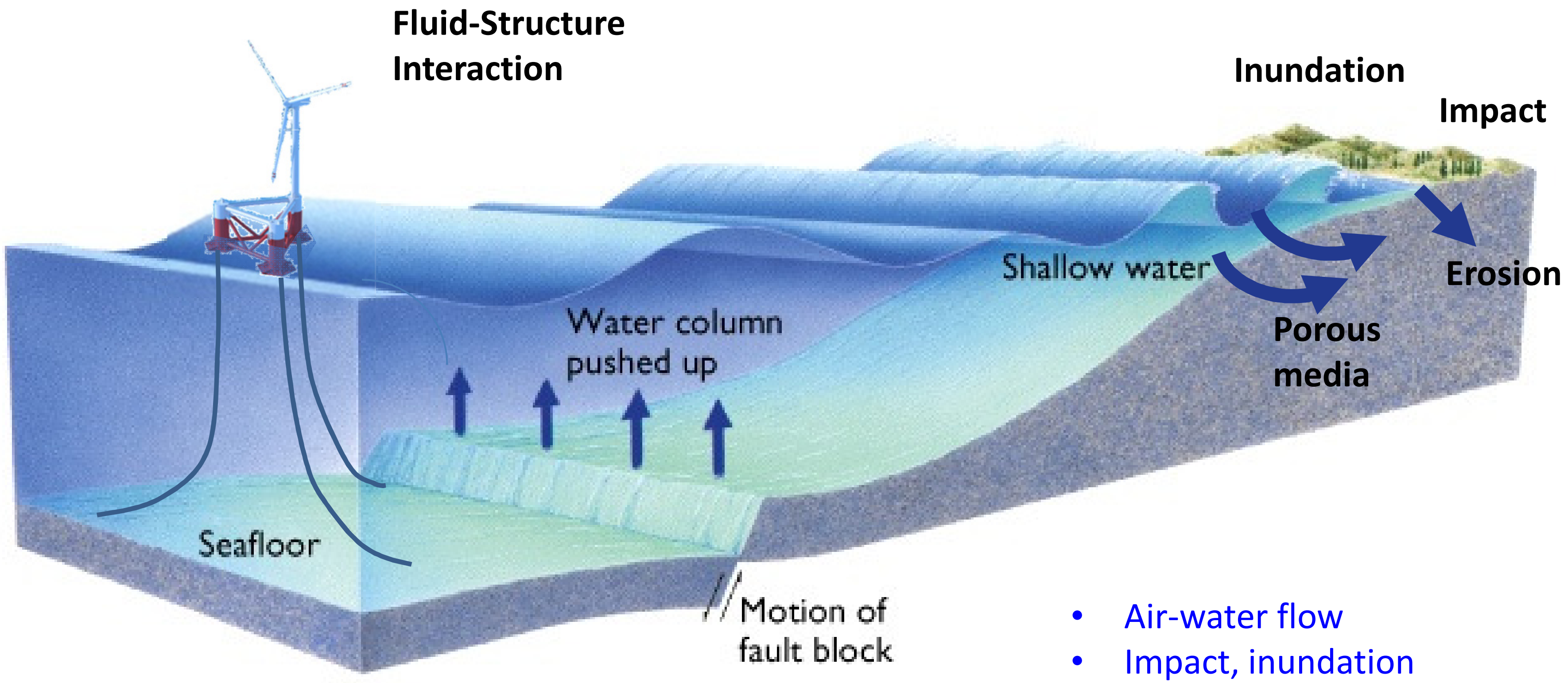
Institut de Mathématique de Toulon

Philippe Fraunié

Institut Méditerranéen d'Océanologie

Alioune Sambe et Thomas Altazin (doctorants)

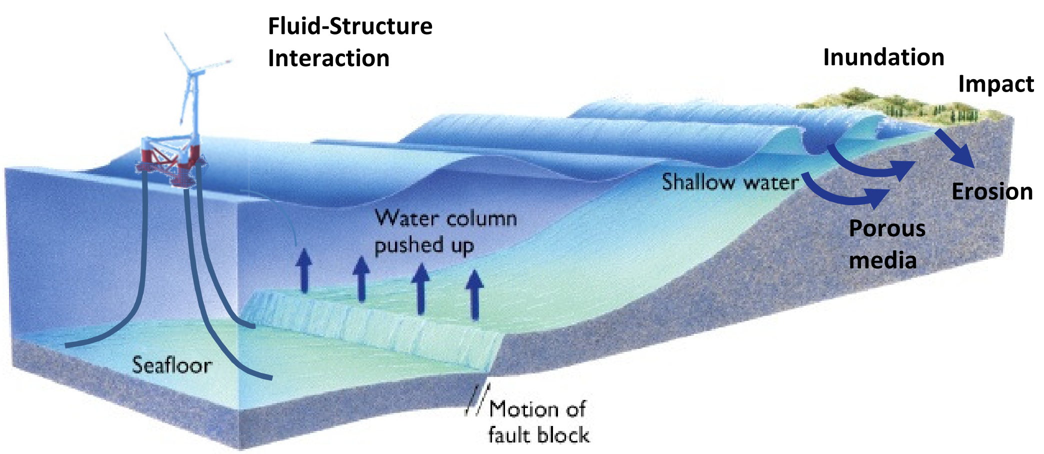
Motivation

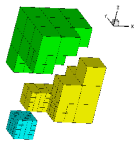


- Air-water flow
- Impact, inundation
- Wave propagation
- Wave breaking
- Flow in porous media
- Erosion
- Fluid-structure interaction

Physical and numerical multi-scale modeling and coupling

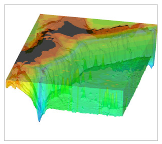
Outline



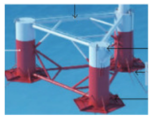


- Hyperbolic solver BB-AMR3D

- Air-Water model

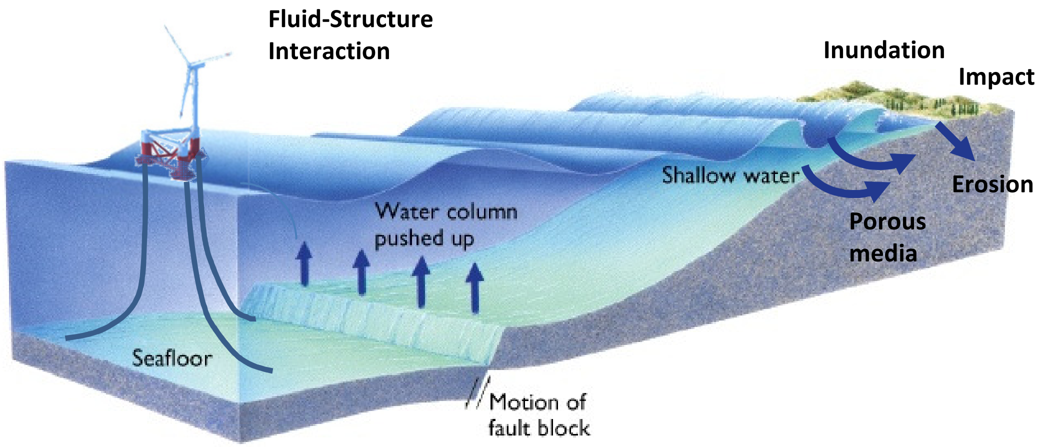


- Wave propagation



- Fluid-structure interaction

Hyperbolic solver BB-AMR3D



P. Helluy, A.N. Sambe, M. Ersoy, L. Yushchenko

- Hyperbolic solver BB-AMR3D
  - Finite volume
  - Local time-stepping
  - BB-AMR
  - Mesh refinement criterion
- Air-Water model
- Wave propagation
- Fluid-structure interaction

Finite volume approximation

$$\frac{\partial w(t)}{\partial t} + \nabla \cdot f(t,w) = G$$

$$\int_{C_k} \frac{\partial w(t)}{\partial t} + \sum_a \int_{\partial C_{k/a}} f(t,w) \cdot \vec{n}_{k/a} = 0$$

$$w_k(t) \approx \frac{1}{|C_k|} \int_{C_k} w(x,t)\, d\Omega \qquad \int_{\partial C_{k/a}} f(t,w) \cdot \vec{n}_{k/a} ds \approx |\partial C_{k/a}|\, F\left(w_k(t), w_a(t), \vec{n}_{k/a}\right) = |\partial C_{k/a}|\, F_{k/a}(t)$$

$$|C_k| \frac{\partial w_k(t)}{\partial t} + \sum_a |\partial C_{k/a}|\, F\left(w_k(t), w_a(t), n_{k/a}\right) = 0$$

Riemann solver

Euler explicit ordre 1

$$w_k(t_{n+1}) = w_k(t_n) - \delta t_n \sum_a \frac{|\partial C_{k/a}|}{|C_k|} F_{k/a}(t_n) \qquad h_k = \frac{|C_k|}{\sum_a |\partial C_{k/a}|} \qquad \text{CFL} \quad \delta t_n \le \text{Min}\left(\frac{h_k}{\|\vec{u}\| + c}\right)$$

Second order in time and space

RK2

$$w_k(t_{n+1}) = w_k(t_n) - \frac{\delta t_n}{|C_k|}\sum_a |\partial C_{k/a}| F_{k/a}(t_{n+1/2})$$

$$w_k(t_{n+1/2}) = w_k(t_n) - \frac{\delta t_n}{2|C_k|}\sum_a |\partial C_{k/a}| F_{k/a}(t_n)$$

AB2

$$w_k(t_{n+1}) = w_k(t_n) - \frac{\delta t_n}{|C_k|}\sum_a |\partial C_{k/a}| \left[F_{k/a}(t_n) + \frac{\delta t_n}{2\delta t_{n-1}}\left(F_{k/a}(t_n) - F_{k/a}(t_{n-1})\right)\right]$$

$$F\left(w_k(t), w_a(t), \vec{n}_{k/a}\right) \approx \Re\left(0, w_k, w_a, \vec{n}_{k/a}\right) \quad \text{ordre 1}$$

$$F\left(w_k(t), w_a(t), \vec{n}_{k/a}\right) \approx \Re\left(0, w_k + \frac{h_k}{2}\nabla w_k, w_a - \frac{h_a}{2}\nabla w_a, \vec{n}_{k/a}\right) \quad \text{ordre 2 MUSCL}$$

Barth-Jespersen's limiter

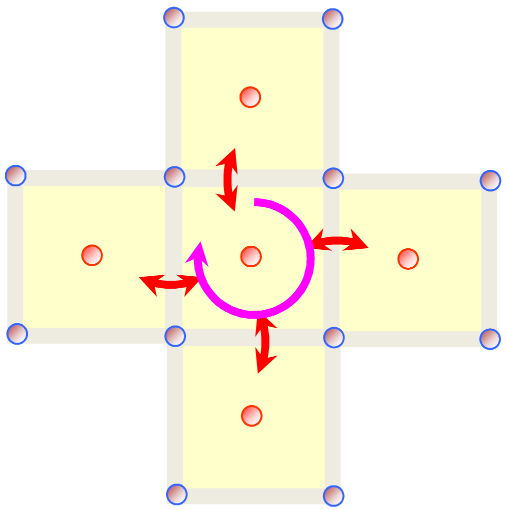
Estimation of primitive variables gradient

$$|\Omega_e|\vec{\nabla}\alpha = \int_{\Omega_e} \nabla\alpha dx = \int_{\partial\Omega_e} \alpha \cdot \vec{n} dl$$

Slope limitation

For each cell i (centroid M_i) of neighbour j, λ is define as

$$Min(\alpha_i, \alpha_j) \le \alpha_i + \lambda\vec{\nabla}\alpha_i \cdot \overrightarrow{M_iM_j} \le Max(\alpha_i, \alpha_j)$$



Local time stepping

Altmann et al., 2009

A cell K is of level n if: $2^{N-n} h_{min} < h_K < 2^{N+1-n} h_{min}$

Maximal level: $N = \log_2\left(\frac{h_{max}}{h_{min}}\right) + 1$

Face level: $niv(L/R) = Min(niv(L), niv(R))$

For $i=1,\ldots,2^{N-1}$

Let j the biggest integer / 2^j divides i

For each face / $niv \geq N-j$

Compute the integral of $F_{L/R}$ on the time interval $2^{N-niv}dt$

Distribute on neighbouring cells

Update all cells / $niv \geq N-j$

Example with 3 levels:

$i=1, \quad j=0$ Compute $F^{(3)}(0)$

Compute $w^{(3)}(dt)$

$i=2, \quad j=1$ Compute $F^{(3)}(dt), \quad F^{(2)}(0)$

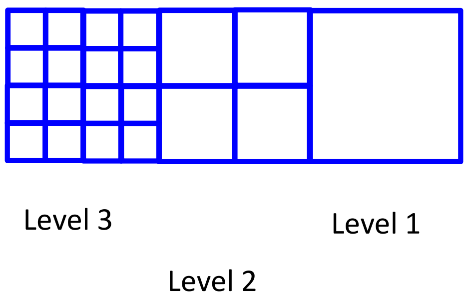
Compute $w^{(3)}(2dt), \quad w^{(2)}(2dt)$

$i=3, \quad j=0$ Compute $F^{(3)}(2dt)$

Compute $w^{(3)}(3dt)$

$i=4, \quad j=2$ Compute $F^{(3)}(3dt), \quad F^{(2)}(2dt), \quad F^{(1)}(0)$

Compute $w^{(3)}(4dt), \quad w^{(2)}(4dt), \quad w^{(1)}(4dt)$

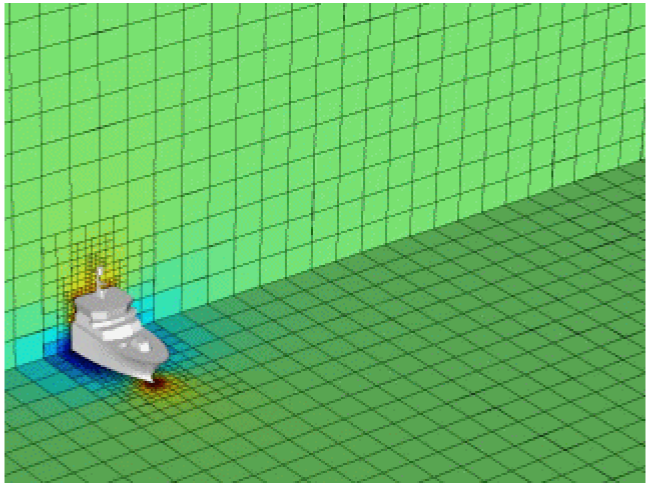


Tang & Warneke projection
Osher & Sanders projection

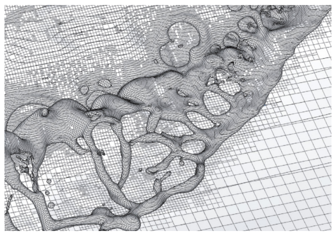
Adaptive Mesh Refinement

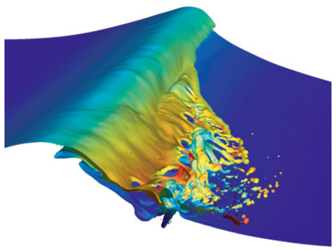
Octree

- Hight scalability
- Mostly cartesian finite volume grid
- Very local mesh refinement



http://gerris.dalembert.upmc.fr/gerris/examples/examples/tangaroa.html#htoc14

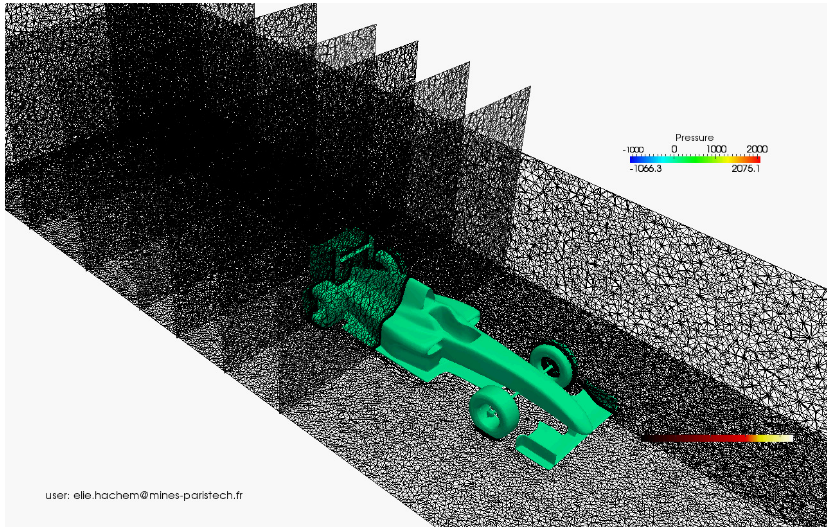


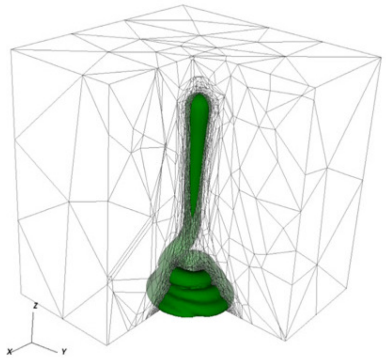


Fuster *et al.*, 2009 (Gerris)

Anisotropic mesh adaptation

- Very powerful boundary layer capturing
- Stabilized finite element
- Very local mesh refinement





Coupez *et al.*, 2013 (Cimlib)

Block-Based Adaptive Mesh Refinement

Step 1: We built an unstructured mesh composed by hexahedral cells which define the initial domain 0

9	10	11	12
5	6	7	8
1	2	3	4

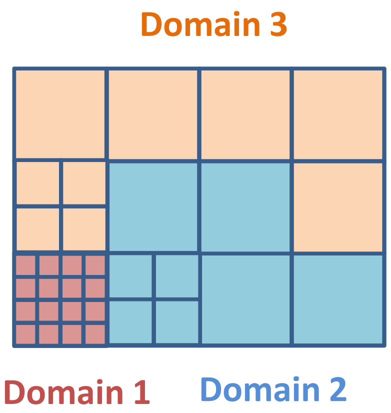
Step 2: Each cell defines a Block which can be locally and temporarily mesh in a cartesian way. The Level of mesh refinement is adapted

B9 1,1,0	B10 1,1,0	B11 1,1,0	B12 1,1,0
B5 1,1,0	B6 1,1,0	B7 1,1,0	B8 1,1,0
B1 1,1,2	B2 1,1,0	B3 1,1,0	B4 1,1,0

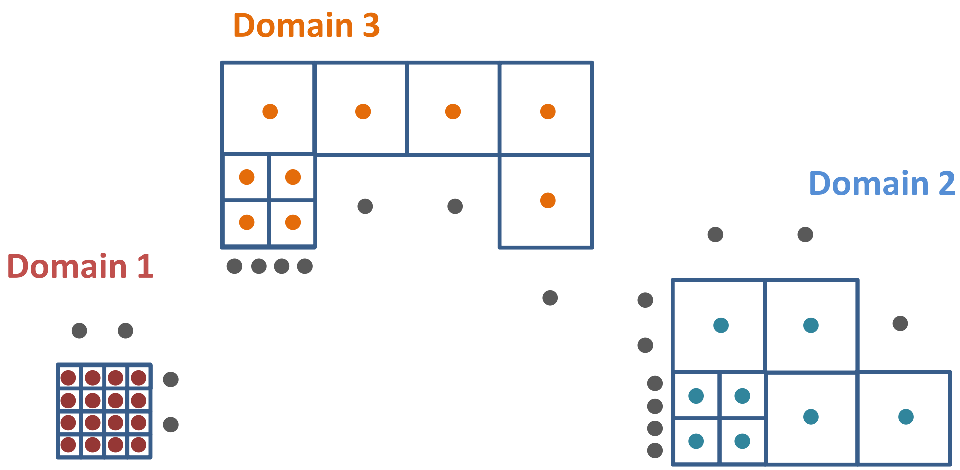
n_x, n_x, n_x: discretization of level 0
nrb : Level of mesh refinement

$2^{nrb}n_x$: number of cells in x-direction

Step 3: According to ~~Cuthill-McKee's~~ scheme, the blocks are allocated to domain in order to balance the Mpi processes.



Step 4: Each block are locally meshed in a temporarily structured way according to their parameters, the adjacent blocks and the domain interfaces.

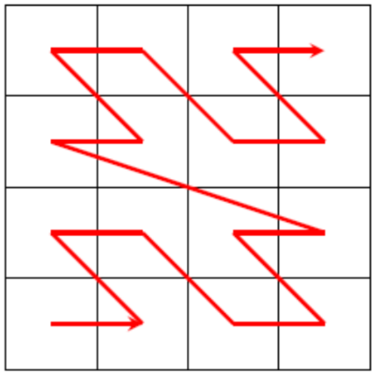


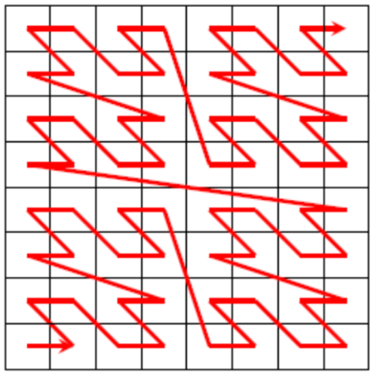
Domain decomposition: Z-ordering

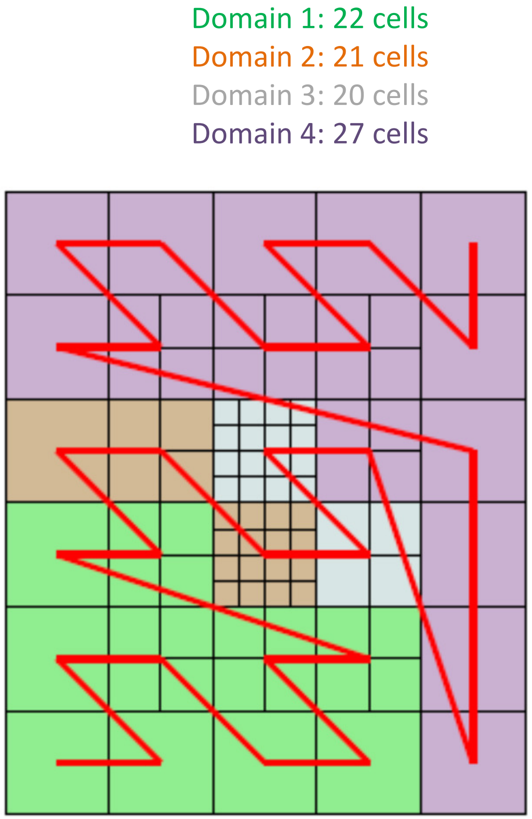
The Morton order (or Z-order) is a mapping from an n-dimensional space onto a linear list of numbers (Space filling curve)

$$(x,y,z)\rightarrow(i(x),i(y),i(z))_{10}\rightarrow(i(x),i(y),i(z))_{2}\rightarrow znum_{2}\rightarrow znum_{10}$$

$$(2,5,0)_{10}\rightarrow(010,101,000)_{2}\rightarrow 010100010_{2}\rightarrow 162_{10}$$







Mesh Refinement Criterion for hyperbolic systems

Mesh refinement criterion: Croisille 1991, Puppo 2002, 2003, 2011 …

$$\frac{\partial w}{\partial t} + \mathrm{div}\, f(w) = 0$$

According to the Lax entropy condition $\mathcal{P} = \frac{\partial s}{\partial t} + \mathrm{div}\,\psi(s) \le 0$

Remarks:

- For every smooth solution $\mathcal{P}=0$
- Across a rarefaction wave $\mathcal{P}=0$
- Across a shock wave $\mathcal{P}<0$

$$\nabla_w \psi = \nabla_w s \nabla_w f$$

Numerical density of entropy production ⇔ Error indicator

The numerical density of entropy production is computed as

$$\mathcal{P}_k^n := \frac{s\left(w_k(t_{n+1})\right) - s\left(w_k(t_n)\right)}{\delta t_n} + \frac{\delta\psi_k(t_n)}{h_k} + \frac{\delta t_n}{2\delta t_{n-1} h_k}\left(\delta\psi_k(t_n) - \delta\psi_k(t_{n-1})\right)$$

$$\overline{\mathcal{P}_\Omega} = \frac{1}{|\Omega|}\int \mathcal{P}_k^n dx \quad ; \quad \overline{\mathcal{P}_{Block}} = \frac{1}{|Block|}\int \mathcal{P}_k^n dx$$

If $\overline{\mathcal{P}_{Block}} \le \alpha_{min} \overline{\mathcal{P}_\Omega}$ the block is coarsened

If $\alpha_{max} \overline{\mathcal{P}_\Omega} \le \overline{\mathcal{P}_{Block}}$ the block is refined

Validation: Euler model

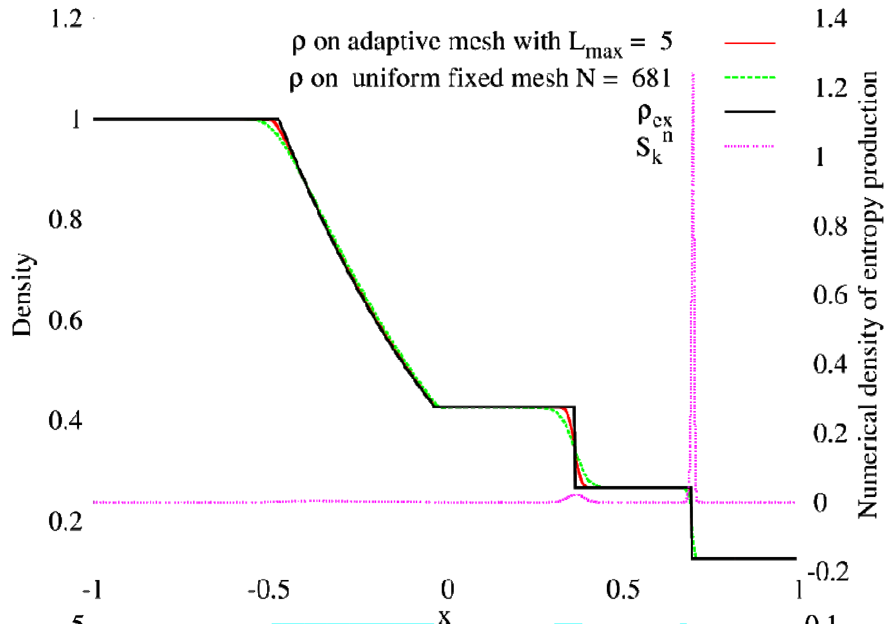
$$
\begin{cases}
\dfrac{\partial \rho}{\partial t} + \dfrac{\partial \rho u}{\partial x} = 0 \\
\dfrac{\partial \rho u}{\partial t} + \dfrac{\partial \left(\rho u^2 + p\right)}{\partial x} = 0 \\
\dfrac{\partial \rho E}{\partial t} + \dfrac{\partial \left(\rho E + p\right)}{\partial x} = 0 \\
p = (\gamma - 1)\rho\left(E - u^2/2\right)
\end{cases}
$$

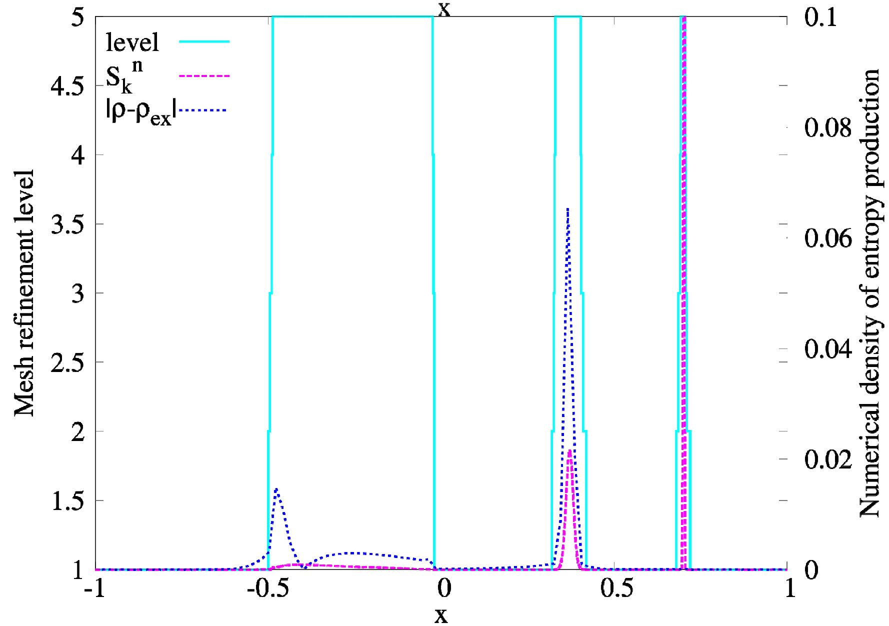
$$
\begin{cases}
\dfrac{\partial s}{\partial t} + \operatorname{div} \psi(s) \leq 0 \\
s = -\rho \ln\left(\dfrac{p}{\rho^{\gamma}}\right) \\
\psi = us
\end{cases}
$$

SOD's test case

$$
(\rho, u, p)(0, x) = \begin{cases} (1., 0., 1.) & \text{si} \quad x \leq 0 \\ (0.125, 0., 0.1) & \text{si} \quad x \leq 0 \end{cases}
$$

$$N_{ini} = 200$$

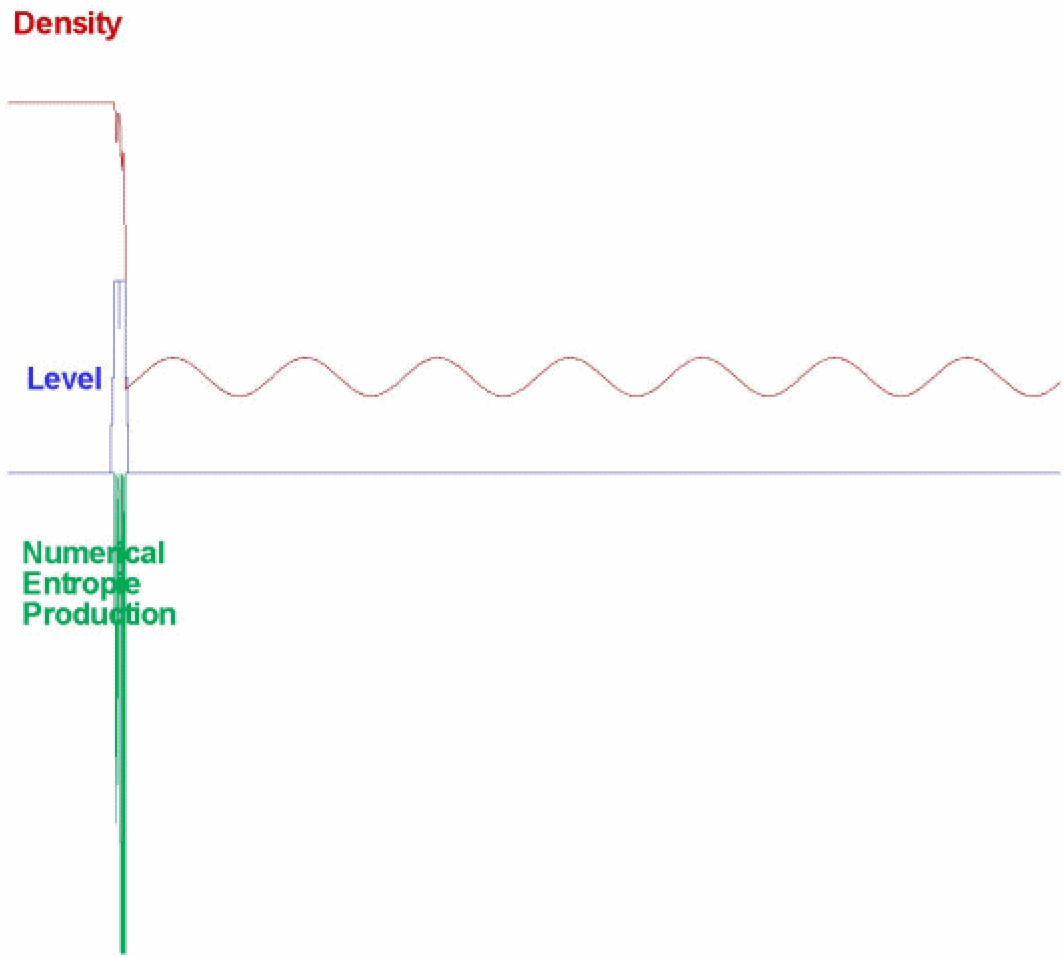




Validation: Euler model

$$\begin{cases} \frac{\partial \rho}{\partial t} + \frac{\partial \rho u}{\partial x} = 0 \\ \frac{\partial \rho u}{\partial t} + \frac{\partial(\rho u^2 + p)}{\partial x} = 0 \\ \frac{\partial \rho E}{\partial t} + \frac{\partial(\rho E + p)}{\partial x} = 0 \\ p = (\gamma - 1)\rho(E - u^2/2) \end{cases}$$

$$\begin{cases} \frac{\partial s}{\partial t} + \operatorname{div} \psi(s) \leq 0 \\ s = -\rho \ln\left(\frac{p}{\rho^\gamma}\right) \\ \psi = us \end{cases}$$



Shu Osher Test case

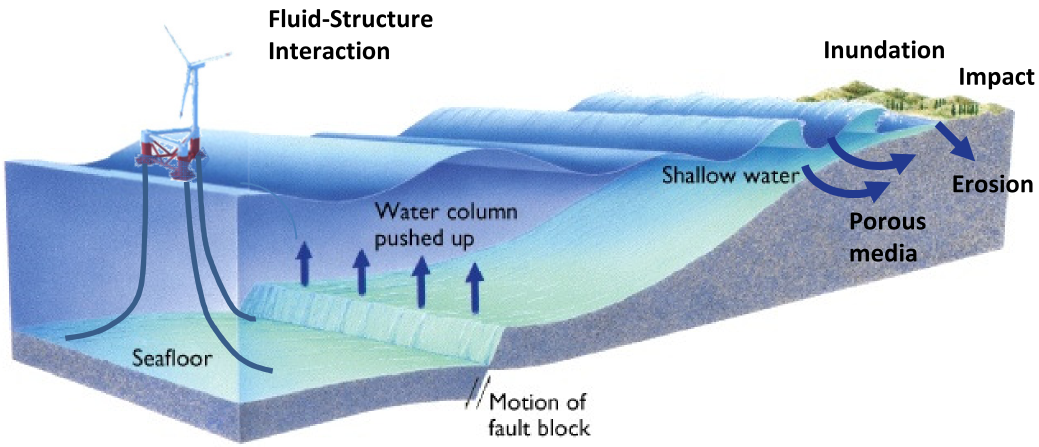
$x \in [0,1]$

$$(\rho, u, p)(0,x) = \begin{cases} (3.857143, 2.629369, 10.3333) & \text{si} \quad x \leq 0.1 \\ (1. + 0.2\sin(50x), 0., 1.) & \text{si} \quad x > 0.1 \end{cases}$$

- Super-convergence
- Accuracy ↗, cpu-time↘

Air-Water model

P. Helluy, T. Barberon, S. Rouy, A.N. Sambe,
D. Sous, P. Fraunié



- Hyperbolic solver BB-AMR3D
- Air-Water model
  - Bi-fluid isothermal Euler Model
  - Numerical tools
  - Dambreaking
- Wave propagation
- Fluid-structure interaction

Wave breaking: which model ?

Model complexity
Cpu time

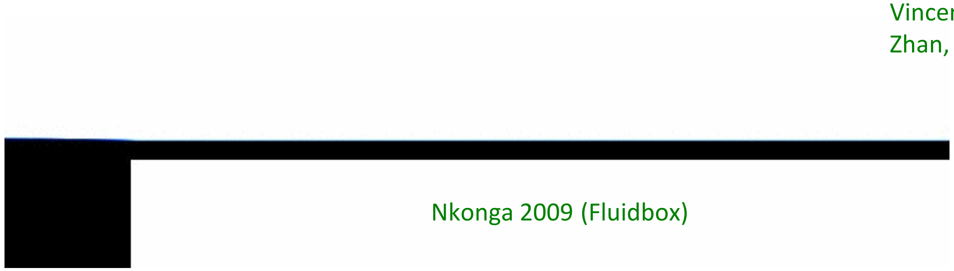
• SPH……. *Difficult to implement and drastically time consuming!* Voileau

• Lattice Boltzmann ……. *???* Grilli

• Navier-Stokes (VF, GD, VOF, Level Set,…): viscous, turbulent, incompressible, multiphase, surface tension, …

……. *Physically relevant but very slow and essentially 2D*

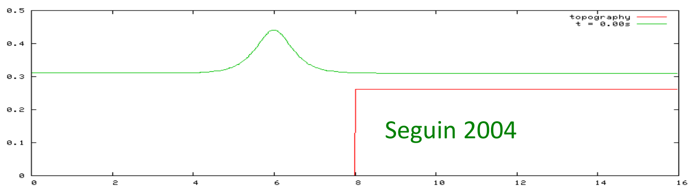
Zaleski, Fuster, Popinet (Gerris), Nkonga (Fluidbox), Vincent, Lubin, Caltagirone (Thetis), Coupez (Forge3D), Zhan, Liu,…



Nkonga 2009 (Fluidbox)

• Boundary Integral Equations Method (BIEM), (incompressible inviscid irrotational flow solver)…….*Very accurate for the propagation but unable to simulate wave breaking*

• Shallow water……. *Fast computing but unable to simulate wave breaking*



Seguin 2004

Zaleski, Fuster, Popinet (Gerris), Diaz, Dutykh (VOLNA), Grilli, Blaise (SLIM), Vincent, Lubin, Caltagirone (Thetis), ,…

Bi-fluid isothermal Euler model

We neglect viscosity, surface tension, turbulence

If Mach number <0.3 fluid flow is *almost* incompressible

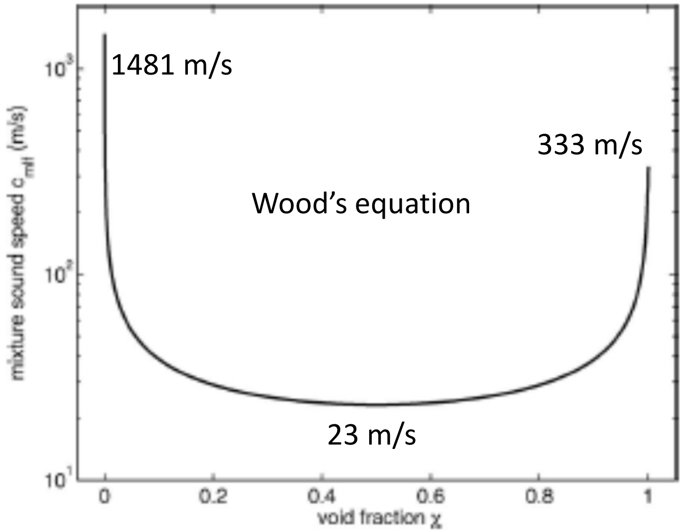
→ The model is relaxed to low compressible flow

- Euler compressible model ……. *Simple and allows fast 3D solvers*
- Explicit scheme ……. *Allows easy parallel implementation*
- EOS with artificial sound speed……. *CFL less restrictive and low numerical viscosity*

A good compromise between relevance, accuracy and computing time

$$
\begin{cases}
\dfrac{\partial \rho}{\partial t} + \mathrm{div}(\rho \vec{u}) = 0 \\
\dfrac{\partial \rho \vec{u}}{\partial t} + \mathrm{div}(\rho \vec{u} \otimes \vec{u} + p \bar{\bar{I}}) = \rho \vec{g} \\
\dfrac{\partial \varphi}{\partial t} + \vec{u} \cdot \nabla \varphi = 0
\end{cases}
$$

$$p = p_0 + c_0^2 \left[\rho - \left(\varphi \rho_A + (1-\varphi) \rho_W \right) \right]$$



Numerical tools

Interface sharpening using time splitting and penalization Kokh, **Kaceniauskas**, Allaire, So, Shukla, Kreiss, Olson, **Shyue**, …

$$\begin{cases} \dfrac{\partial \rho}{\partial t} + \mathrm{div}(\rho \vec{u}) = 0 \\ \dfrac{\partial \rho \vec{u}}{\partial t} + \mathrm{div}(\rho \vec{u} \otimes \vec{u} + p \,\overline{\overline{I}}) = \rho \vec{g} \\ \dfrac{\partial \varphi}{\partial t} + \vec{u} \cdot \nabla \varphi = 0 \\ p = p_0 + c_0^2 \left[\rho - \left(\varphi \rho_w + (1-\varphi)\rho_a \right) \right] \end{cases}$$

$$\begin{cases} \dfrac{\partial \rho}{\partial \tau} = -s(\varphi)(\rho_w - \rho_a) \\ \dfrac{\partial \rho \vec{u}}{\partial \tau} = -s(\varphi)(\rho_w - \rho_a)\vec{u} \\ \dfrac{\partial \varphi}{\partial \tau} = s(\varphi) \\ s(\varphi) = \varphi^2 (1-\varphi)^2 (c - \varphi) \end{cases}$$

- ✓Stability
- ✓Conservation
- ✓ Preserve constant u,p states

Adaptive mesh refinement using the numerical production of entropy

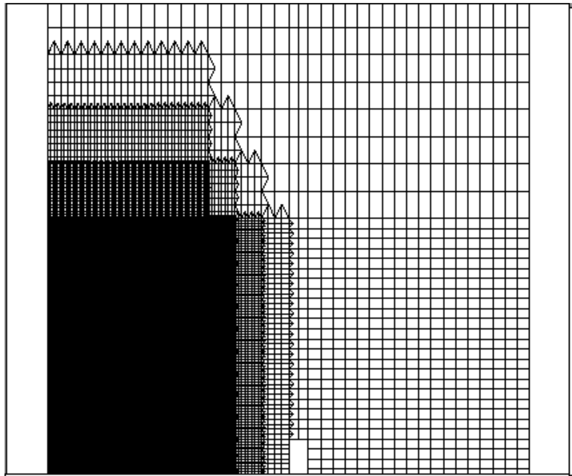
$$s = \frac{1}{2}\rho u^2 + c_0^2 \rho \ln(\rho) - c_0^2 (\rho_W - \rho_A)\varphi$$

$$\psi(s) = \left(s + c_0^2 \rho + c_0^2 (\rho_W - \rho_A)\varphi \right)\vec{u} = \left(\frac{1}{2}\rho u^2 + c_0^2 \rho \left(\ln(\rho) + 1 \right) \right)\vec{u}$$

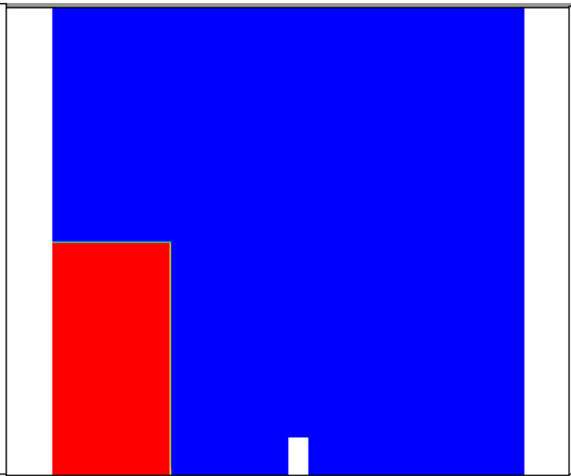
2-3D Dambreaking with obstacle

321 Blocks - 321 Domains - 120 Cpu

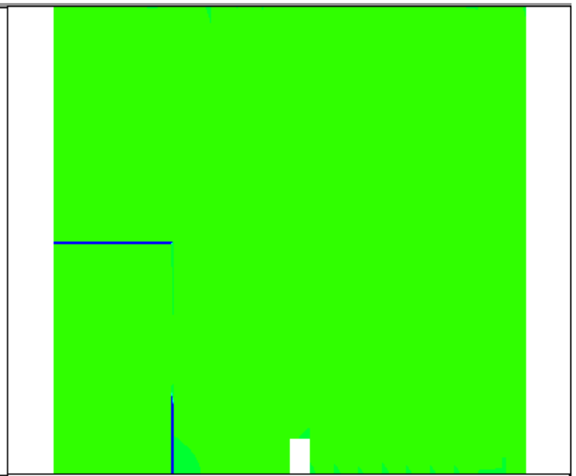
Mesh

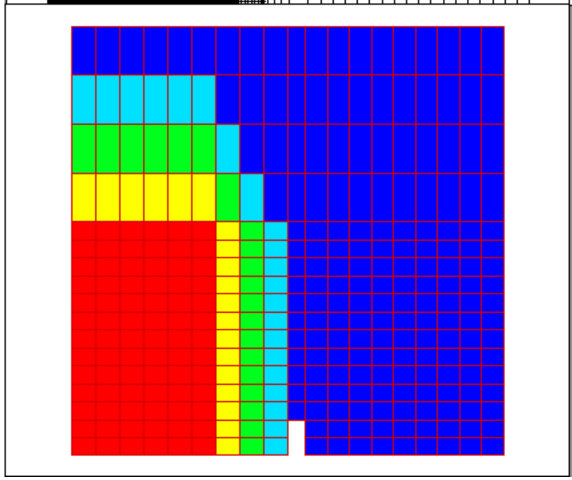


Density



Density of numerical Entropy production





Level

$\alpha_{min} = 0.02$

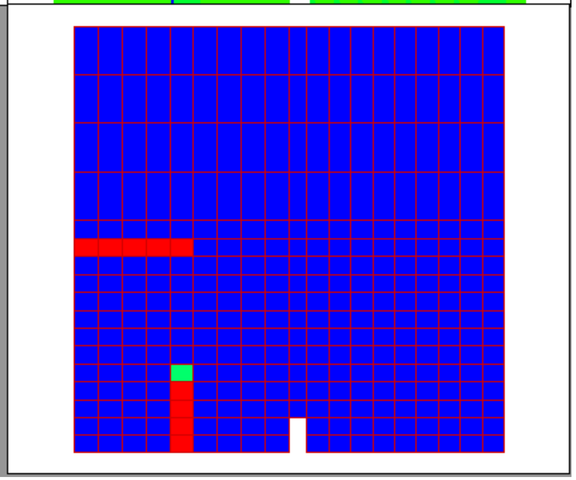
$\alpha_{max} = 0.2$

Levels : 0 to 4

number of cells $\approx 70\,000 - 100\,000$

Interface sharpening

10 nodes of 12 cores

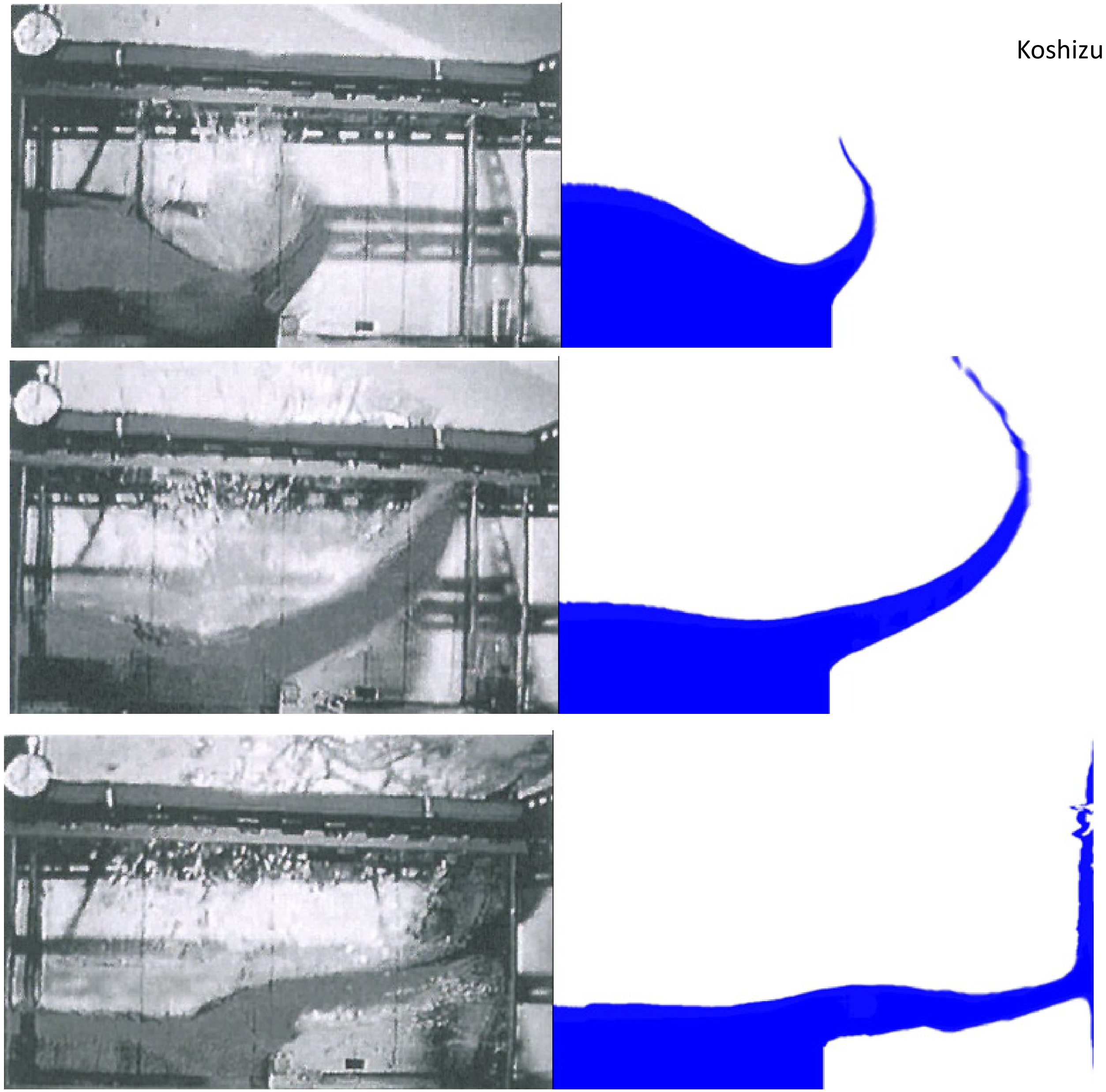


Criterion / block

Computations have been performed at the mesocentre of Aix-Marseille university

2-3D Dambreaking with obstacle: Experimental confrontation

Koshizuka, Tamako, Oka 1995

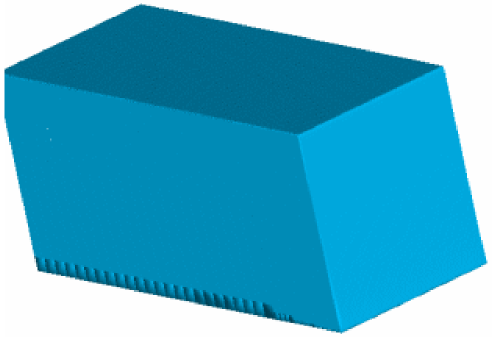


T=0.2s

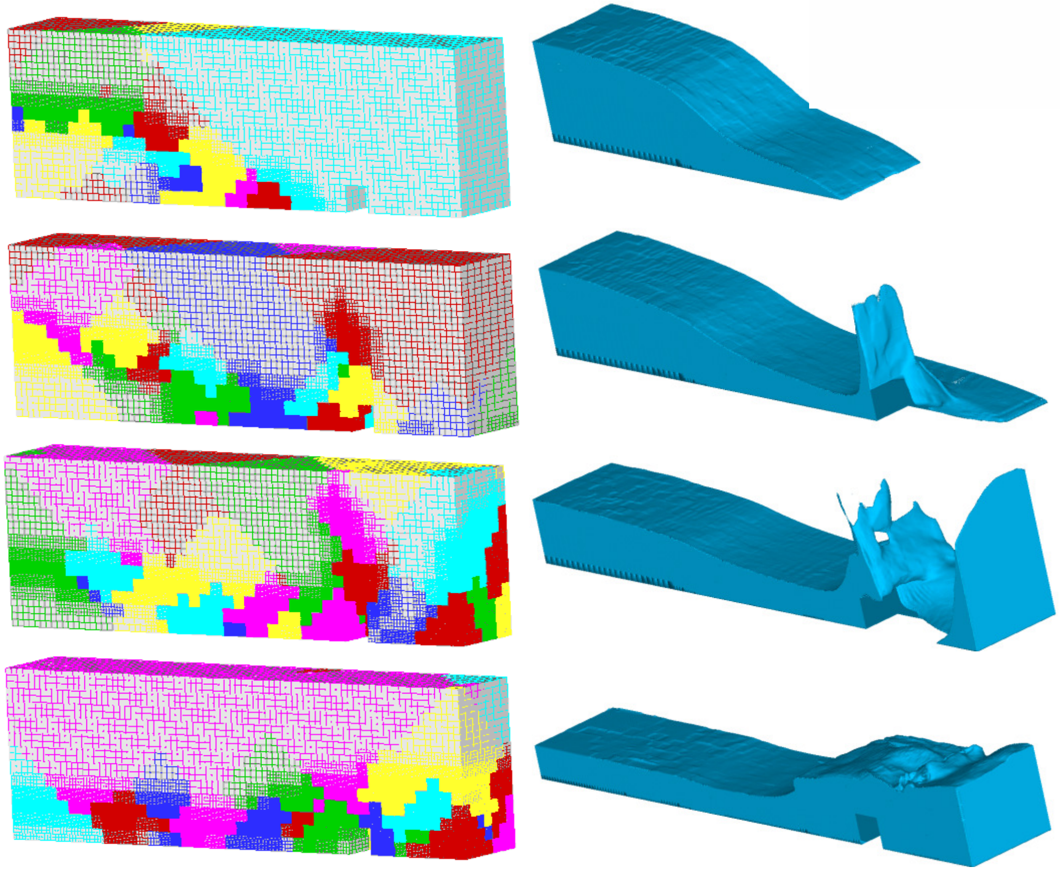
T=0.3s

T=0.4s

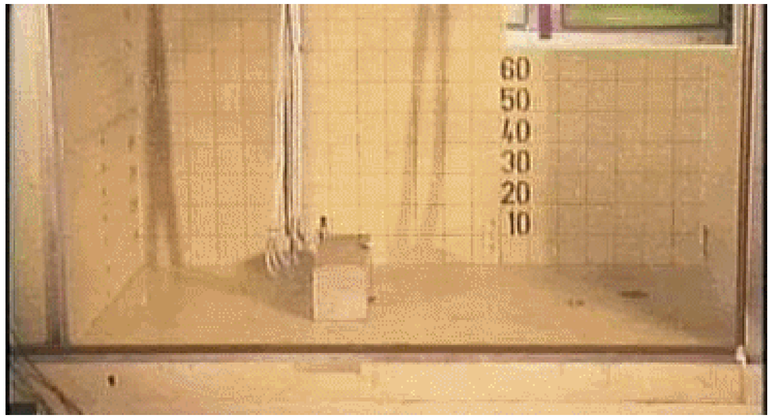
Balance distribution of cpu load: Kleefsman's test case



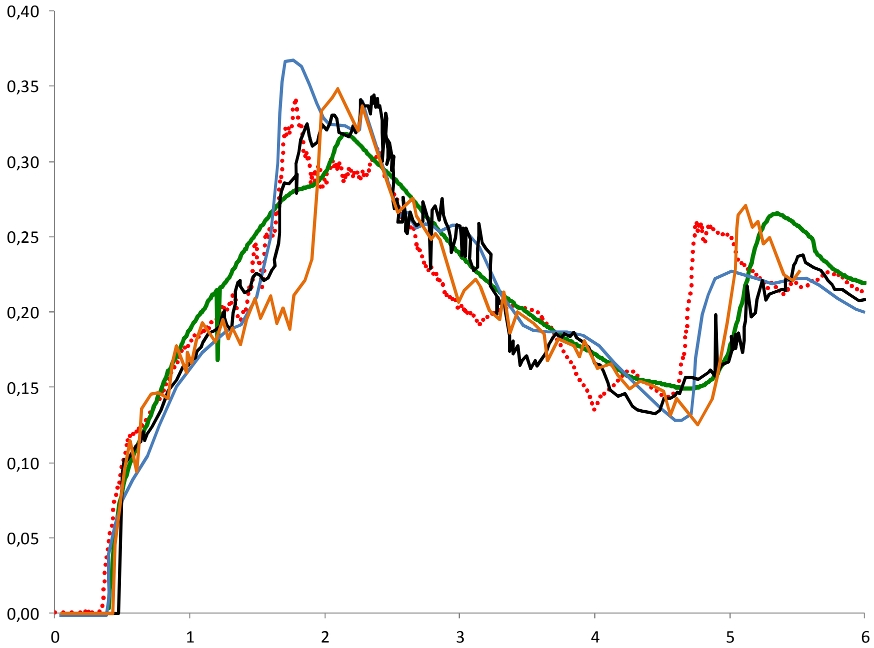
48 Domains = 48 Cpus = 3628 Blocks
4 mesh refinement levels

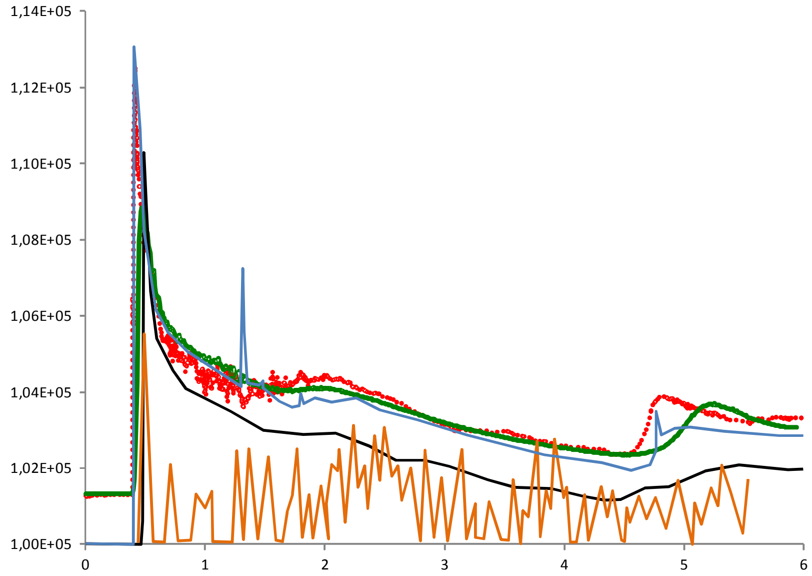


Maritime Research Institute Netherlands (MARIN)
K.M.T. Kleefsman (2005)



Confrontation with others CFD codes





Experiment

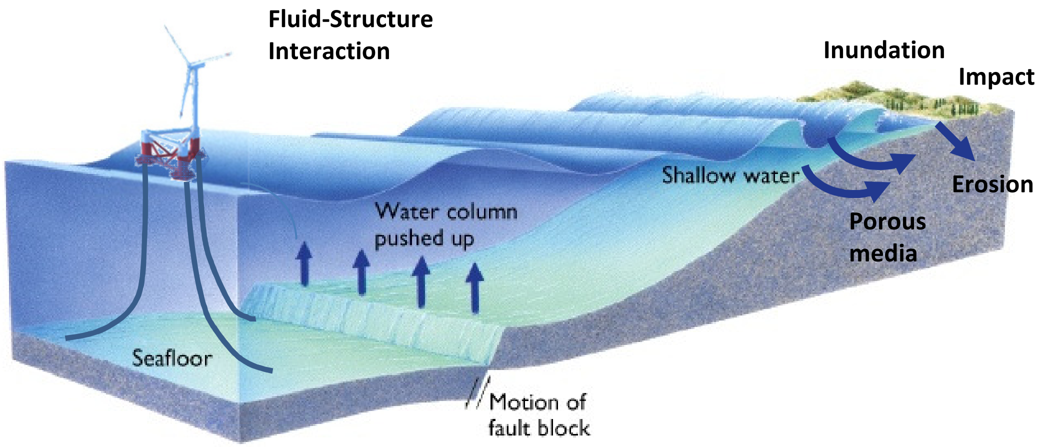
SPH Violeau et al. 2010

Our computation 2011

VOF Kleefsman et al. 2005

VOF-SM Vincent et al. 2010

Wave propagation



K. Pons, M. Ersoy, R. Marcer

- Hyperbolic solver BB-AMR3D
- Air-Water model
- Wave propagation
  - Shallow water Model
  - Numerical tools
  - Examples
  - Shallow water / Bi-fluid Euler coupling
- Fluid-structure interaction

PRINCIPIA

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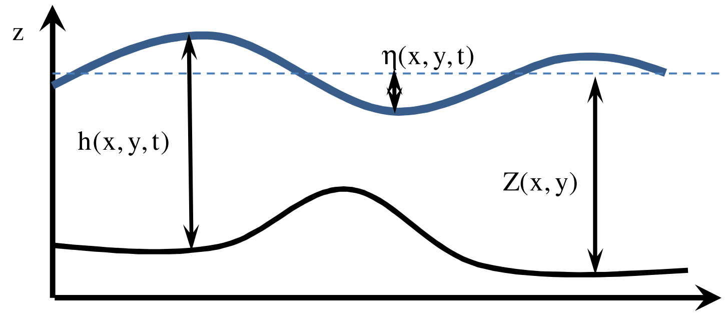
Shallow-water model (Saint-Venant model)

$$\begin{cases} \dfrac{\partial h}{\partial t} + \mathrm{div}(h\vec{u}) = 0 \\ \dfrac{\partial h\vec{u}}{\partial t} + \mathrm{div}\left(h\vec{u} \otimes \vec{u} + g\dfrac{h^2}{2}\bar{\bar{I}} \right) = -\rho h \nabla Z \end{cases}$$



Adaptive mesh refinement using the numerical production of entropy

$$s = h\frac{\|\vec{u}\|^2}{2} + g\frac{h^2}{2} + ghZ \quad , \quad \psi = \left(s + g\frac{h^2}{2}\right)\vec{u}$$

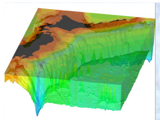
Well balanced hydrostatic reconstruction by Audusse *et al.* 2004

$\Delta Z_{k/a}$ Jump of bathymetry across cells k and a

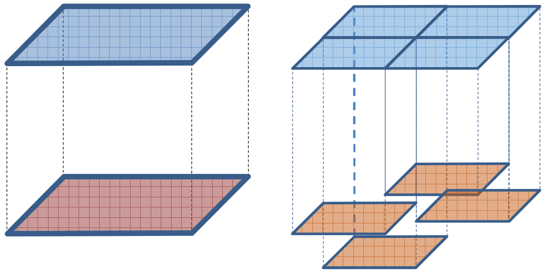
with

$$h_k^* = \max\left(0, h_k - \max(0, \Delta Z_{k/a})\right)$$
$$h_a^* = \max\left(0, h_a - \max(0, \Delta Z_{k/a})\right)$$

$$F\left(w_k^*(t), w_a^*(t), \vec{n}_{k/a}\right) + \left\{\begin{matrix} 0 \\ \frac{g}{2}\left(h_k^2 - \left(h_k^*\right)^2\right)\vec{n}_{k/a} \end{matrix}\right\}\Bigg|_{C_k} + \left\{\begin{matrix} 0 \\ \frac{g}{2}\left(h_a^2 - \left(h_a^*\right)^2\right)\vec{n}_{k/a} \end{matrix}\right\}\Bigg|_{C_a}$$



Numerical tools: Bathymetry and BB-AMR



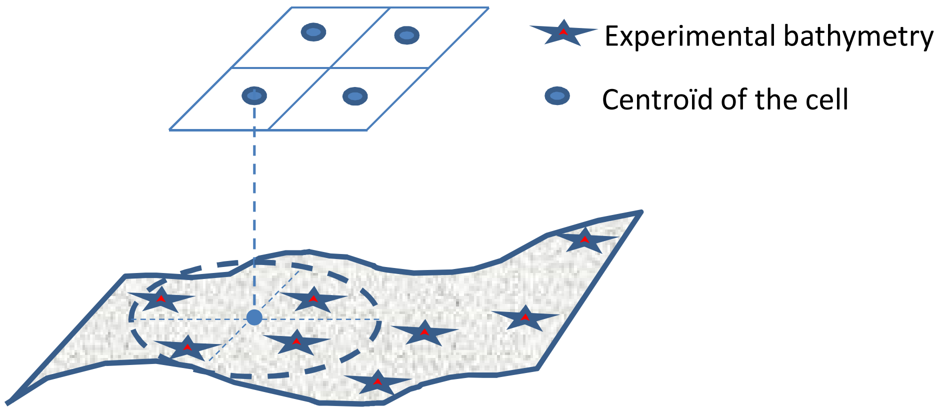
$$\int_{OldMesh} \rho dv = \int_{NewMesh} \rho dv \qquad |C_k| Z_k = \sum_{i=1}^{2^d} |C_{ki}| Z_{ki}$$

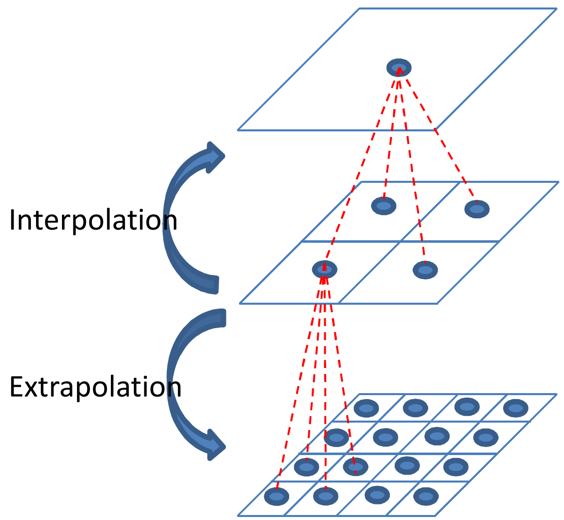
The dynamic discretization of the bathymetry
Goals:

- Mass conservation, still water steady state (η=cste)
- Avoiding spirious waves
- Low cost interpolation from experimental database

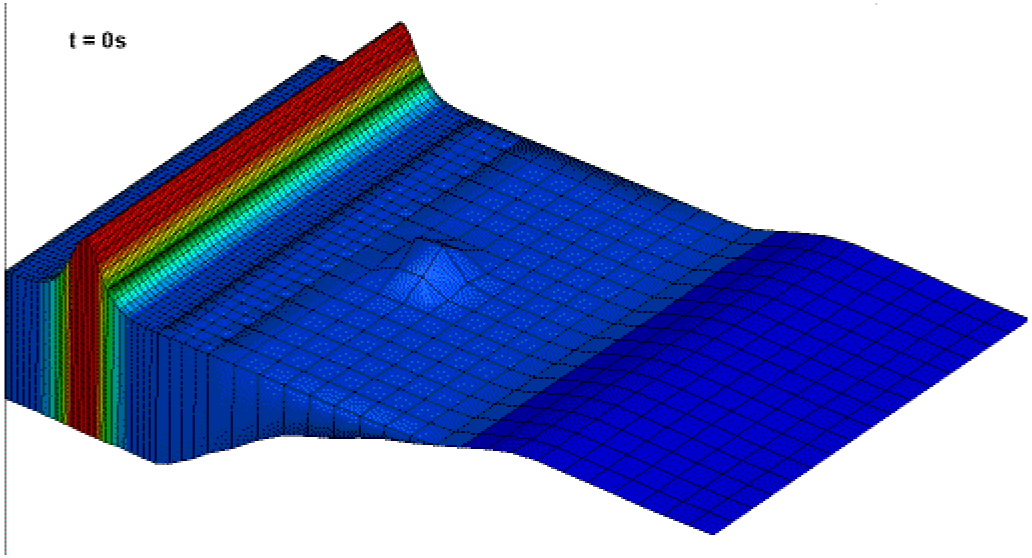
Particular case : the shoreline
(solution-> always at the lowest mesh refinement level)

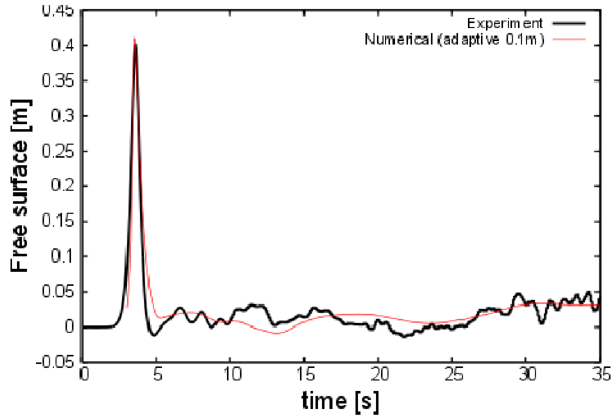
Mean square interpolation of the experimental bathymetry on a reference grid per block

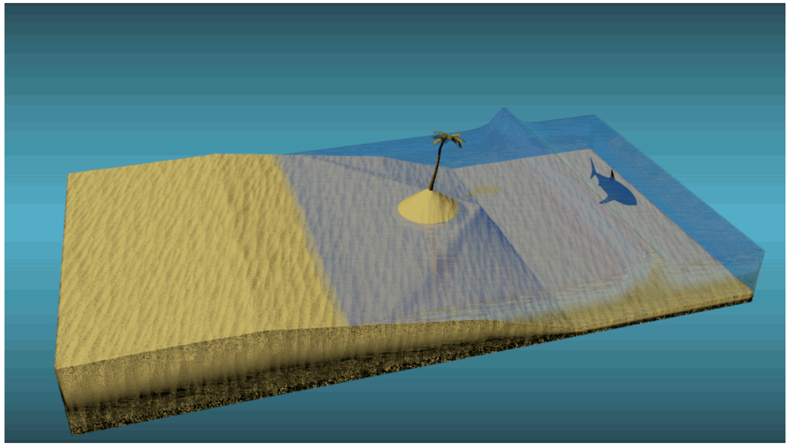


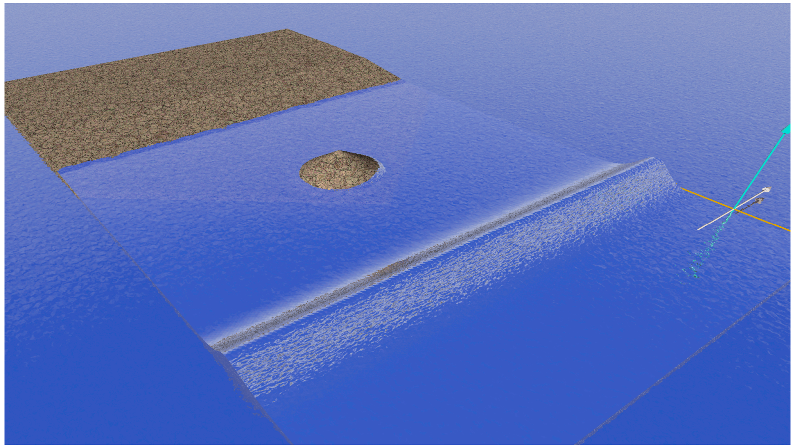


Solitary Wave over conical island: Lynett et al. 2010



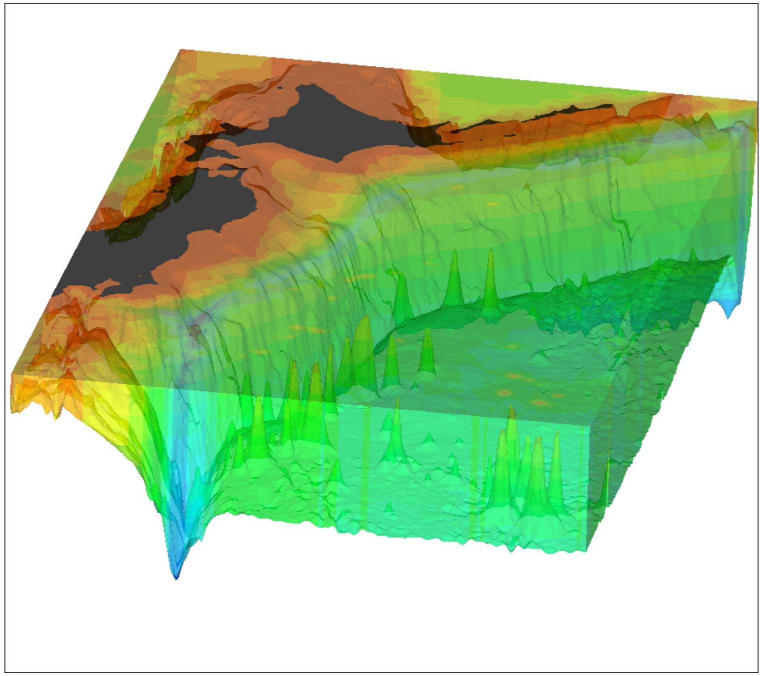




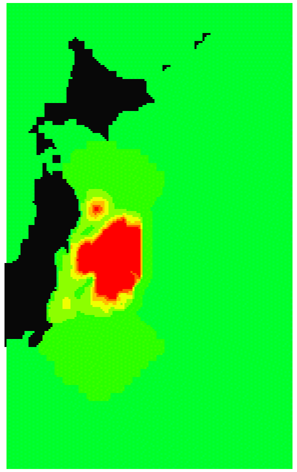


Tsunami Tohoku-Oki 2011

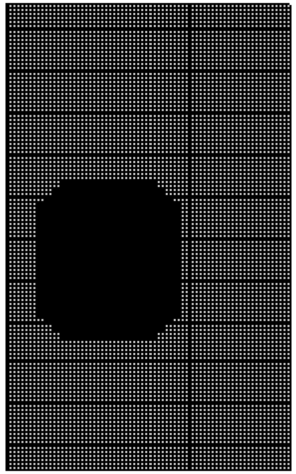
Bathymetry



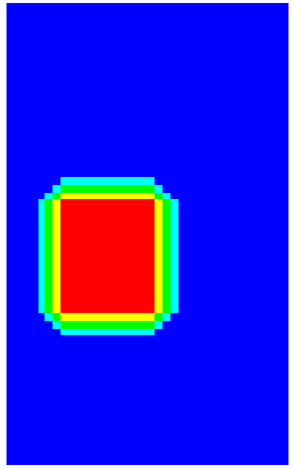
Water Level

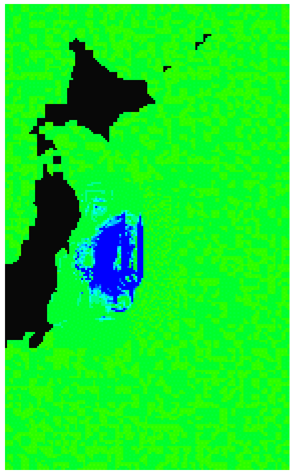


Mesh

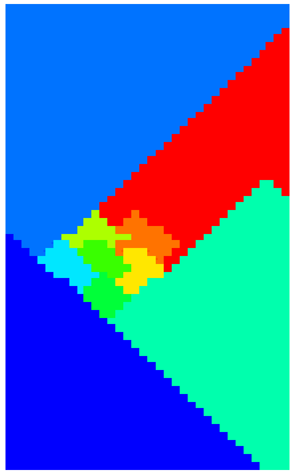


Mesh refinement Level

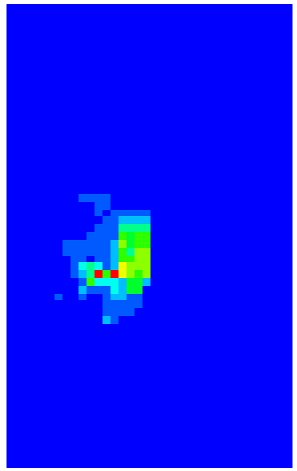




Density of numerical Entropy production

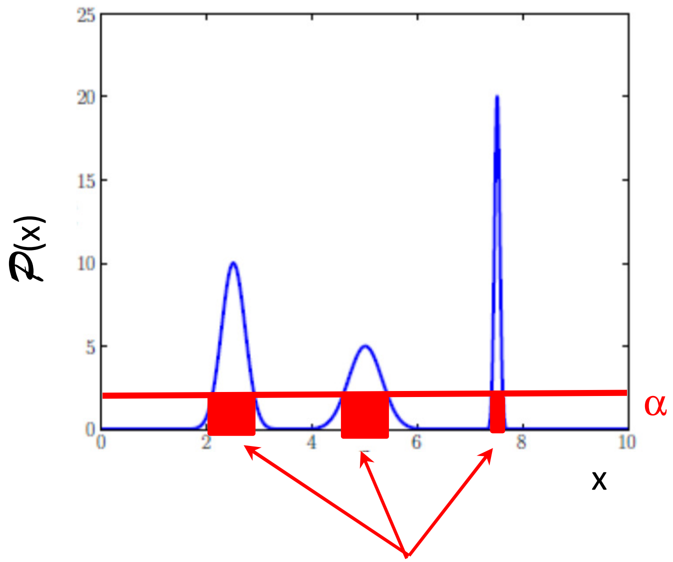


Domains

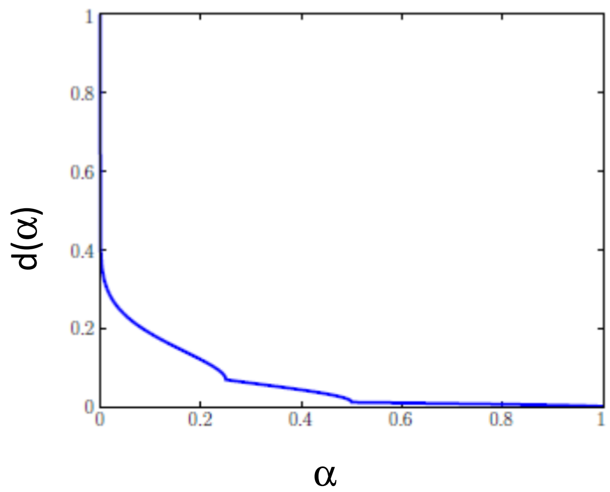


Criterion / block

Automatic threshold



Distribution fonction



$$\alpha_{op} = \min\left(\overline{\mathcal{P}}, \max_{0<\alpha<\mathcal{P}_\infty}(\alpha\, d(\alpha))\right)$$

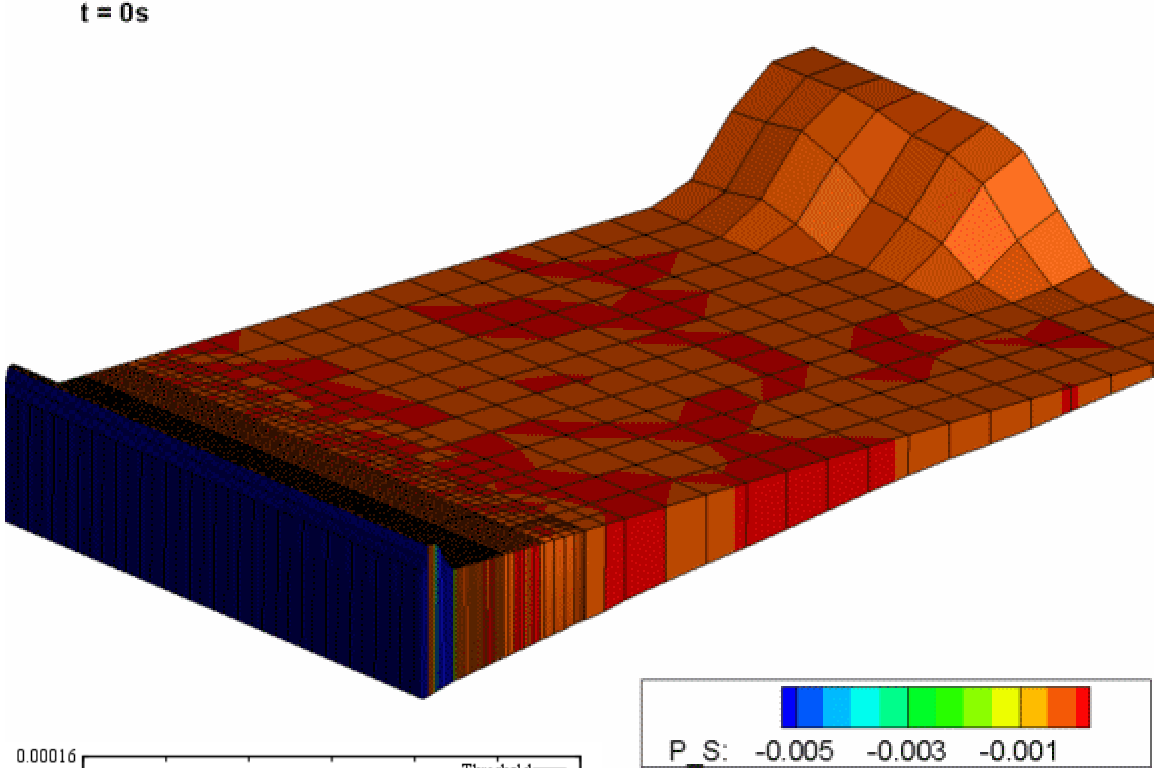
Dannehoffer 1987, Powel 1989, …

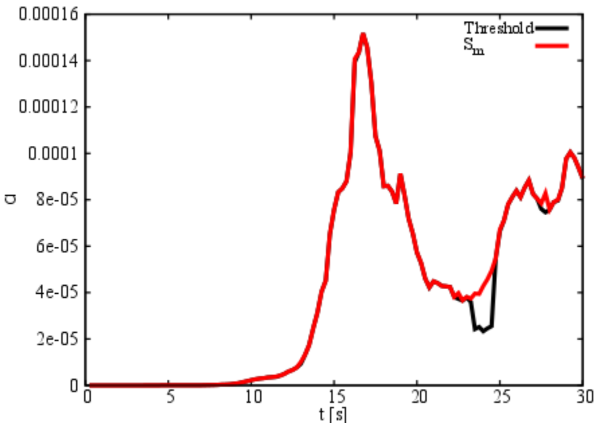
If $\overline{\mathcal{P}_{Block}} \le \alpha\, \overline{\mathcal{P}_{\Omega}}$ the block is coarsened

If $\alpha\, \overline{\mathcal{P}_{\Omega}} \le \overline{\mathcal{P}_{Block}}$ the block is refined

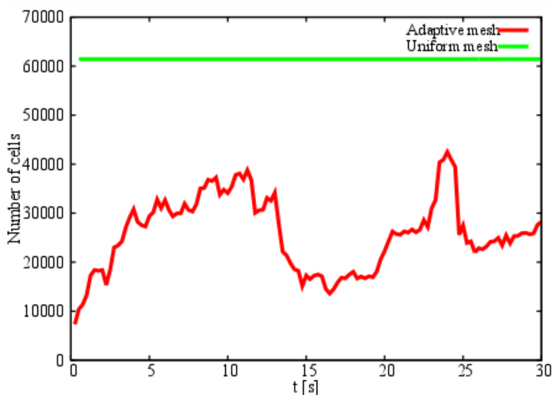
Automatic threshold: Benchmark Money-Valley beach

240 blocks

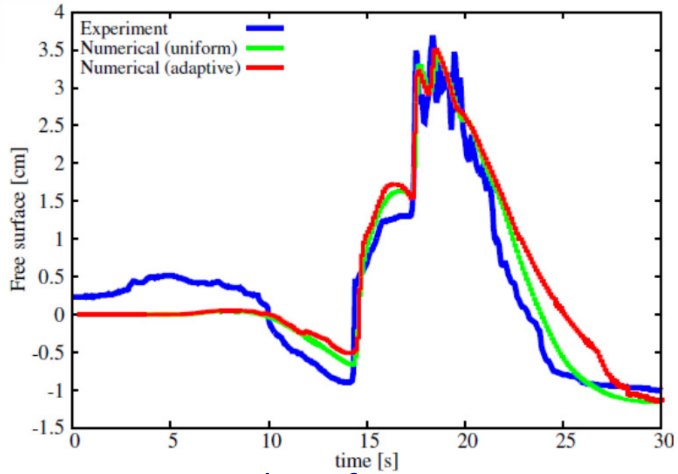




Threshold



Number of cells



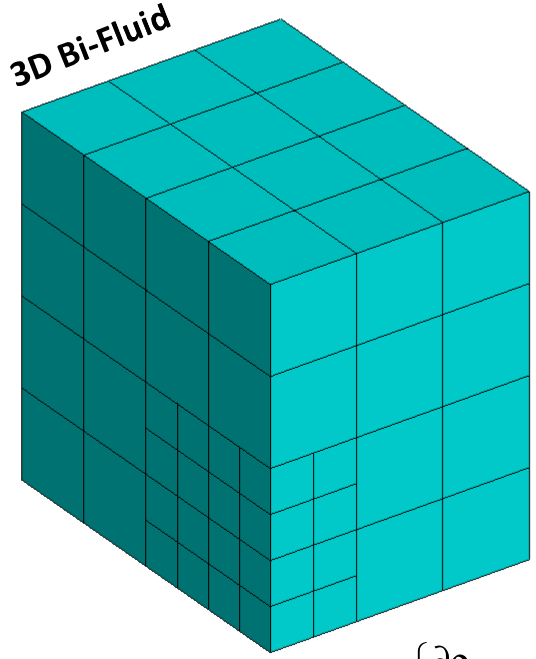
Experimental confrontation gauge 1

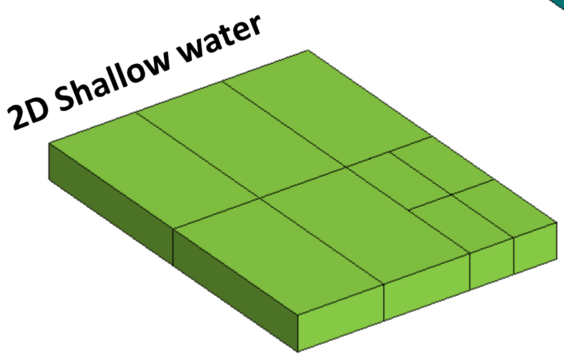
Shallow water / Bi-fluid Euler coupling

$$\begin{cases} \dfrac{\partial h}{\partial t} + \mathrm{div}(h\vec{u}) = 0 \\ \dfrac{\partial h\vec{u}}{\partial t} + \mathrm{div}(h\vec{u} \otimes \vec{u} + g\dfrac{h^2}{2}\overline{\overline{I}}) = -\rho h \nabla Z \end{cases}$$

$$s = h\frac{\|\vec{u}\|^2}{2} + g\frac{h^2}{2} + ghZ$$

$$\psi = \left(s + g\frac{h^2}{2} \right)\vec{u}$$



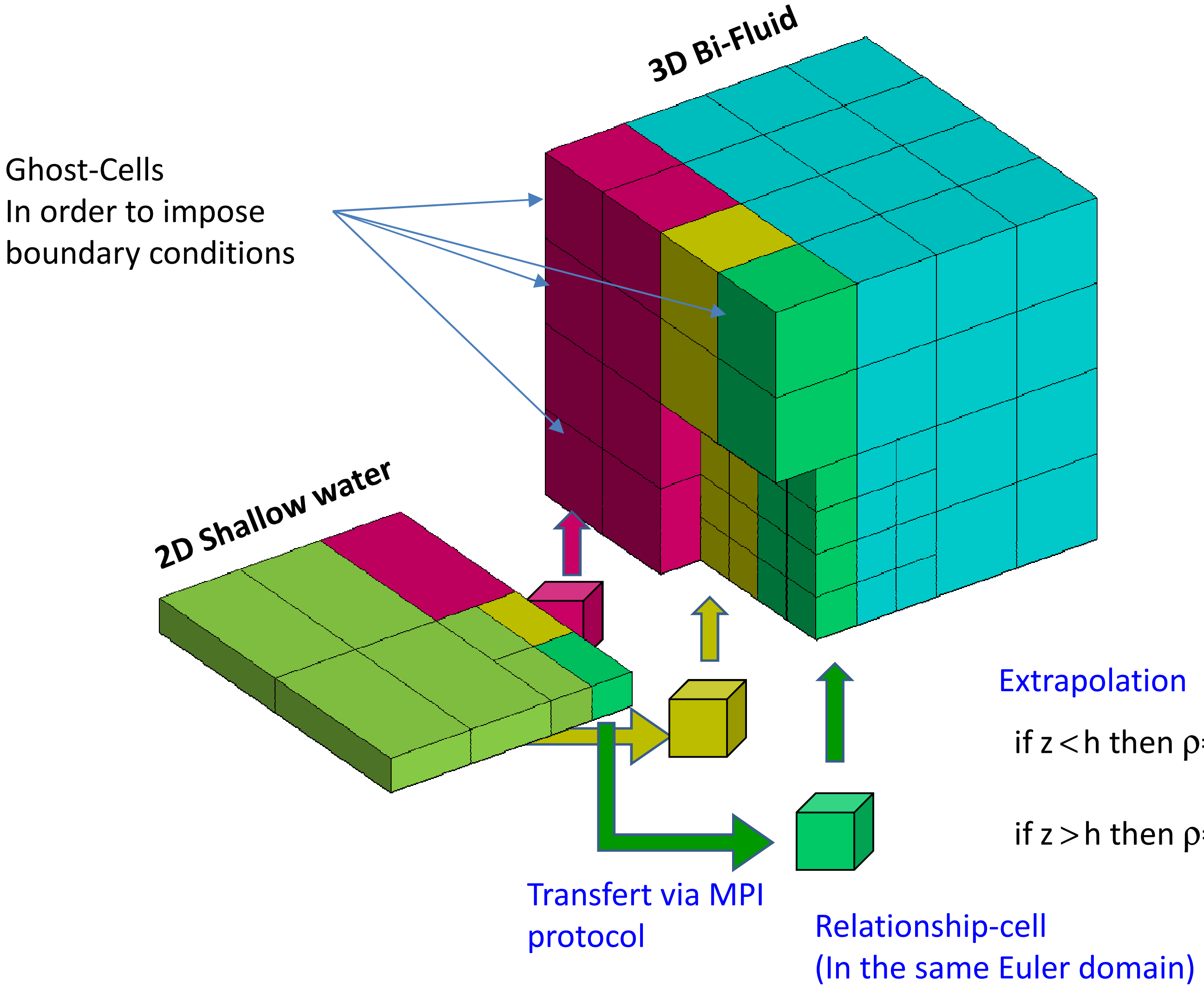


$$\begin{cases} \dfrac{\partial \rho}{\partial t} + \mathrm{div}(\rho\vec{u}) = 0 \\ \dfrac{\partial \rho\vec{u}}{\partial t} + \mathrm{div}(\rho\vec{u} \otimes \vec{u} + p\overline{\overline{I}}) = \rho\vec{g} \\ \dfrac{\partial \varphi}{\partial t} + \vec{u} \cdot \nabla\varphi = 0 \\ p = p_0 + c_0^2\left[\rho - \left(\varphi\rho_A + (1-\varphi)\rho_W\right)\right] \end{cases}$$

$$s = \frac{1}{2}\rho u^2 + c_0^2 \rho \ln(\rho) - c_0^2 \left(\rho_W - \rho_A\right)\varphi$$

$$\psi(s) = \left(s + c_0^2\rho + c_0^2\left(\rho_W - \rho_A\right)\varphi\right)\vec{u}$$

Extrapolation Shallow water to Euler



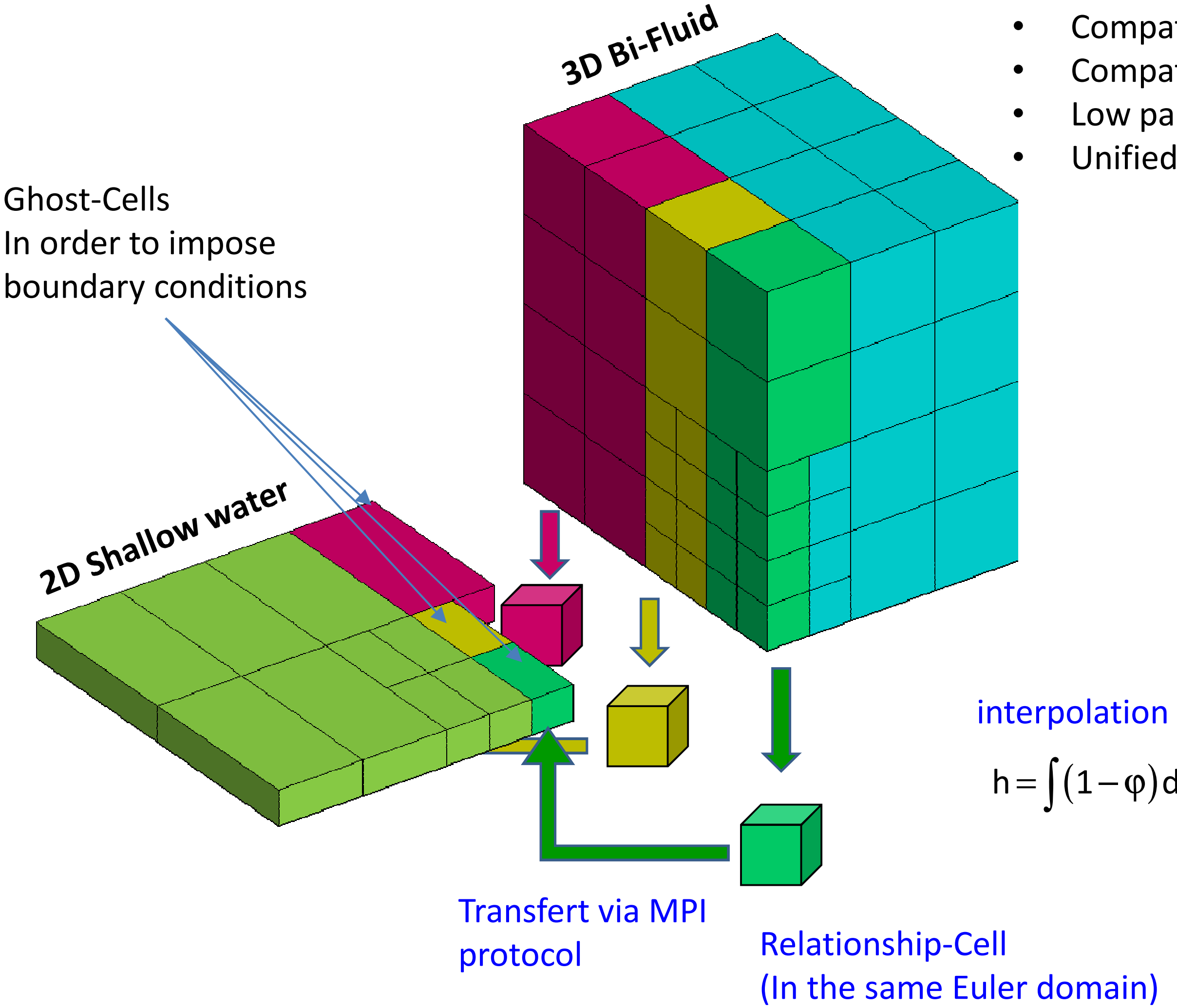
Extrapolation

$$\text{if } z < h \text{ then } \rho = \rho_w, \quad \vec{u} = \begin{Bmatrix} \vec{u}_{SV} \\ 0 \end{Bmatrix}, \frac{\partial p}{\partial n} = 0$$

$$\text{if } z > h \text{ then } \rho = \rho_A, \quad \vec{u} \approx \vec{0}, p = p_0$$

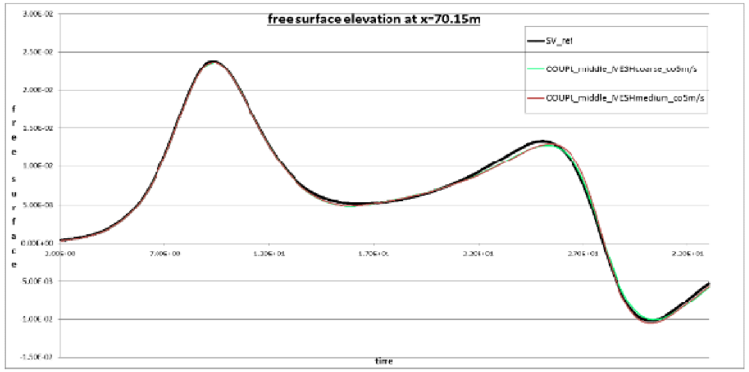
Interpolation Euler to Shallow water

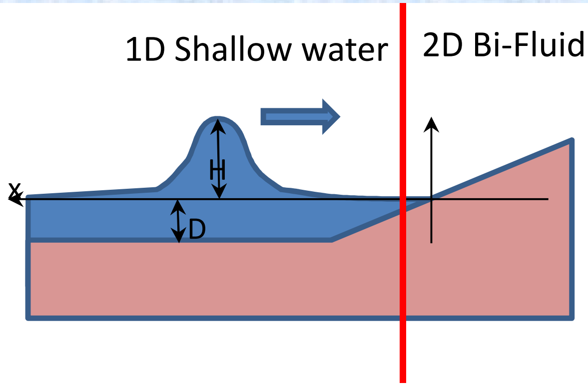
- Compatible with the AMR procedure
- Compatible with the domain decomposition
- Low parallel communications
- Unified model

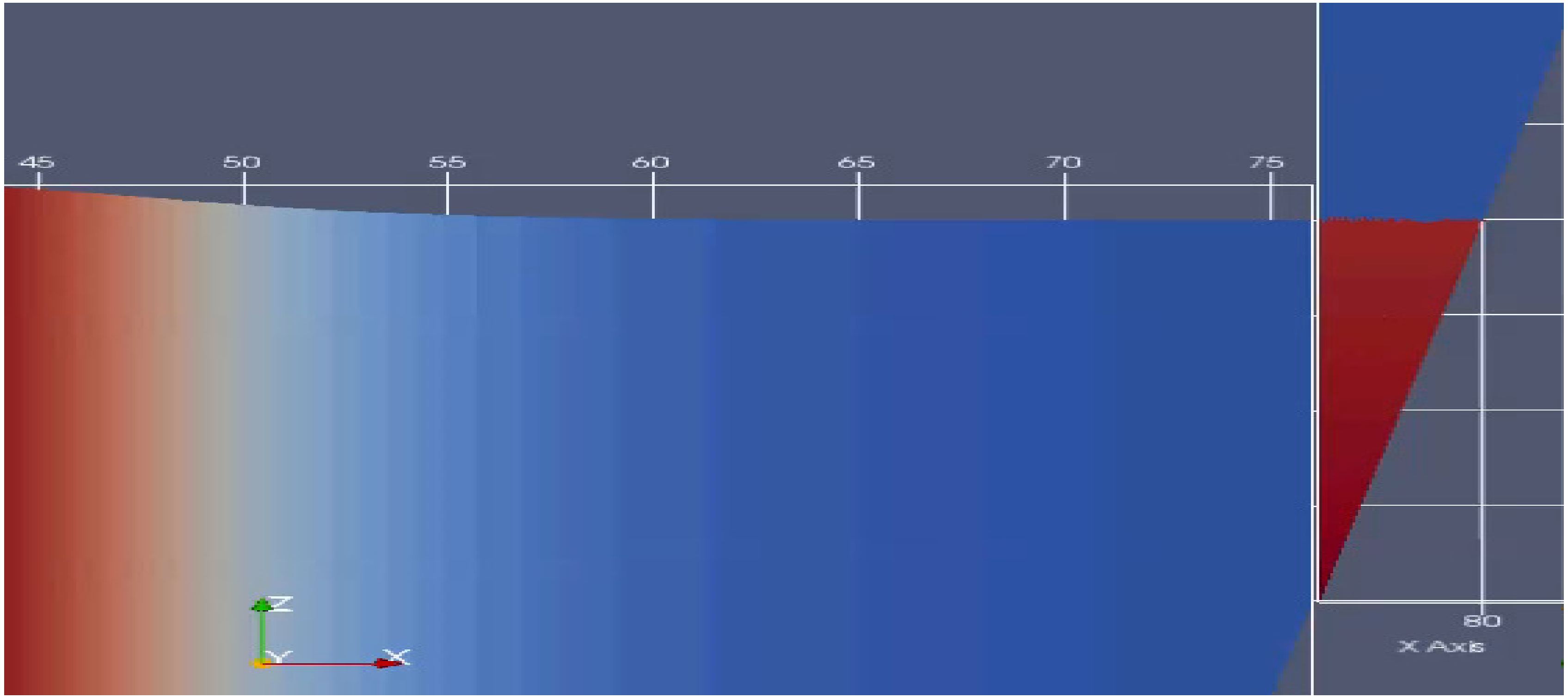


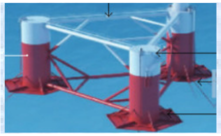
$$h = \int (1-\varphi)\,dz \quad \vec{u} = \int (1-\varphi)\,\vec{u}_{EU}\,dz$$

Run-up of a solitary wave Synolakis, 1987

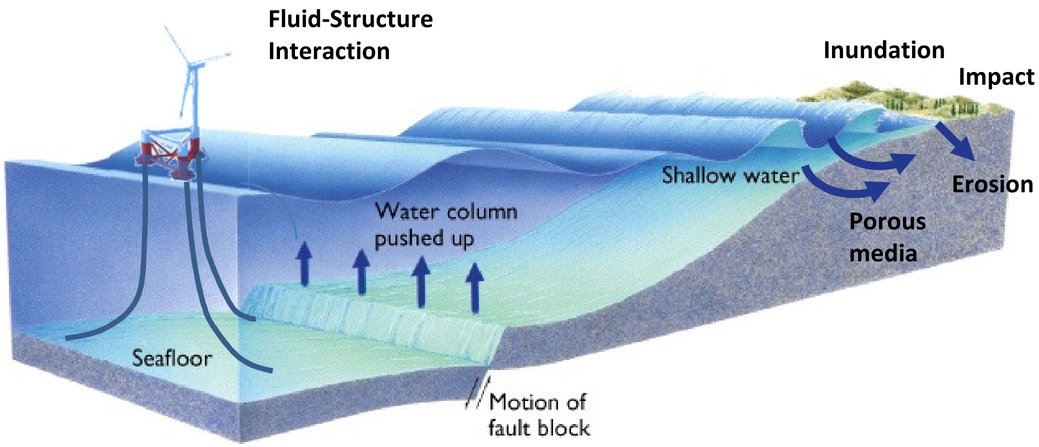








Fluid-Structure Interaction

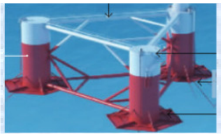


T. Altazin, P. Fraunié

- Hyperbolic solver BB-AMR3D
- Air-Water model
- Wave propagation
- Fluid-structure interaction
    - FSI Model
    - Numerical tools
    - Examples

Projet CHEF
Comportement
Aero/**H**ydrodynamique des
Éoliennes **F**lottantes

Région
Provence
Alpes
Côte d'Azur



A monolithic approach

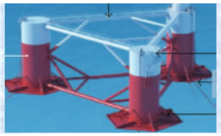
Monolithic approach: fluid and solid are considered simultaneously

The rigid body is considered as a « rigid fluid ».
The velocity field inside the « solid » is projected to rigid space

M. Coquerelle, G,-H,. Cottet, ”A vortex level set method for two-way coupling of an incompressible fluid colliding rigid bodies”, J. Comp. Phys., 2008,

The formulation is equivalent in the compressible case

$$\frac{\partial \rho \vec{u}}{\partial t} + \mathrm{div}(\rho \vec{u} \otimes \vec{u} + p\,\bar{\bar{I}}) = \rho \vec{g} + AR$$



Numerical tools

- Adaptive mesh refinement using numerical production of entropy and enhanced near to the fluid-solid interface
- Normal stress and velocity continuity at the interface
- Penalization using prediction – correction method

Prediction $$\frac{\partial \rho \vec{u}}{\partial t} + \mathrm{div}(\rho \vec{u} \otimes \vec{u} + p\,\overline{\overline{I}}) = \rho \vec{g}$$

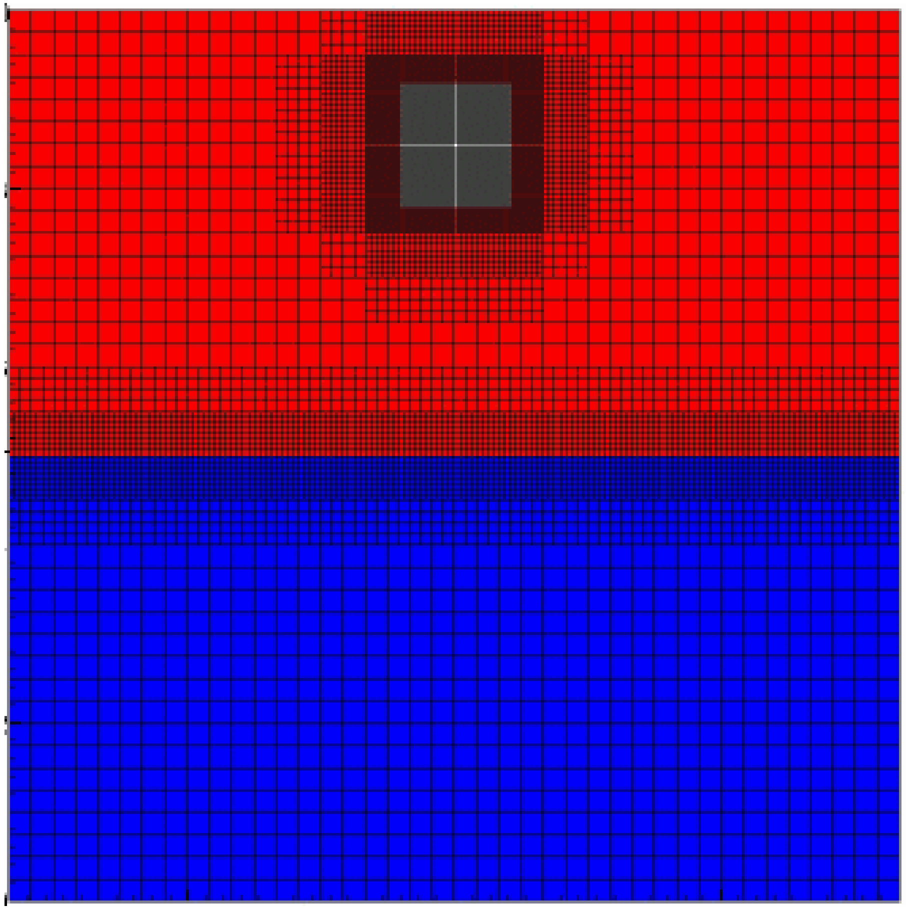
Correction $$\frac{\partial \rho \vec{u}^*}{\partial \tau} = \chi_s \lambda \rho_s (\vec{u} - \vec{u}_s)$$

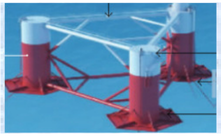
- projection of the predicted velocity over the rigid motion vector space

$$\vec{u}_s(M) = \frac{1}{m}\int_\Omega \chi_s \rho \vec{u}\, d\Omega + \left(\overline{\overline{J}}^{-1} \int_\Omega \chi_s \rho \overrightarrow{GM} \wedge \vec{u}\, d\Omega \right) \wedge \overrightarrow{GM}$$

- Determination of the indicator function using ray-casting
- Definition of the bodies using OBJ meshes

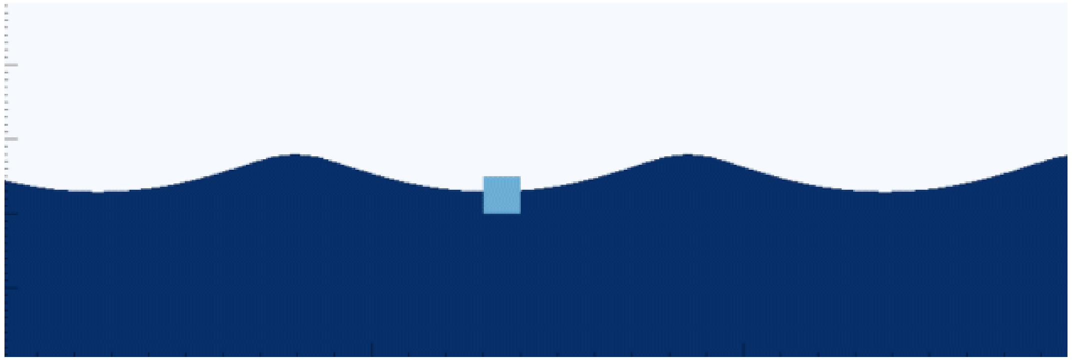
Free fall of a cube, water entry problem

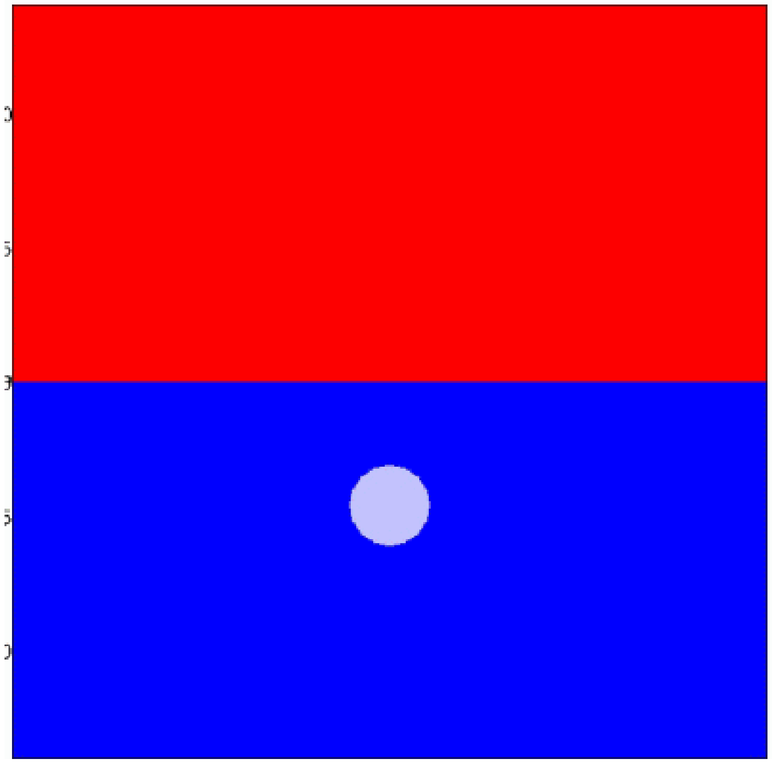




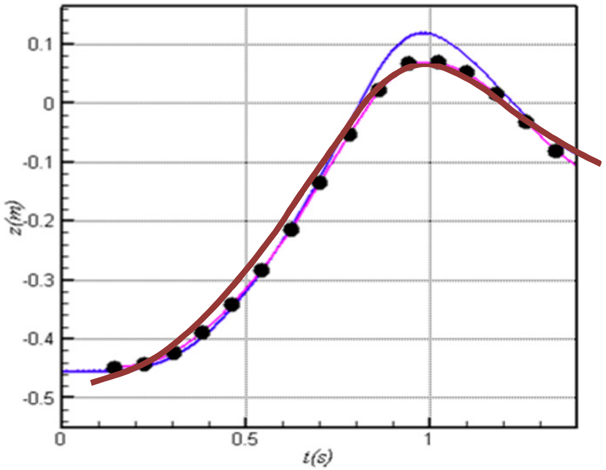
Others examples …

5th order Stoke's swell and floating rigid body

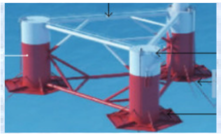




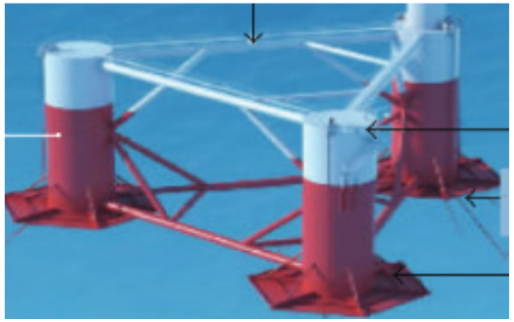
Free raising of a cylindrical buoy
(Colicchio et al., 2009)



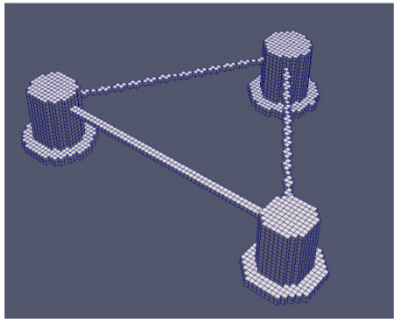
3D numerical experiment



Application to floating wind turbine



WindFloat: A floating foundation for offshore wind turbines, D. Roddier et al., 2010,



OBJ mesh

Outlook

Outlook

- A 3D finite volume code solving hyperbolic systems using BB-AMR with entropic criterion, a good compromise between relevance, accuracy and computing time .
  - Low Mach bi-fluid isothermal Euler model.
  - Shallow water model.
  - Monolithic fluid-structure interaction model.
- Shallow water / Bi-fluid Euler coupling.
- Application to wave propagation, wave breaking and buoy motion.

Perspectives

- Implementation of relaxed Serre-Green-Naghdi model (Favrie, Gavrilyuk 2017).
- Experimental validation of 3D FSI.
- Extension to variable density.
- Coupling bi-fluid / FSI / SGN.
- Subgrid two phases models

Thank you for your attention

• F. Golay, P. Helluy, ”Numerical schemes for low Mach wave breaking”, Int. J. Comp. Fluid Dyn., 2007.

• Sambe A., Golay F., Sous D., Fraunié P., R. Marcer, “Numerical wave breaking over macro-roughness”, Eur. J. Mech. B/Fluid, 2011.

• Golay F., Ersoy M., Yushchenko L., D. Sous, “Block-Based Adaptive Mesh Refinement scheme using numerical density of entropy production for three-dimensional two-fluid flows”, Int. J,Comp. Fluid Dyn., 2015.

• Marcer R., Pons K., Journeau C., Golay F., “Validation of CFD models for tsunami simulation. TANDEM Project”, Rev. Paralia, 2015.

• Altazin T., Ersoy M., Golay F., Sous D., Yushchenko L., “Numerical investigation of BB-AMR scheme using entropy production as refinement criterion”, Int. J. Comp. Fluid Dyn., 2016.

Announcement

- **France Energies Marines : *www.france-energies-marines.org/***

- **ADEME : www.ademe.fr/**

- **Région Occitanie**

- **Institut France Québec Maritime *www.ifqm.info/fr/accueil/***

- **Appel à projet PHC Maghreb 2019 : L'espace méditerranéen face aux enjeux climatiques et énergétiques .**