ON A NEW GENERATION HYDRODYNAMICS MODELING PLATFORM FOR COASTAL APPLICATION:

UHAINA

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(BRGM, DRP-R3C)

Storm surge in Saint-Jean de Luz (France)

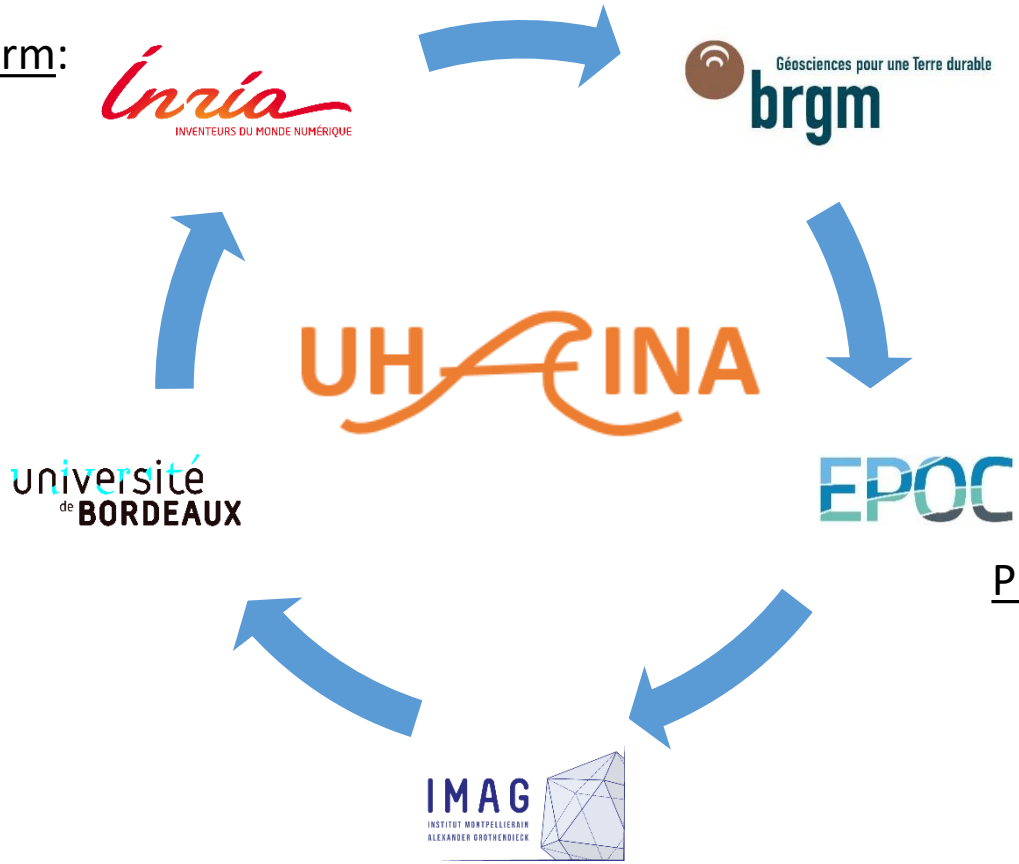
Consortium :

UH INA

Numerical Schemes and modeling :
- M. Ricchiuto

HPC, Aerosol Platform:
- V. Perrier

Real applications and numerics :
- A.G. Filippini
- L. Arpaia
- R. Pedreros



PDE modeling :
- D. Lannes

Physics and modeling :
- P. Bonneton

High order schemes :
- F. Marche

Géosciences pour une Terre durable brgm

Applications :

- Global and regional scales ➡ large physical domains (hundreds or thousands *km*)
  storms and hurricanes surges ;

Xyntia storm's effects on La Faute sur mer (France 2010).

Hurricane Ike strikes Texas (2008)

Applications :

- Global and regional scales ➡ large physical domains (hundreds or thousands *km*) storms and hurricanes surges ;
- Extreme waves : tsunamis ;

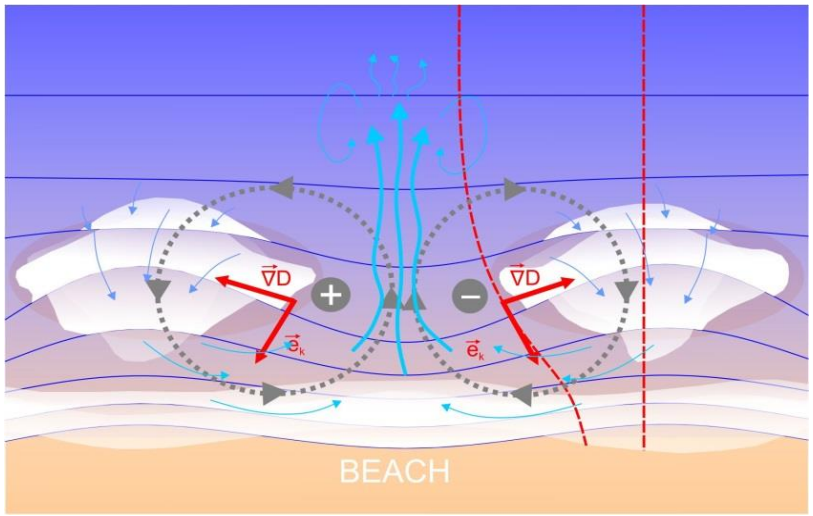
Tsunami hits Sendai Bay (Japan 2011).

Tsunami hitting Sumatra (2004)

Applications :

- Global and regional scales ➡ large physical domains (hundreds or thousands *km*) storms and hurricanes surges ;
- Extreme waves : tsunamis ;
- Wave-induced circulations : rip currents ;

Rip currents on the ocean coast.



Castelle et al. 2013

Applications :

- Global and regional scales ➡ large physical domains (hundreds or thousands *km*)
  storms and hurricanes surges ;
- Extreme waves : tsunamis ;
- Wave-induced circulations : rip currents ;
- Energetic swell and storm waves (*m* to *km*) :
  - Propagation in coastal environments ;
  - Submersion : overtopping and flooding ;
  - Impact on coastal structures.

Wave flooding on a coastal settlement.

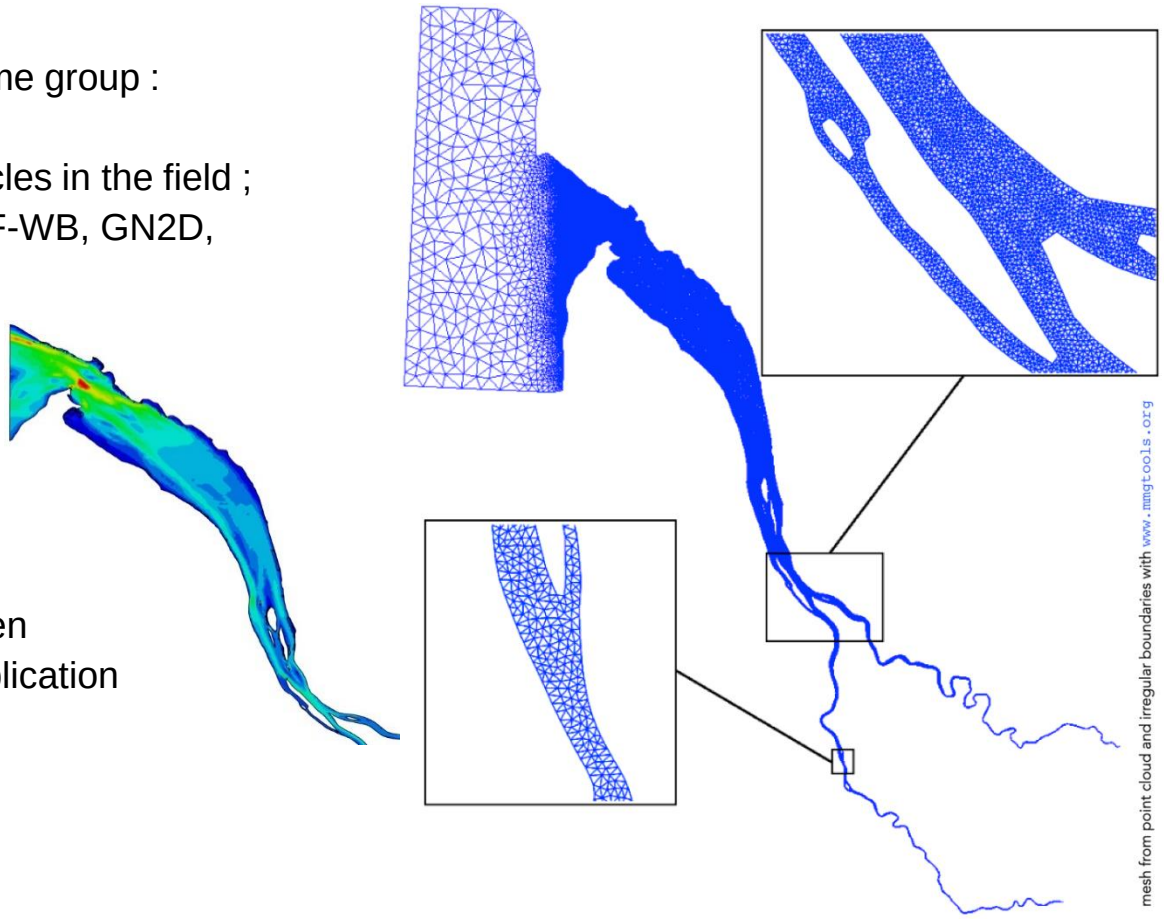
Storm hitting the venetian harbour of Chania (Crete).

Motivations :

- Existing models :
  - Old low order numerical schemes ⇒ poor description in shocks ;
    ⇒ poor description of wave dispersion/breaking ;
  - Structured meshes ⇒ use of nested grid for scale refinement ;
  - Badly parallelised ⇒ problem size limitations ;
  - Too specific ⇒ many codes to deal with (multiple results formats) ;
    ⇒ time-demanding pre/post processing operations.

- 15 years of joint research from the same group :
  - 8 PhD defenses ;
  - a large amount of published articles in the field ;
  - research codes : SLOWS, SURF-WB, GN2D, WaveBox.

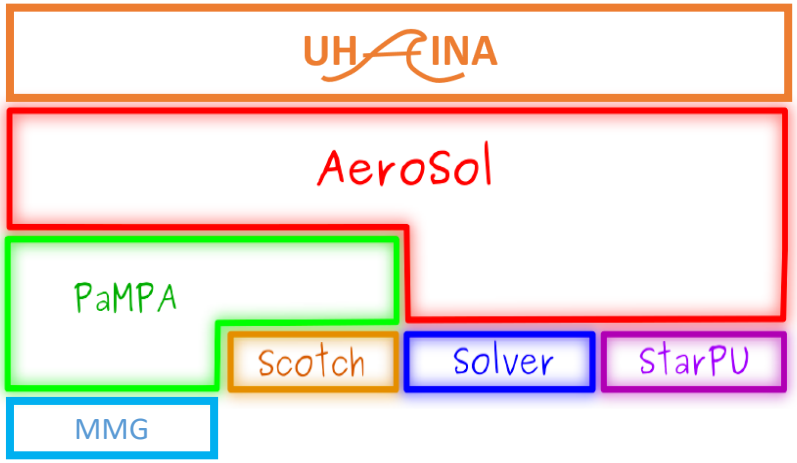
- **UHAINA**
  - Capitalize on our past activity ;
  - Provide operational tool with state of the art (models, schemes, HPC,…) ;
  - Set up continuous bridge between ongoing/future research and application on real scenarios.



Background :

Modern software architecture based on INRIA BSO products :

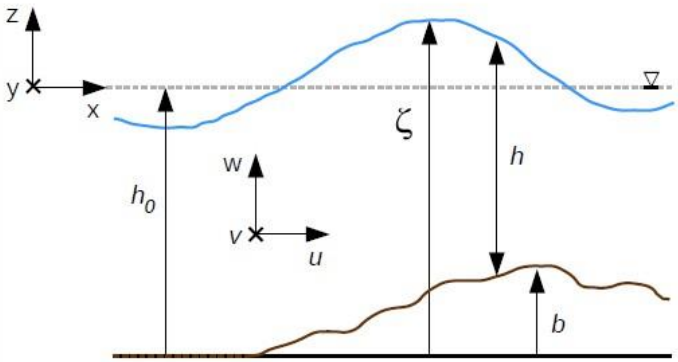
- Finite element library AeroSol :
  - Aribitrary High-order finite elements library (continuous or discontinuous) for CFD applications ;
  - Dedicated to nonlinear advection-diffusion problems : Aeronautical Solver ;
  - (Few) template abstraction (model, numerical flux, internal/external linear solver, ...) ;
  - Runs on structured, unstructured and hybrid meshes to handle complex geometries .
- User/developer transparent handling of distributed memory (PaMPA) .
- Efficient partitioning (Scotch) .
- Multiple algebraic libraries and linear solvers : BLAS, UMFPACK, PETSc, MUMPS, …
- Par – MMG for parallel adaptive re-meshing (*ongoing*)
- StarPU for real time optimization of shared/distributed execution (*ongoing*)

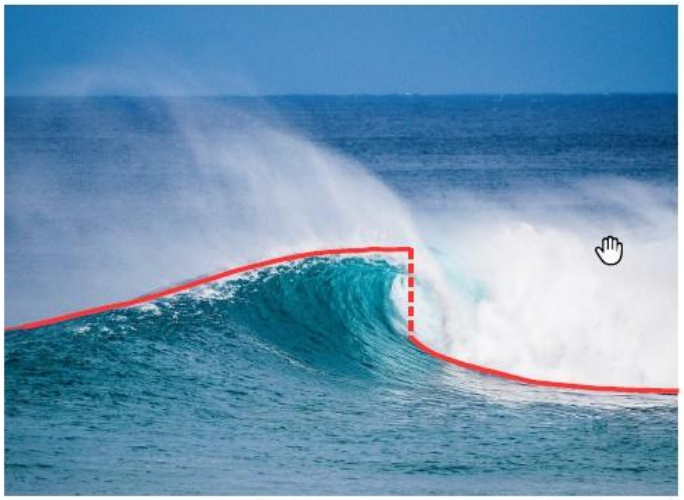


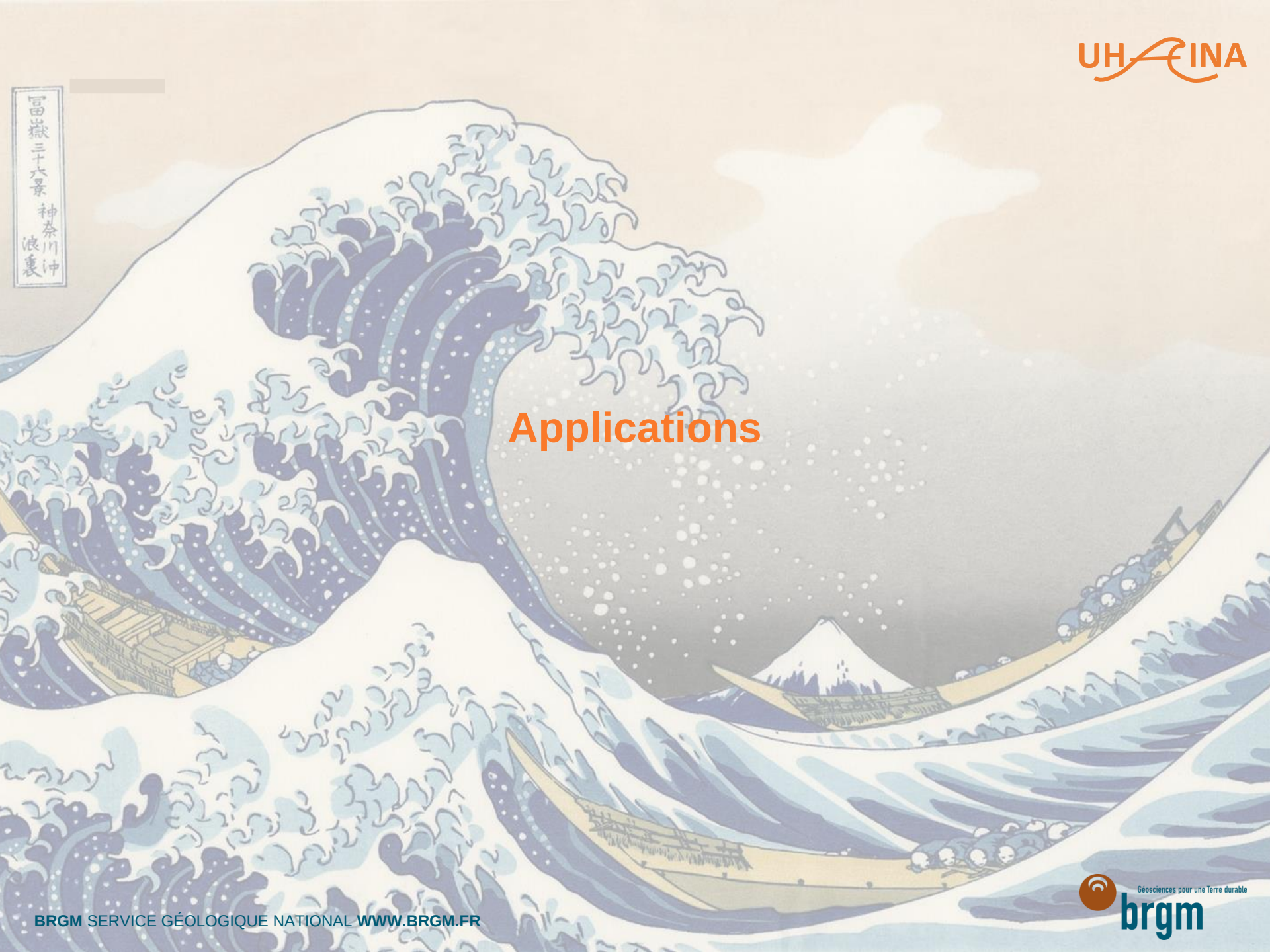
Mathematical Model :

2DH asymptotic approximation of the Euler equations:

- Hydrostatic module: nonlinear Shallow Water (SW) equations ;
  - Entropy Viscosity limiter for shock capturing ;
  - Heterogeneous Friction ;
  - River discharge ;
  - Spherical coordinates :
    - ✓ Coriolis force ;
    - ✓ Atmospheric pressure ;
    - ✓ Wind .
- Non-hydrostatic module : fully nonlinear and weakly dispersive Green-Naghdi (GN) equations ;
  - Wave breaking module :
    - ✓ Physical trigger mechanism for detection :
      - Vertical velocity ;
      - Free surface slope ;
    - ✓ Energy dissipation mechanism :
      - hydrid shock based method (SW-GN) .
- 3D (multi-layer) (*in the near future*)

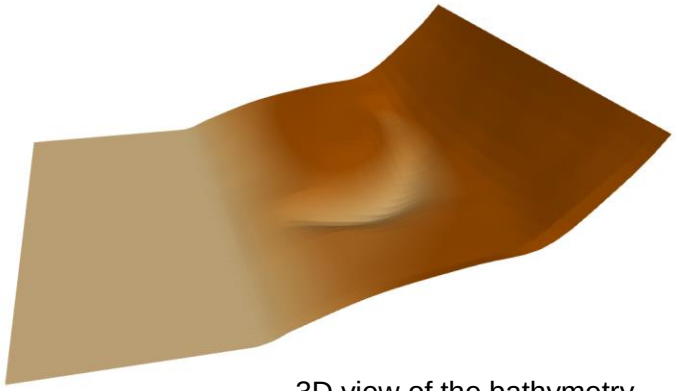




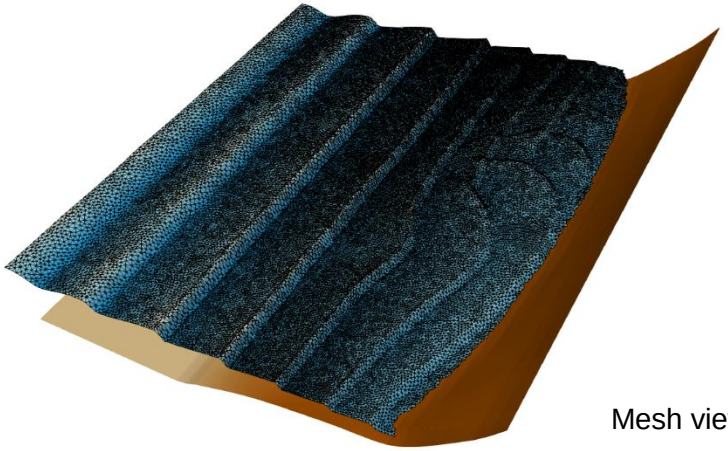


Applications

Applications : Ridge and runnel system

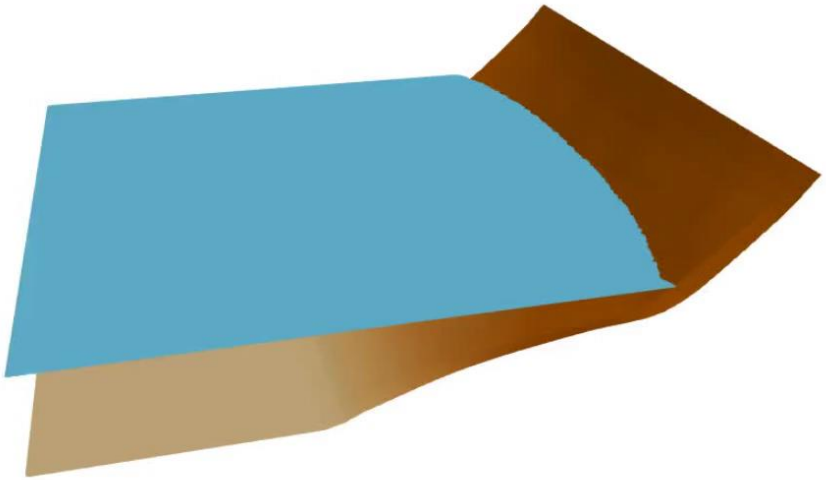


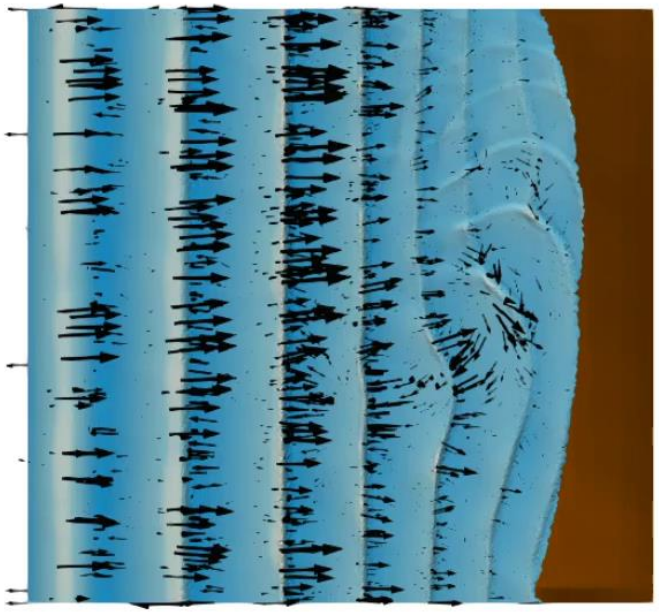
3D view of the bathymetry



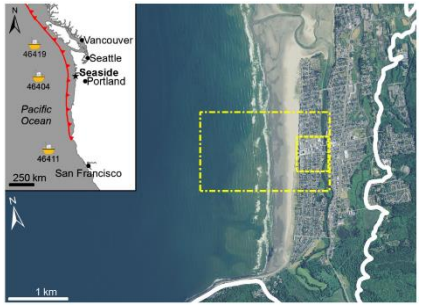
Mesh view

- Number of Elements : 65 660
- Mesh size : 4 m – 1 m
- Final time : 6 min
- Computational time : 8 hours
- Number of processors : 120 procs

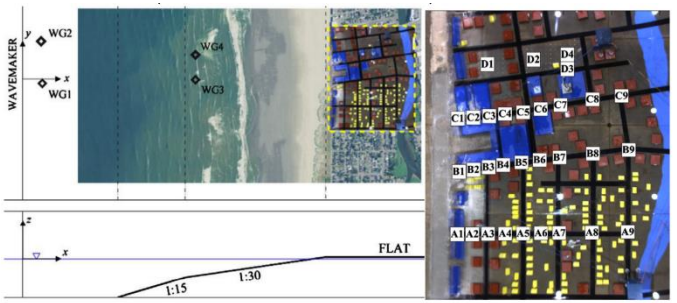


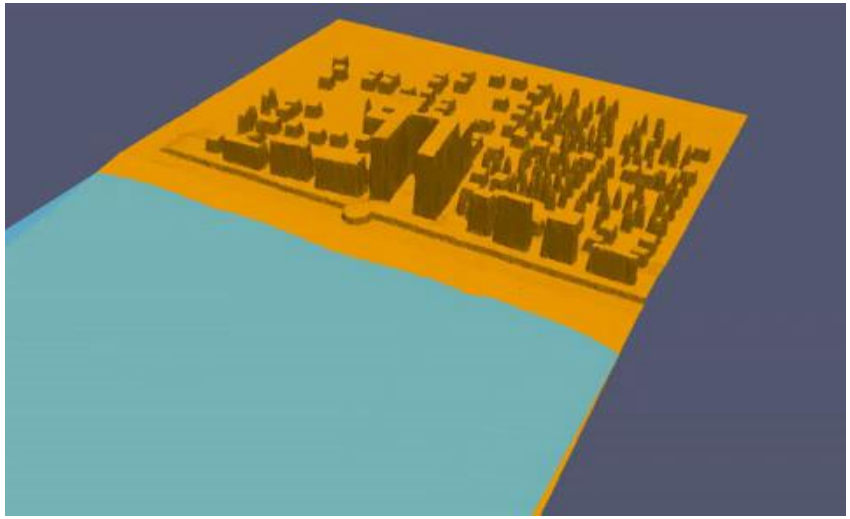


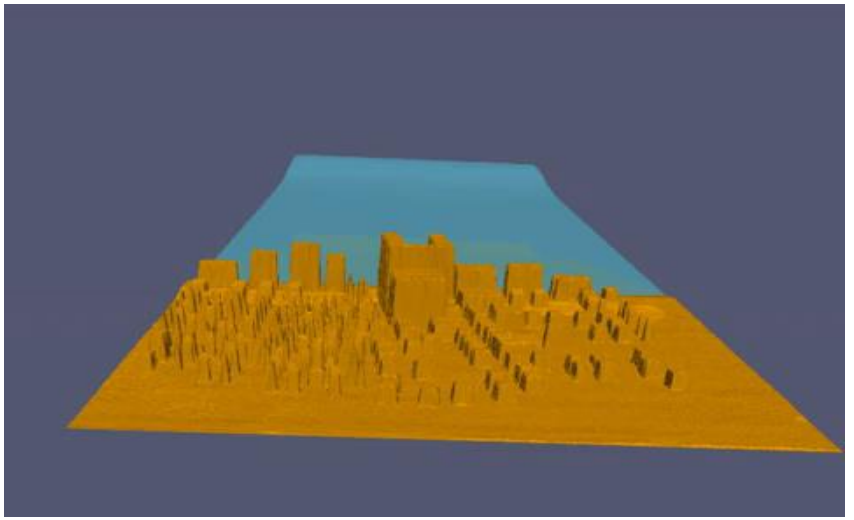
Applications : Seaside experiment *(H.Park et al. 2013)*



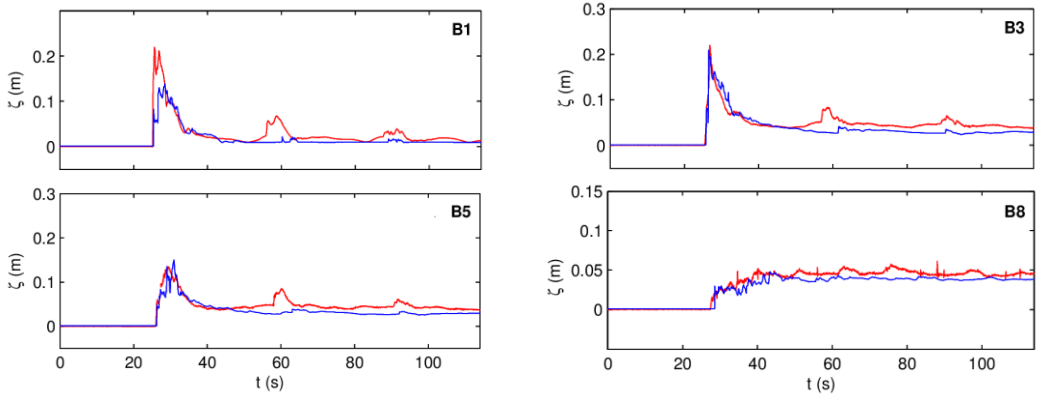
Experiment Setup







- Number of Elements : 345 706
- Mesh size : 50 cm – 2.5 cm
- Final time : 2 min
- Computational time : 8.5 hours
- Number of processors : 240 procs



Applications : Tide submersion on Bay of Authie *(France)*

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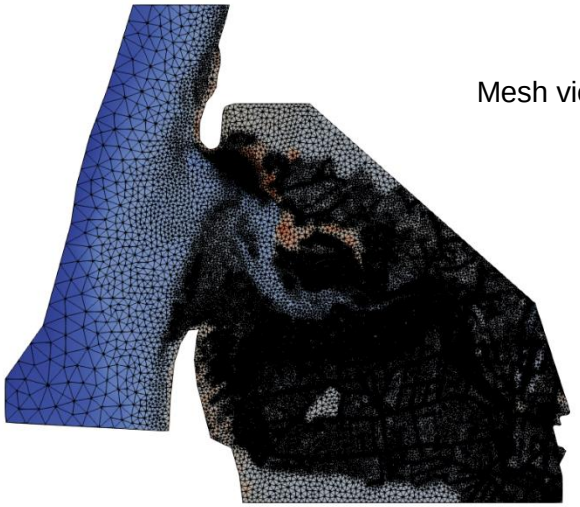


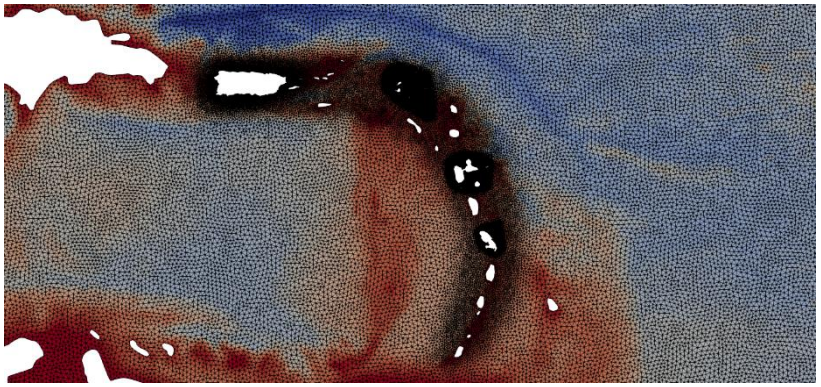
Mesh views

- Number of Elements : 222 328
- Mesh size : 500 m - 7 m
- Final time : 12 hours
- Computational time : 18 hours
- Number of processors : 196 procs

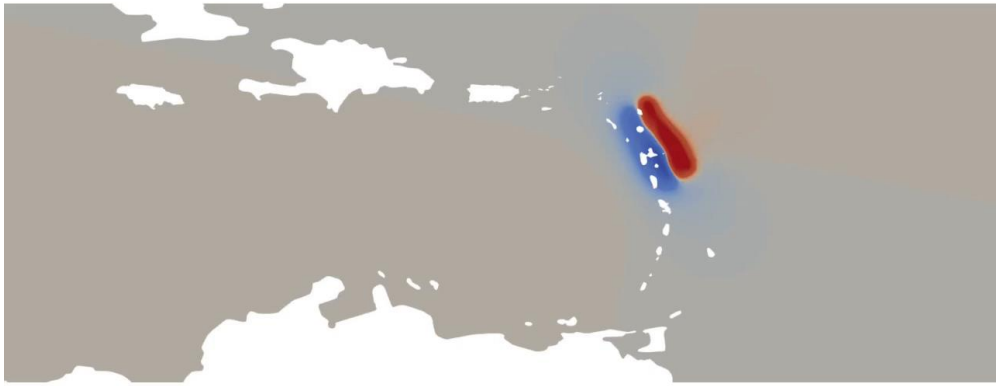
Free surface elevation (m)

Speed of currents (m/s)

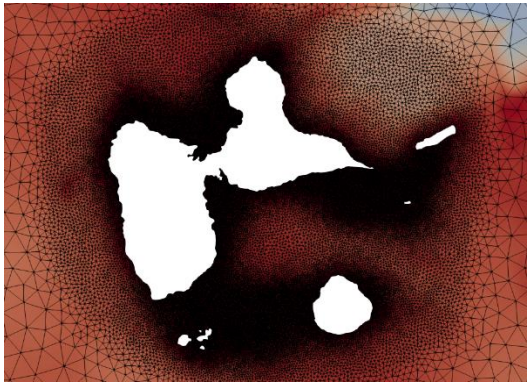
Applications : Tsunamis Feuillet Fault *(Caribbean sea)*

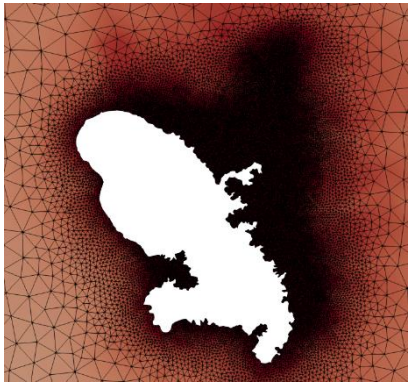


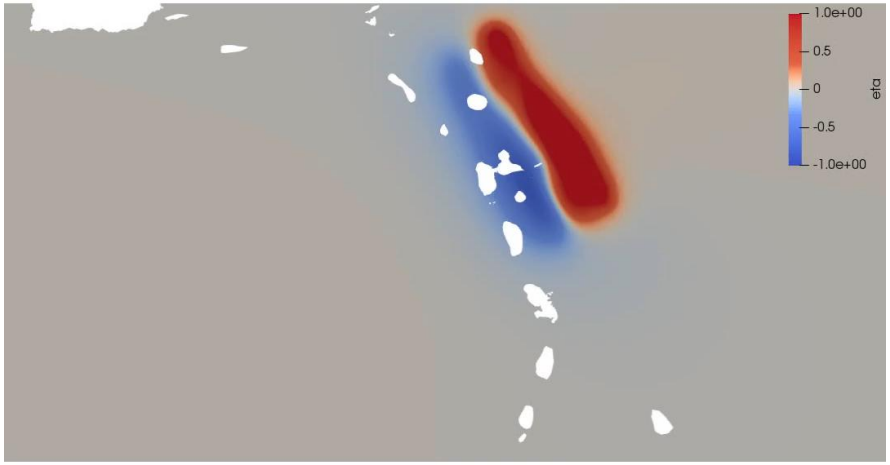
Mesh views



Free surface elevation (m)







Free surface elevation (m)

- Number of Elements : 260 324
- Mesh size : 10 km – 0.2 km
- Final time : 2.5 hours
- Computational time : 9 hours
- Number of processors : 196 procs

Conclusions and Perspectives :

- **UHAINA :**
  - Discotinuous Galerkin High-Order schemes with shock capturing ;
  - Unstructured meshes ;
  - HPC ;
  - Read/write standard NetCDF Ugrid files (GIS) ;
- User-friendly for non-code-specialists ;
- Set up continuous bridge between ongoing/future research and application on real scenarios.
- Operational and open-source :
  - UHAINA-SW, beta version (beginning 2021) ;
  - UHAINA-SW, first optimized version (end 2021) ;
  - UHAINA-GN, beta version (end 2021)
  - UHAINA-GN, first optimized version (2022) ;

Tsunami hits Natori (Miyagi, Japan 2011).

Thank you
for your attention !