Modélisation de la submersion marine : applications avancées d’aujourd’hui et défis de demain

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NumWave 2017 WORKSHOP
Numerical Advances on Wave Propagation in Shallow Waters

Géosciences pour une Terre durable

Montpellier, 11 - 13 décembre 2017

- Submersion et représentation du terrain
- Cas du tsunami de Tohoku-Oki 2011 – Japon
- Prévisions des inondations cycloniques à la Réunion
- Tempête Johanna (2008) à Gâvres (Morbihan)
- Principaux défis

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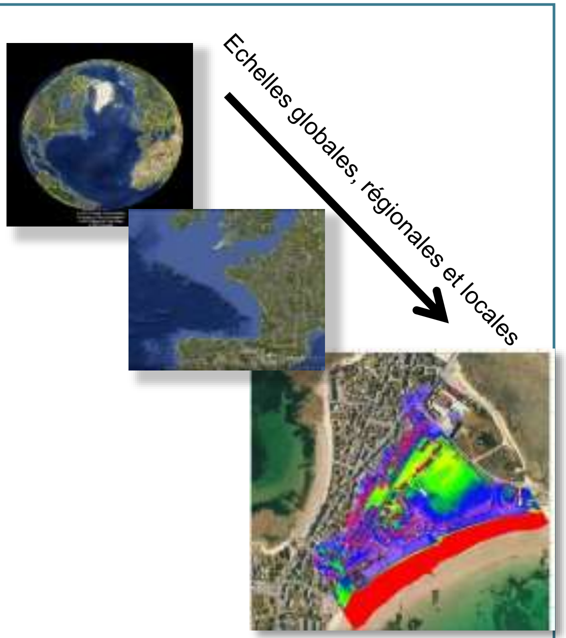
Submersion marine

Multi disciplinarité – Multi échelles



Expertise géologique

Mesures et Analyses

Bases de données

Modélisations
(vagues, niveaux d'eau, submersion)

Documentation historique

Retours d'expérience

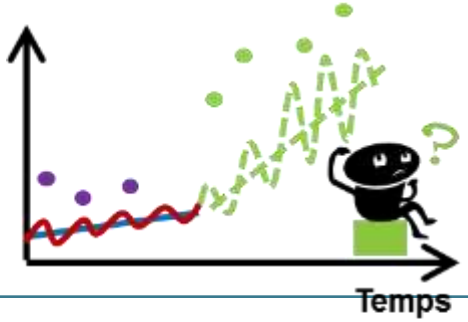
Analyse d'extrêmes et incertitudes

Impacts / dommages
(vulnérabilité du bâti, personnes)

Effets du climat

Adaptation, Prévention, Prévision, Appui
Gestion de crise

- Echelles évènementielles à long-terme
- Aléas d'origines météo (tempêtes et cyclones) et tellurique (tsunamis)



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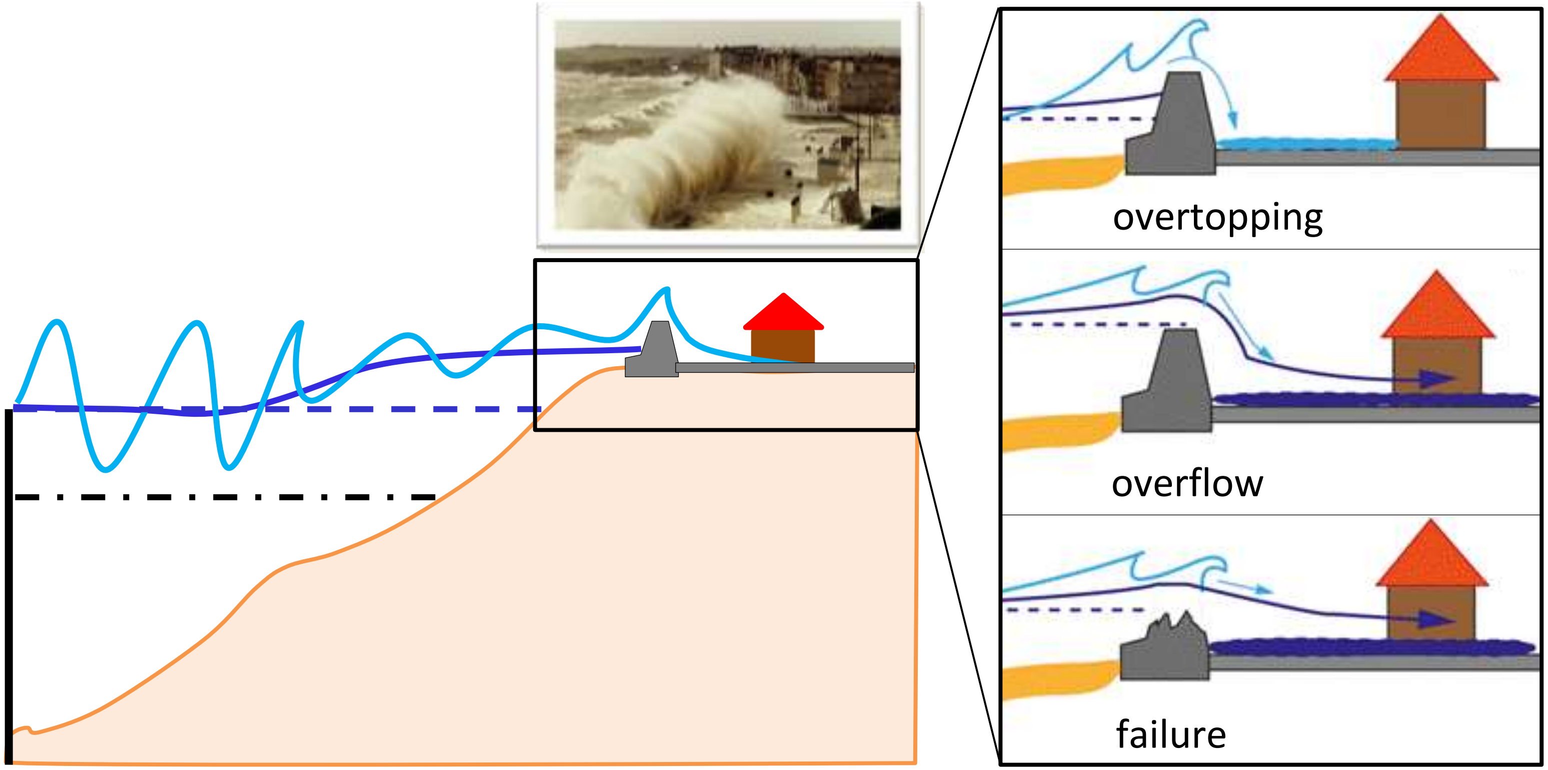
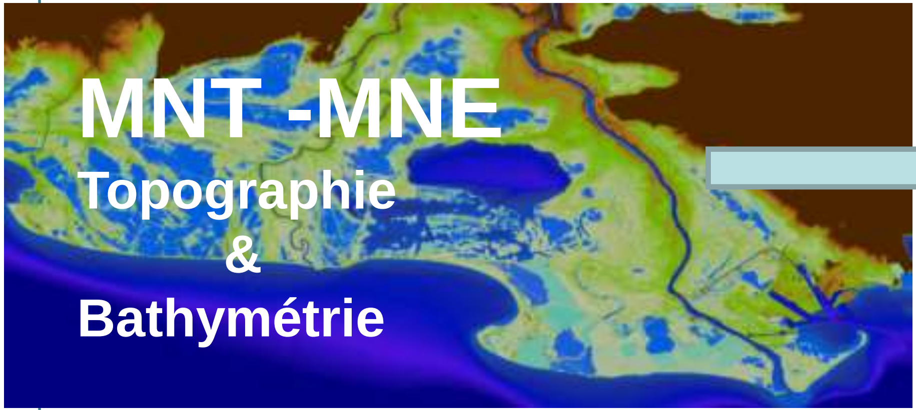
Context: Phenomena



- Instantaneous level (incl. waves)
- Static level (Tide, atm. surge, wave set-up)
- Still water level (Tide, atm. Surge)
- Mean sea-level

2 - Représentation du terrain

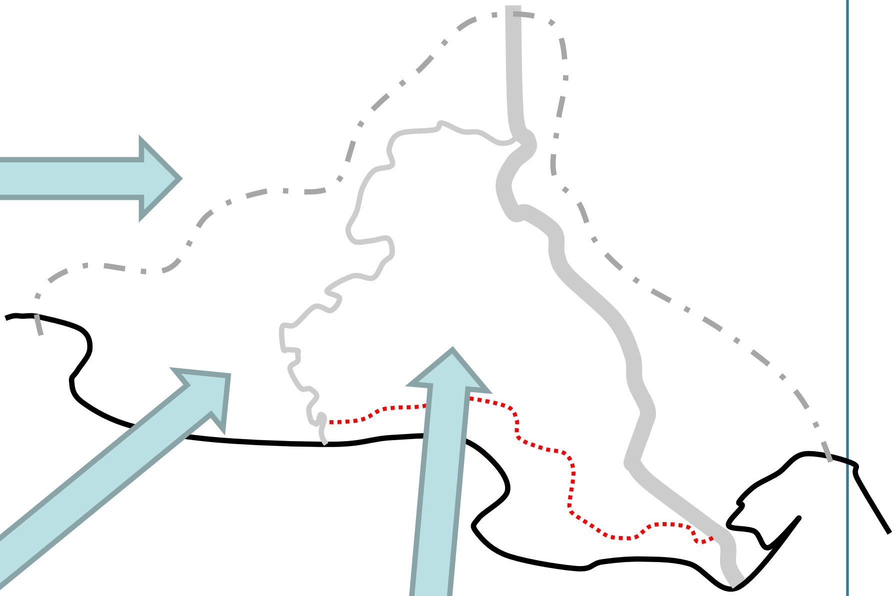


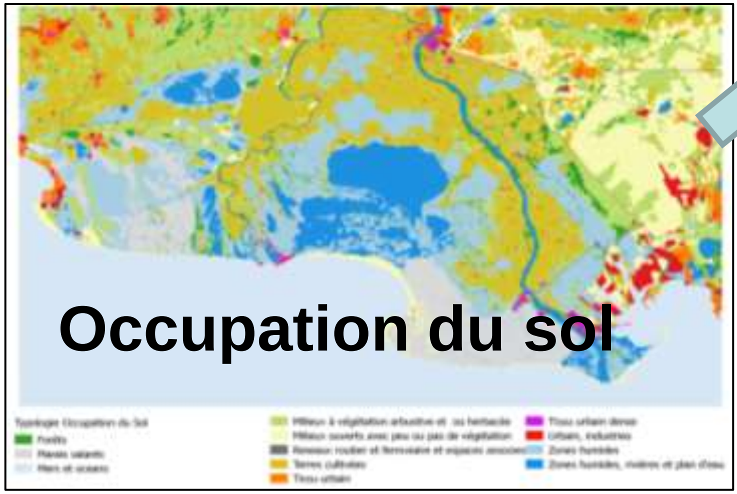
MNT -MNE

Topographie

&

Bathymétrie



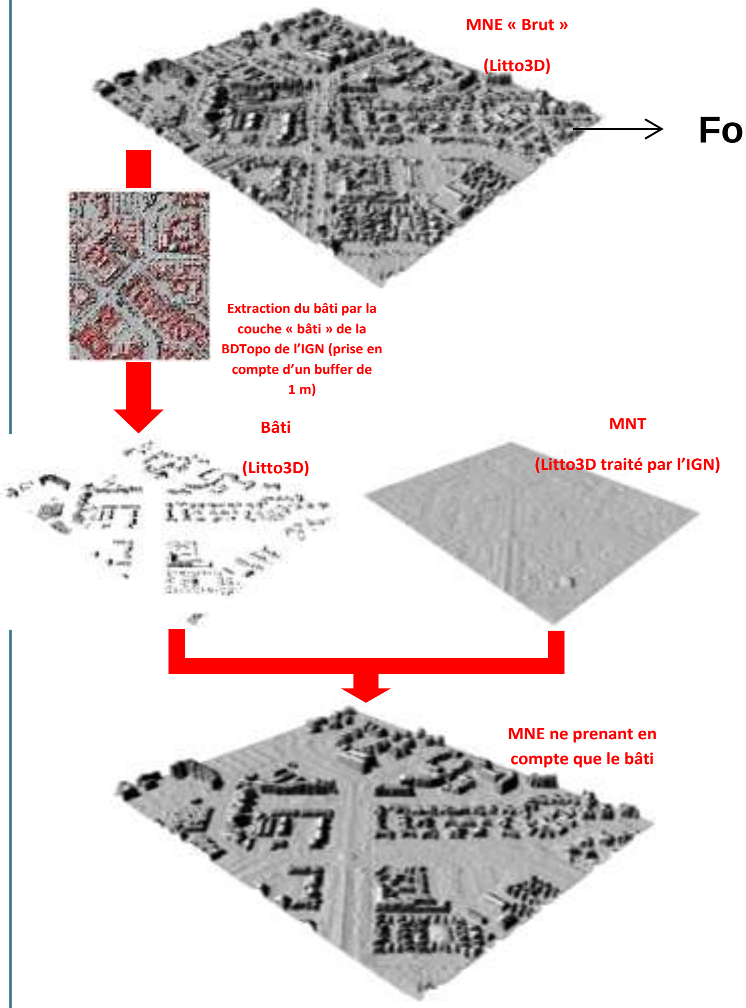


Occupation du sol

Connexions hydrauliques

2 – MNE : submersion échelle locale

> Intégration du bâti (résolution métrique)



MNE « Brut »

(Litto3D)

Fourni avec Litto3D ou reconstitué

Extraction du bâti par la couche « bâti » de la BDTopo de l'IGN (prise en compte d'un buffer de 1 m)

Bâti

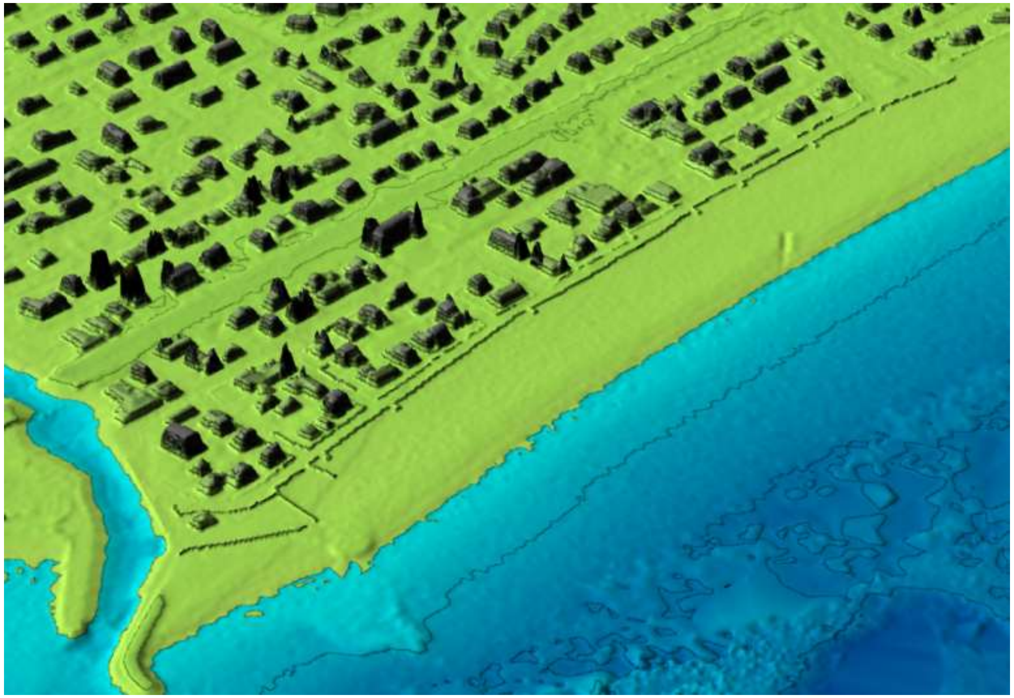
(Litto3D)

MNT

(Litto3D traité par l'IGN)

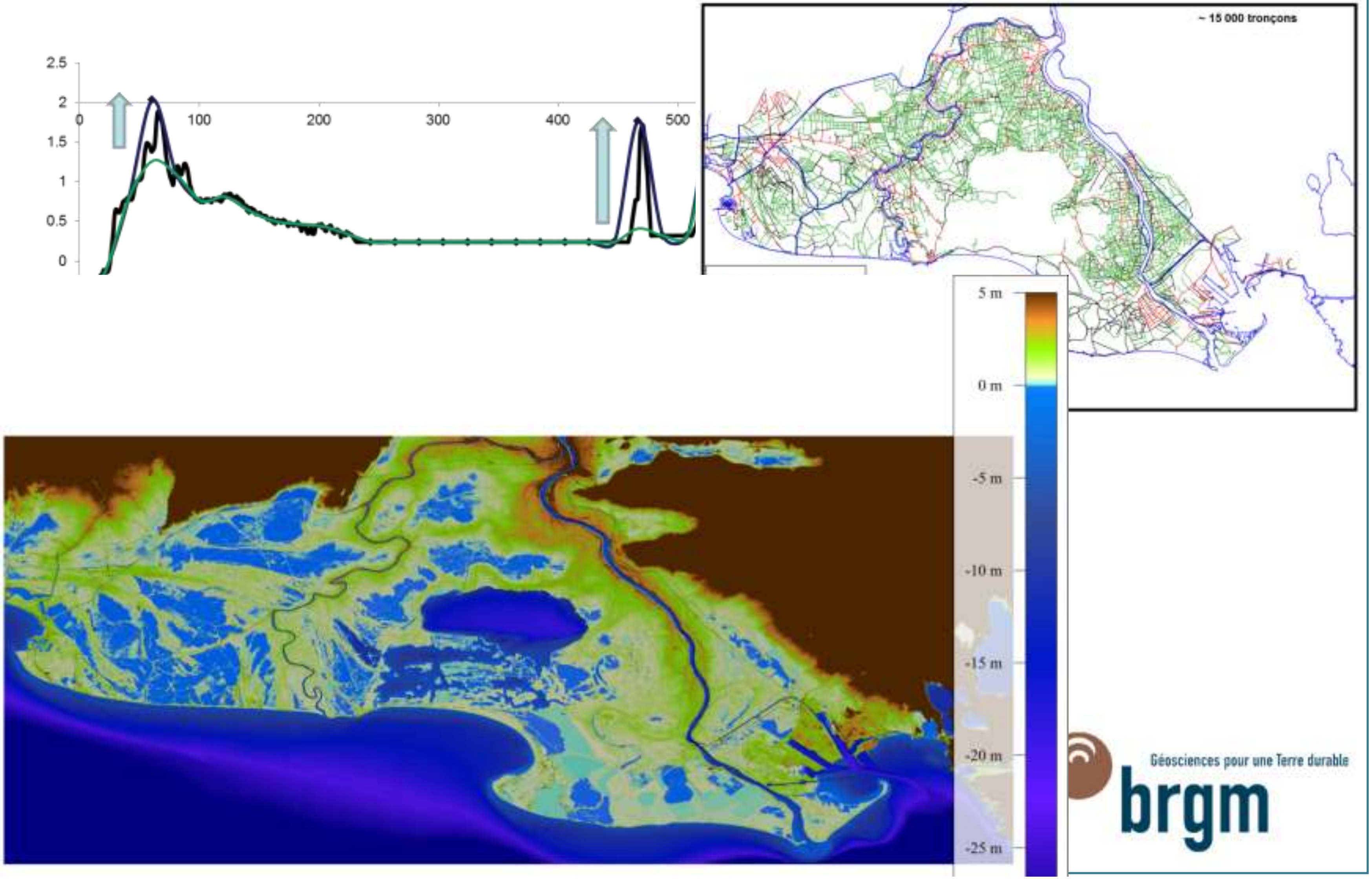
MNE ne prenant en compte que le bâti

Exemple d'application au Litto3D sur Hyères (83)



2 – MNT : submersion échelle régionale

> Résolution décamétrique



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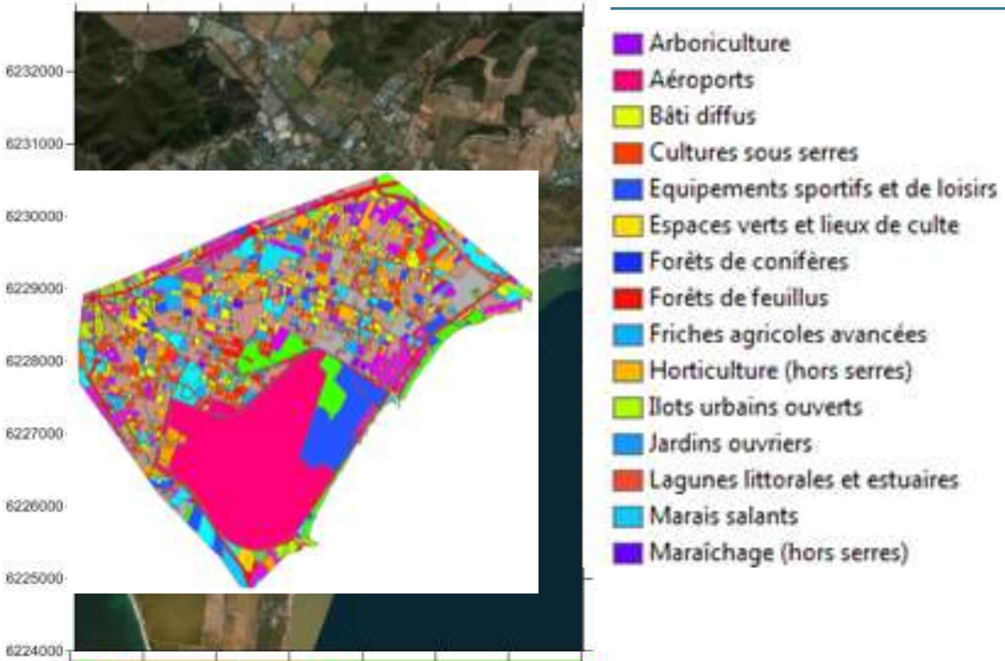
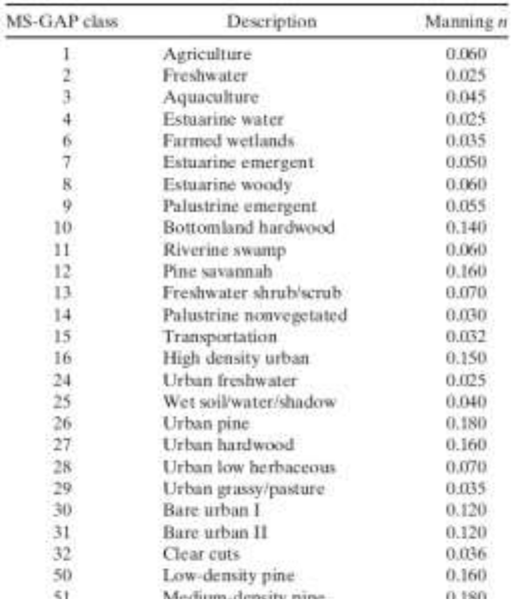
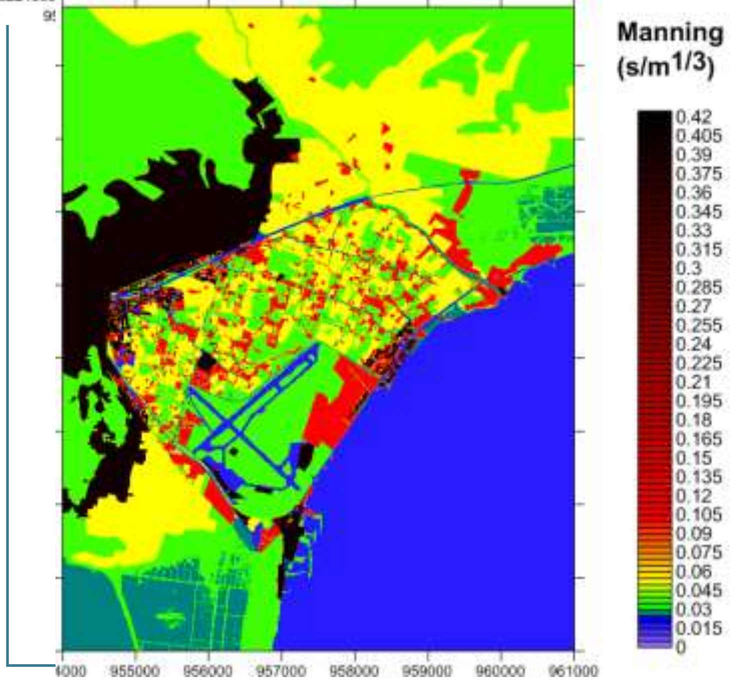
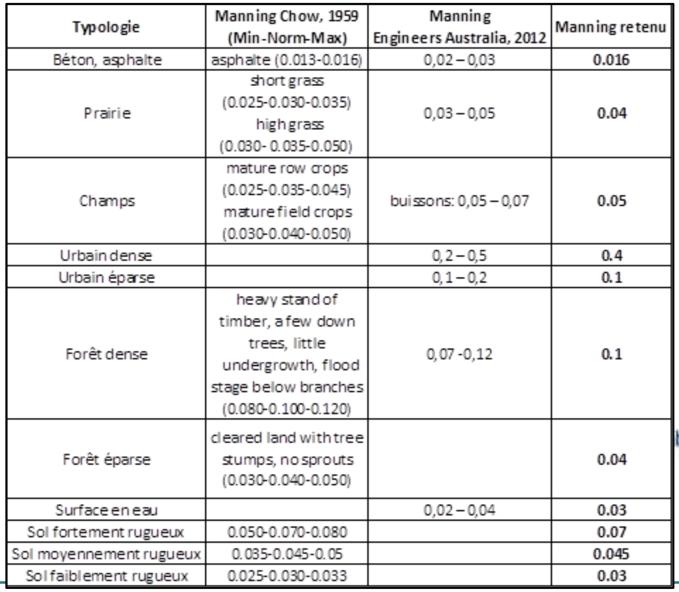
2- Occupation du sol





MS-GAP class	Description	Manning *n*
1	Agriculture	0.060
2	Freshwater	0.025
3	Aquaculture	0.045
4	Estuarine water	0.025
6	Farmed wetlands	0.035
7	Estuarine emergent	0.050
8	Estuarine woody	0.060
9	Palustrine emergent	0.055
10	Bottomland hardwood	0.140
11	Riverine swamp	0.060
12	Pine savannah	0.160
13	Freshwater shrub/scrub	0.070
14	Palustrine nonvegetated	0.030
15	Transportation	0.032
16	High density urban	0.150
24	Urban freshwater	0.025
25	Wet soil/water/shadow	0.040
26	Urban pine	0.180
27	Urban hardwood	0.160
28	Urban low herbaceous	0.070
29	Urban grassy/pasture	0.035
30	Bare urban I	0.120
31	Bare urban II	0.120
32	Clear cuts	0.036
50	Low-density pine	0.160
51	Medium-density pine	0.180





Typologie	Manning Chow, 1959 (Min-Norm-Max)	Manning Engineers Australia, 2012	Manning retenu
Béton, asphalte	asphalte (0.013-0.016)	0,02 – 0,03	**0.016**
Prairie	short grass (0.025-0.030-0.035) high grass (0.030- 0.035-0.050)	0,03 – 0,05	**0.04**
Champs	mature row crops (0.025-0.035-0.045) mature field crops (0.030-0.040-0.050)	buissons: 0,05 – 0,07	**0.05**
Urbain dense		0,2 – 0,5	**0.4**
Urbain éparse		0,1 – 0,2	**0.1**
Forêt dense	heavy stand of timber, a few down trees, little undergrowth, flood stage below branches (0.080-0.100-0.120)	0,07 -0,12	**0.1**
Forêt éparse	cleared land with tree stumps, no sprouts (0.030-0.040-0.050)		**0.04**
Surface en eau		0,02 – 0,04	**0.03**
Sol fortement rugueux	0.050-0.070-0.080		**0.07**
Sol moyennement rugueux	0.035-0.045-0.05		**0.045**
Sol faiblement rugueux	0.025-0.030-0.033		**0.03**

Modelling strategy : Tohoku-Oki Tsunami

> **Model: FUNWAVE-TVD (Shi et al., 2012)**

- Solve the Boussinesq equations (Wei et al.,1995)
- Dispersive terms can be desactivated (->NLSW)
- Calculation on structured grid => use of nested grids (offline)

> **Tsunami generation with Okada (1985) formulation**

> **Selected source model: Satake et al. (2013)**

> **4 hours simulated**
> **2 configurations of 5 nested grids**

> **Several datasets**

- Topo-bathymetry from Gebco 30’’ for large scale
- DTM provided by MRI (Y. Hayashi) and topo-bathymetric datasets provided by Tokyo University (Sasaki et al., 2012)
- Heterogeneous friction according to land use for finest ranks

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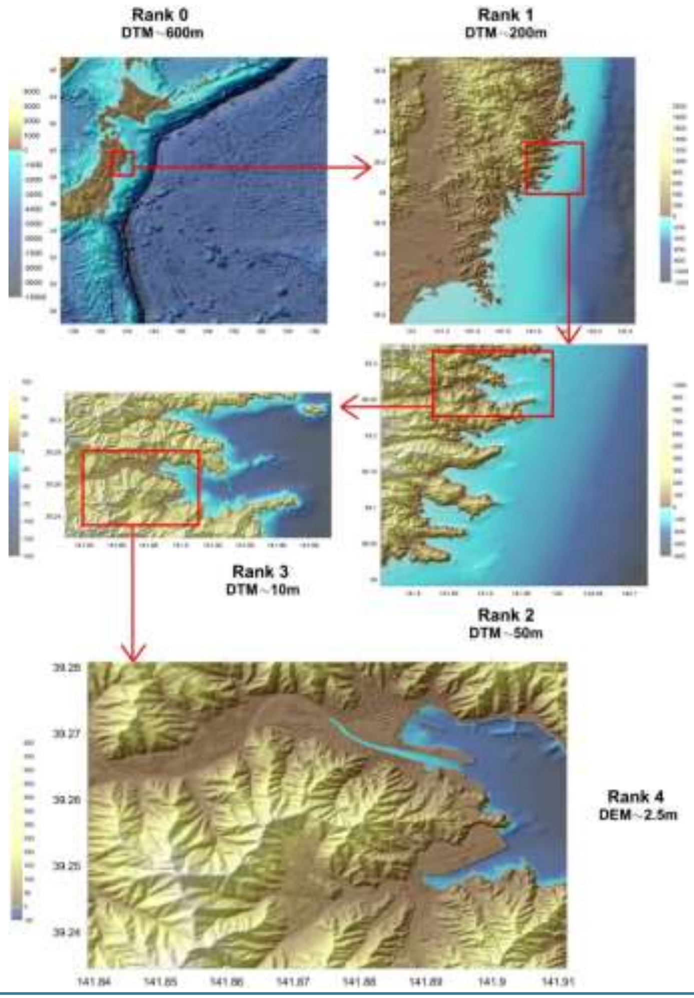
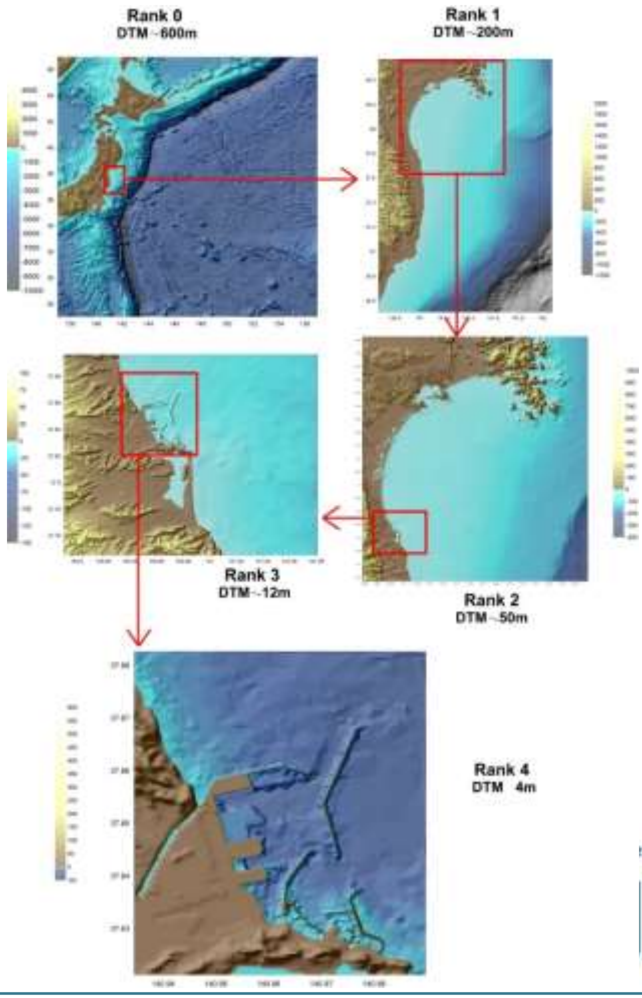
Modelling strategy

> **2 configurations of 5 nested grids**

Kamaishi



Sendai/Soma



How to integrate the whole complexity of such an event in simulations ?

> **According to available data, attempt to use the most adaptated approaches for each « step » of the simulation chain**

- Description of the source complexity
- Dispersive effects
- Role of the breakwater in Kamaishi
- Advantage of very high resolution

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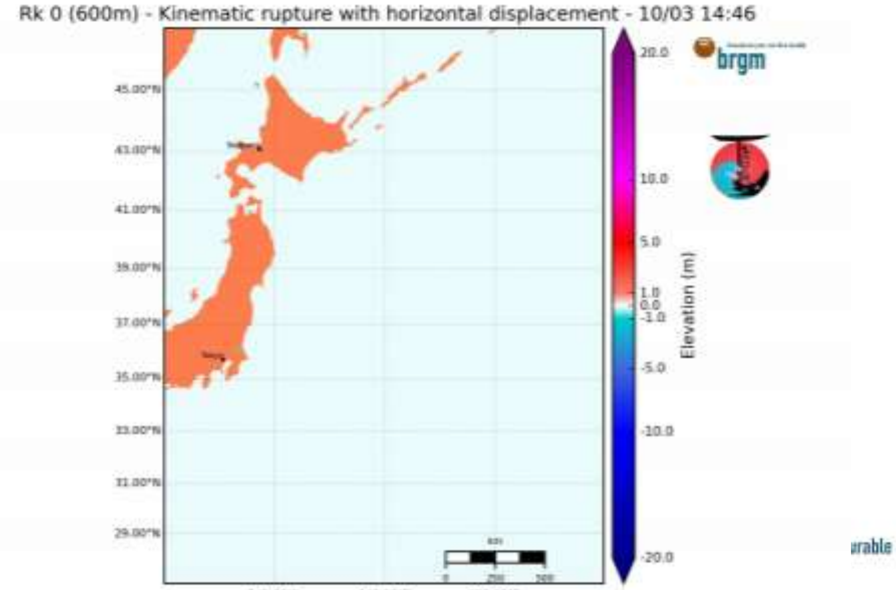
Source complexity

- Selected source model: Satake et al. (2013)

- Heterogeneous distribution of the slip (55 sub-faults)
- Kinematic rupture on 5 minutes (time delayed every 30 seconds)
- Tsunami generation:



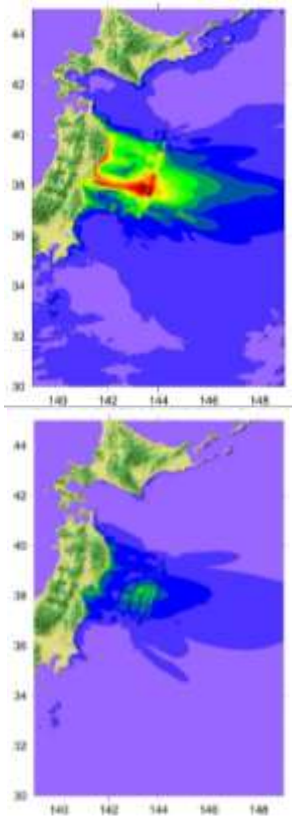
Source complexity

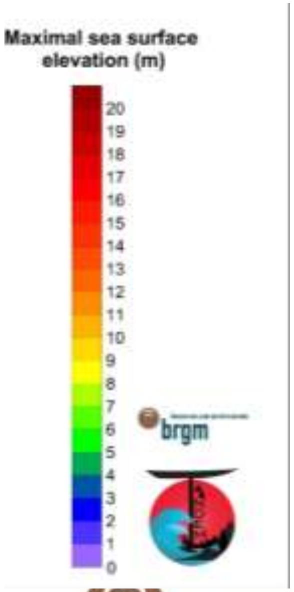
> Effect of:

- The kinematics of the rupture

Instantaneous rupture

Kinematic rupture





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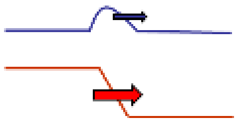
Source complexity

> Effect of:

- The kinematics of the rupture
- The contribution of the horizontal displacement (Tanioka & Satake, 1996)

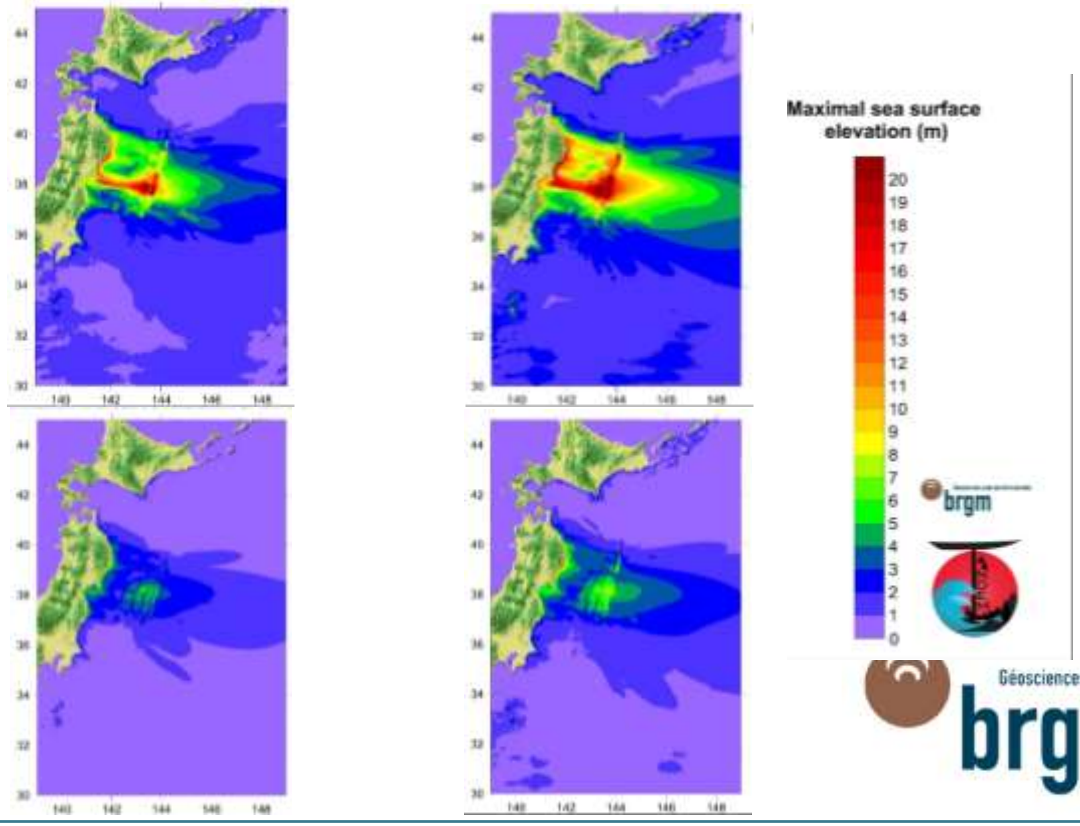


Without horizontal displacement

With horizontal displacement

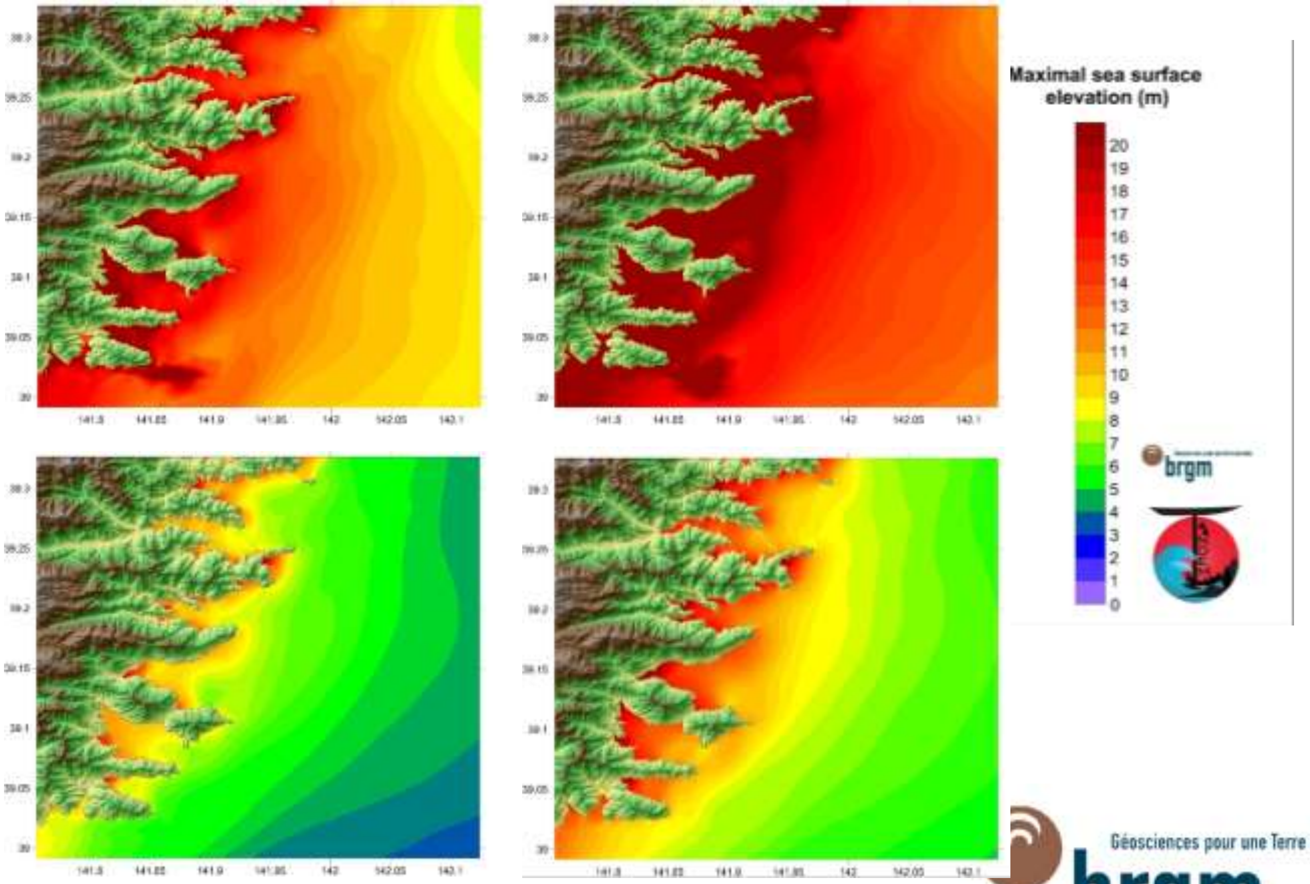
Instantaneous rupture

Kinematic rupture



Source complexity

> **At Rank 2 for Kamaishi (grid mesh: 50m)**



Without horizontal displacement

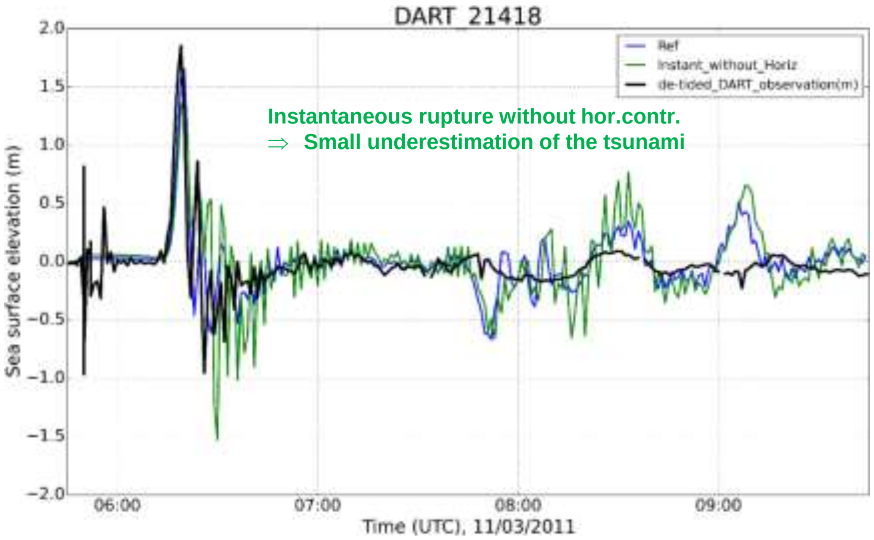
With horizontal displacement

Instantaneous rupture

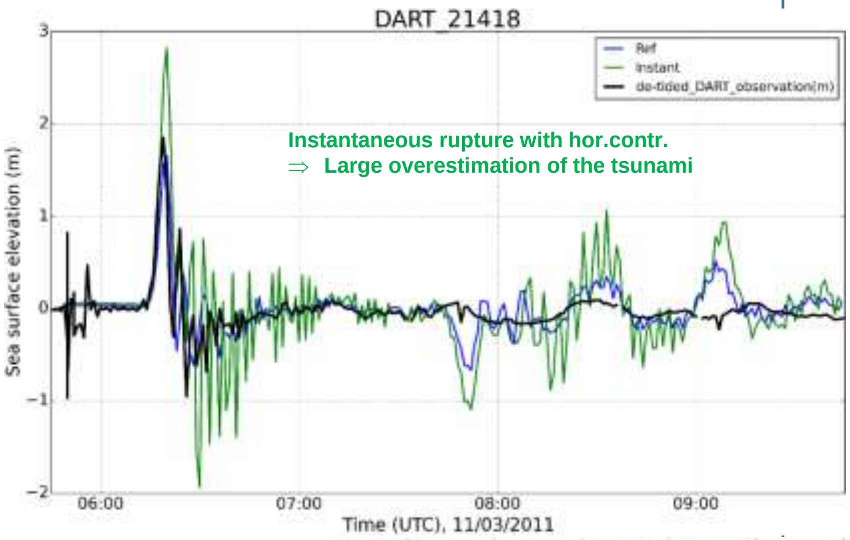
Kinematic rupture

> **Is the most complex description the most realistic ?**

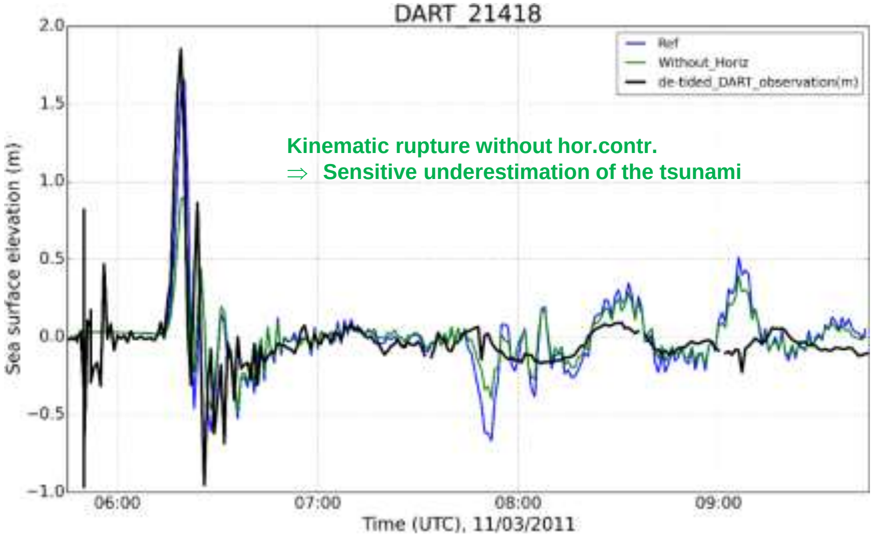
Source complexity



Instantaneous rupture without hor.contr.
⇒ Small underestimation of the tsunami

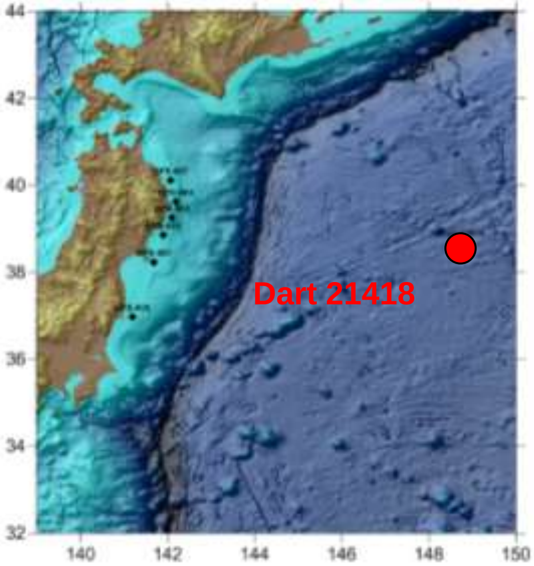


Instantaneous rupture with hor.contr.
⇒ Large overestimation of the tsunami

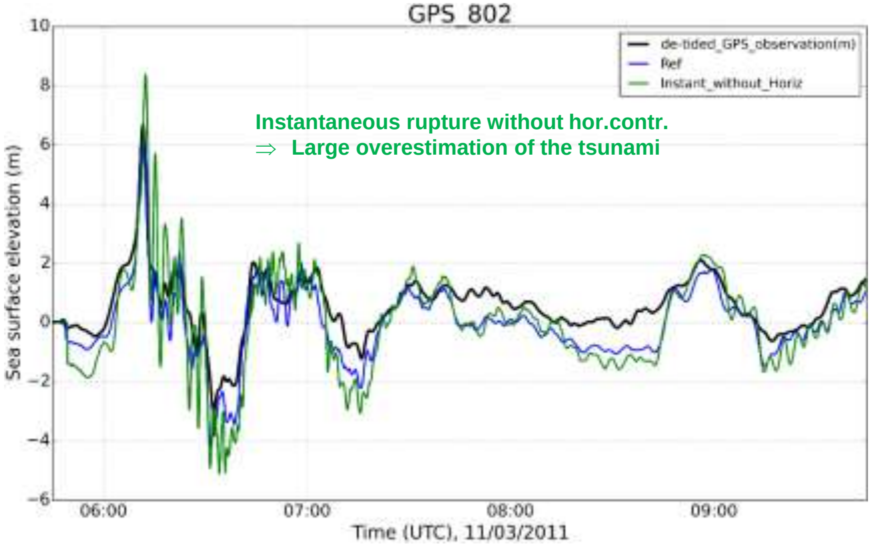


Kinematic rupture without hor.contr.
⇒ Sensitive underestimation of the tsunami

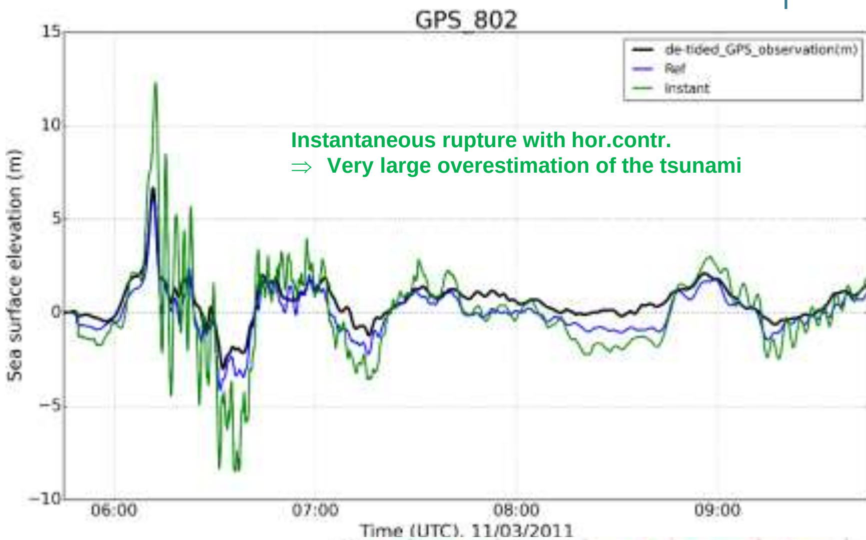
Ref = Kinematic rupture with contribution of the horizontal displacement
⇒ Best correlation with the DART



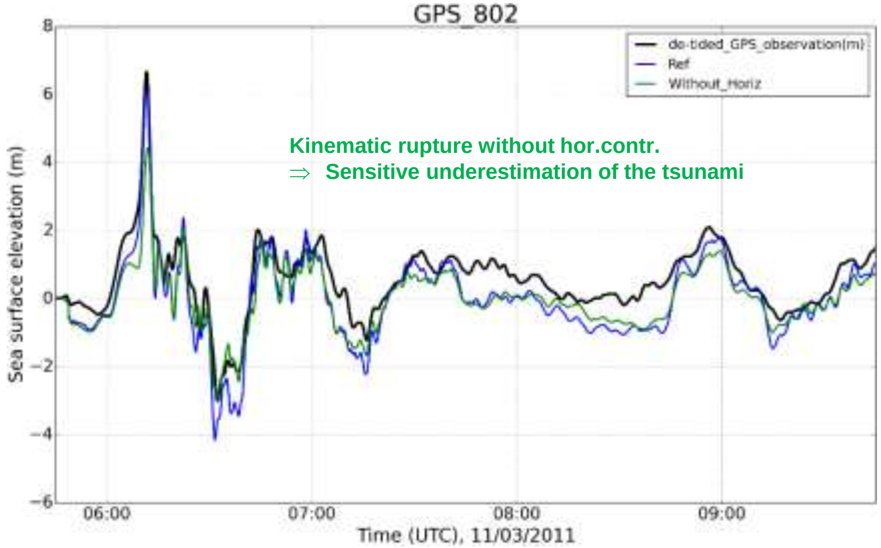
Source complexity



Instantaneous rupture without hor.contr.
⇒ Large overestimation of the tsunami

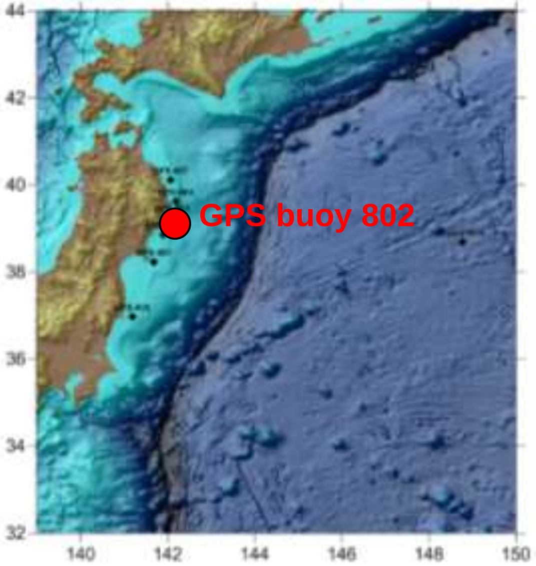


Instantaneous rupture with hor.contr.
⇒ Very large overestimation of the tsunami

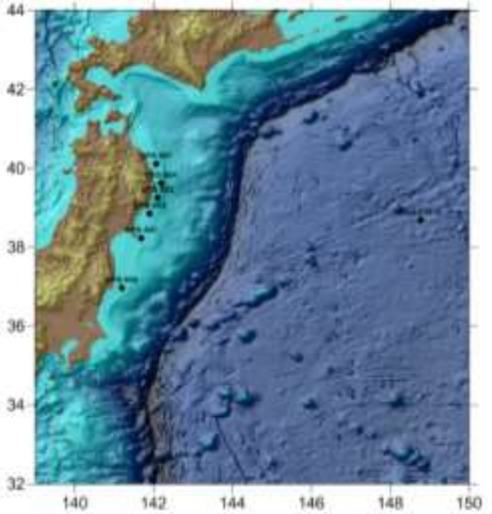


Kinematic rupture without hor.contr.
⇒ Sensitive underestimation of the tsunami

Ref = Kinematic rupture with contribution of the horizontal displacement
⇒ Best correlation



Source complexity



+++ Very large overestimation (several meters)
++ Large overestimation (a few meters)
+ Significant overestimation (metric)
= Correct estimation (at about 0.5m)
- Significant underestimation (metric)
- - Large underestimation (a few meters)
- - - Very large underestimation (several meters)

	Dart 21418	GPS buoy 807	GPS buoy 804	GPS buoy 802	GPS buoy 803	GPS buoy 801	GPS buoy 806
Instantaneous rupture Without Hor. Contr.	-	++	++	++	++	+++	+
Instantaneous rupture With Hor. Contr.	++	+++	+++	+++	+++	+++	++
Kinematic rupture Without Hor. Contr.	-	- -	- - -	- -	- - -	- - -	- -
Kinematic rupture With Hor. Contr.	=	=	- -	=	=	- -	-

Kinematic rupture → **Avoid a large overestimation of the tsunami**

Contribution of the horizontal displacement → **Avoid a significant underestimation of the tsunami**

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- Description of the source complexity
- Dispersive effects
- Role of the breakwater in Kamaishi
- Advantage of very high resolution

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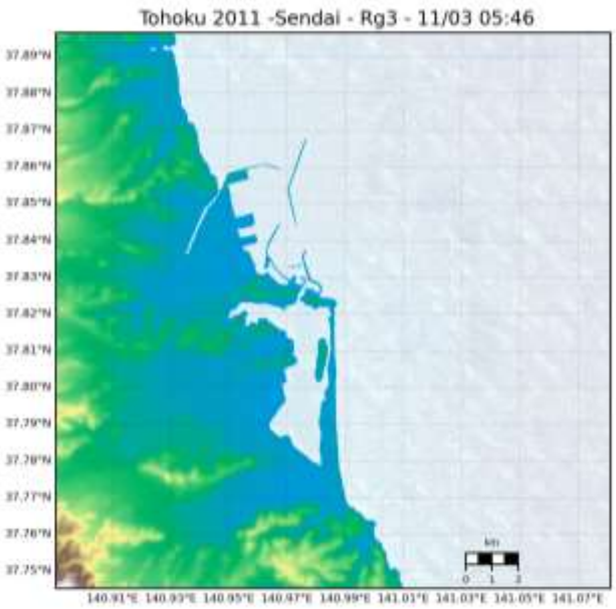
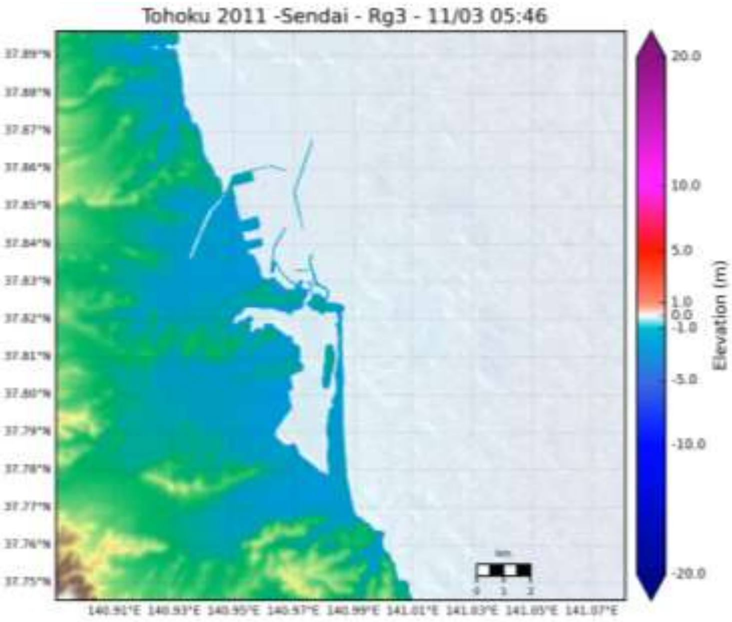
Dispersive effects

- **Simulation of the tsunami with and without considering dispersive terms**
- **No significant differences in Kamaishi**
- **Important dispersive effects in Sendai bay (shallow bathymetry)**

With dispersive terms



Without dispersive terms



Appear to be significant at Rank 3 (grid mesh 12m)

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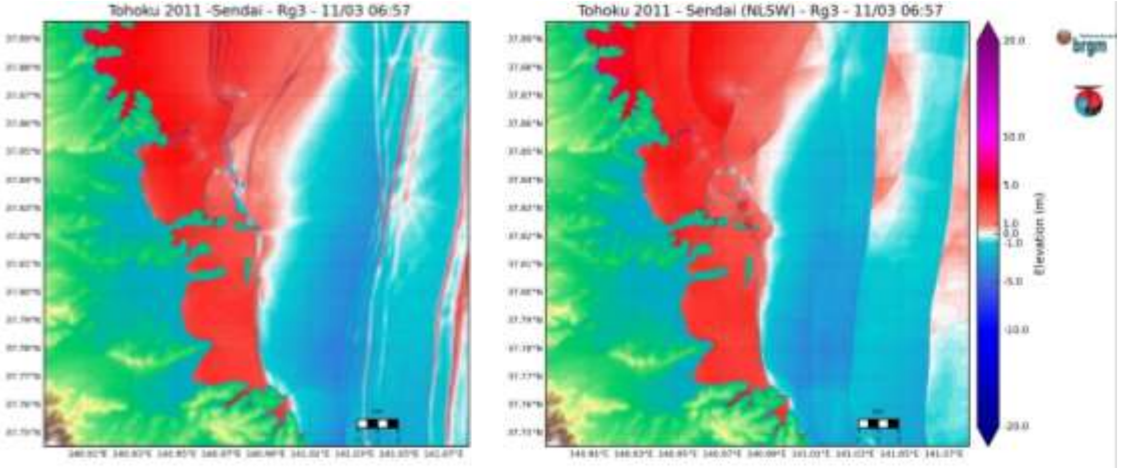
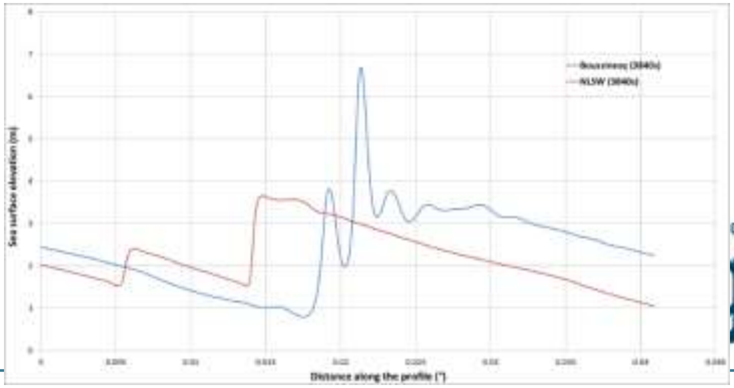
Dispersive effects

- **Simulation of the tsunami with and without considering dispersive terms**
- **Important dispersive effects in Sendai bay**

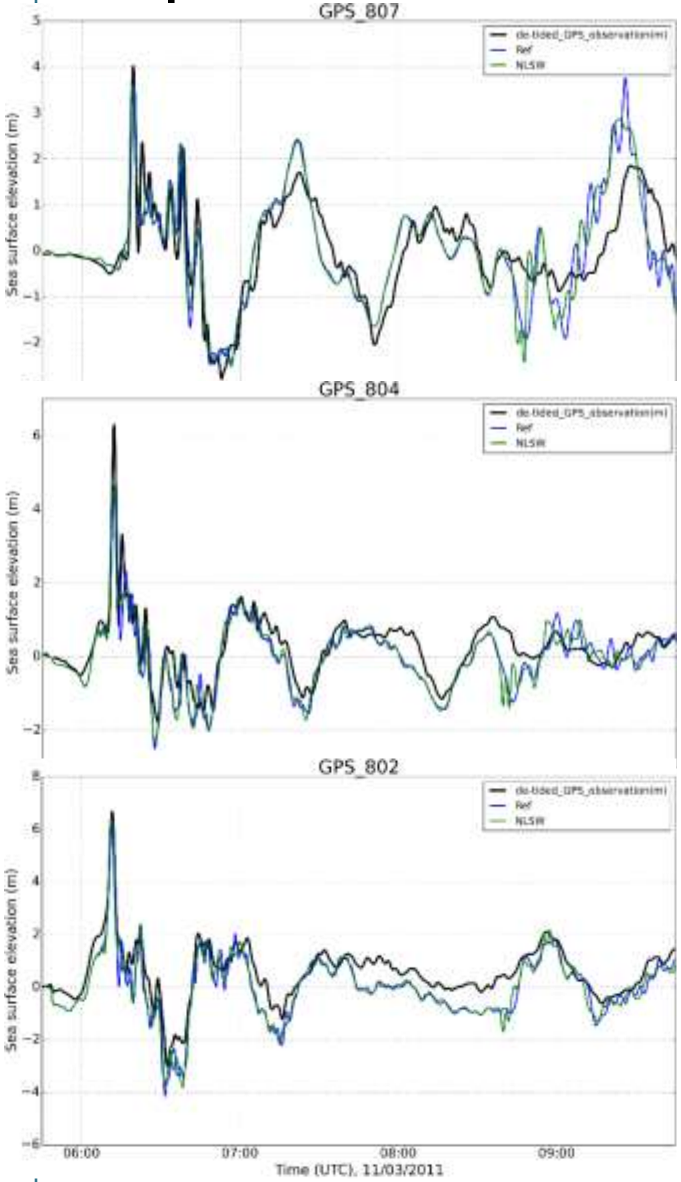


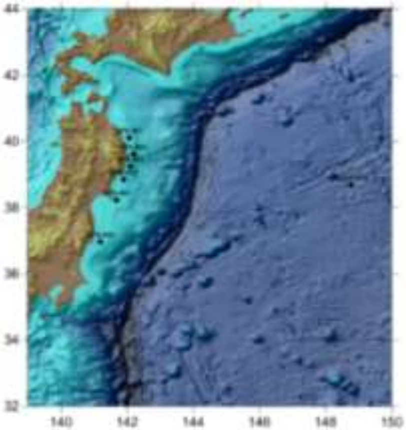
With dispersive terms ***Without dispersive terms***

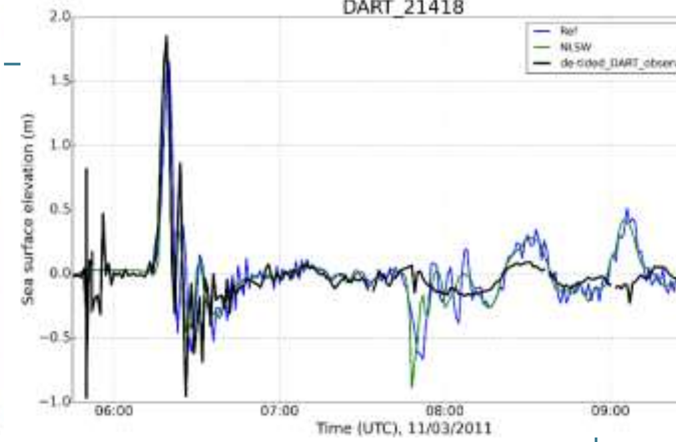
Example of a profile in Rank 3 after 3840 s simulated

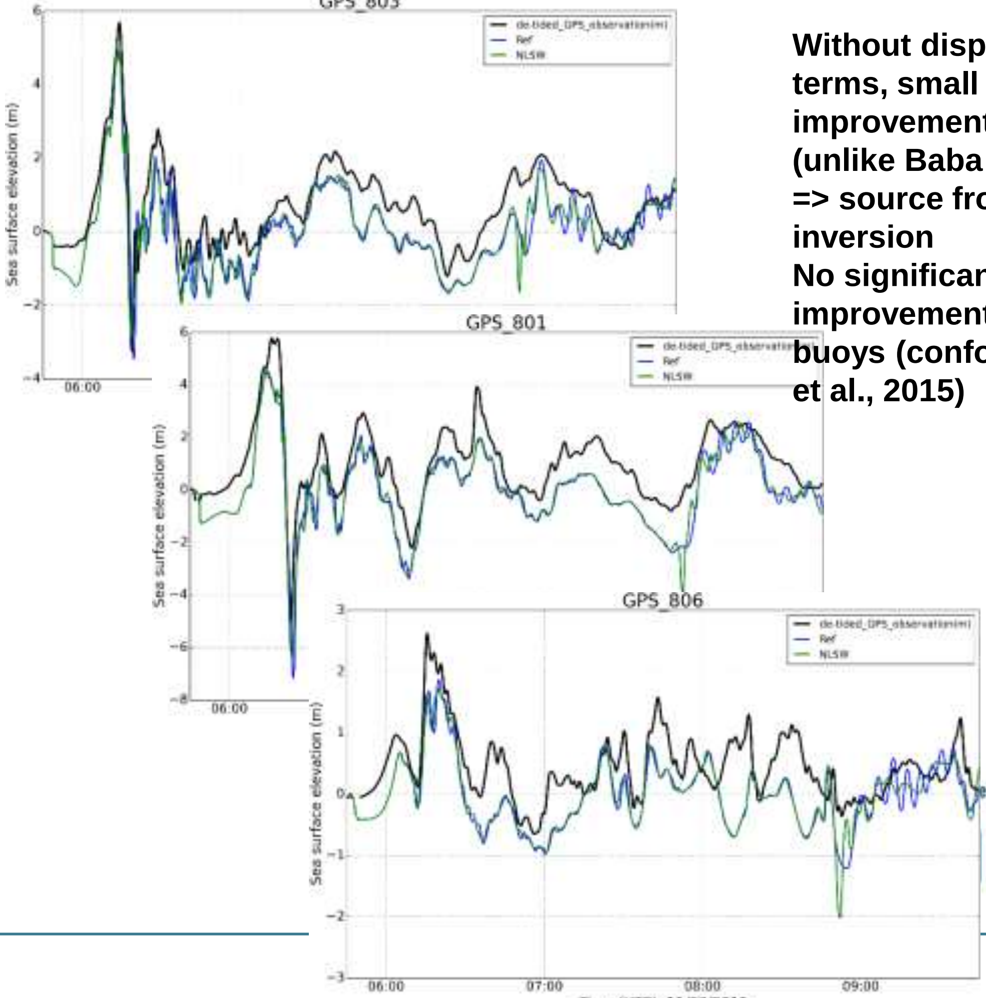


Dispersive effects









Without dispersive terms, small improvement on the dart (unlike Baba et al., 2015) => source from NLSW inversion

No significant improvement on GPS buoys (conform to Baba et al., 2015)

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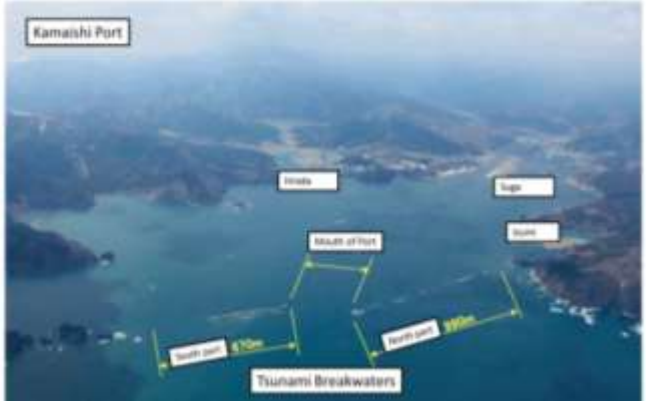
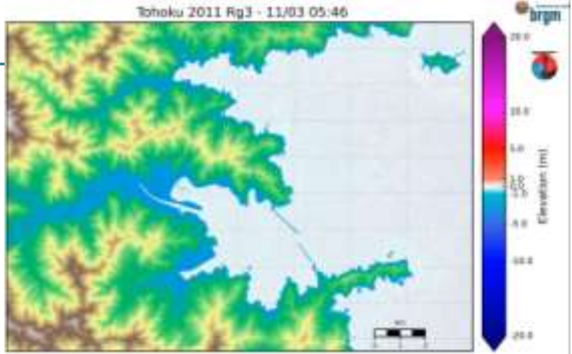


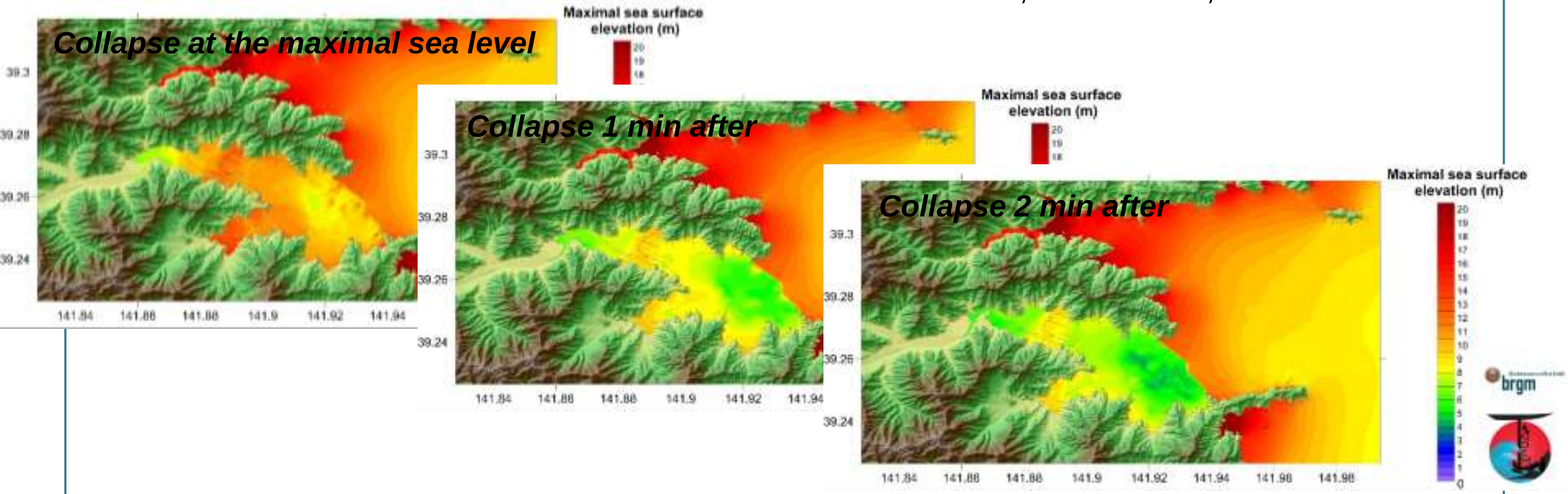
Arikawa et al. (2012)

Role of the breakwater in Kamaishi



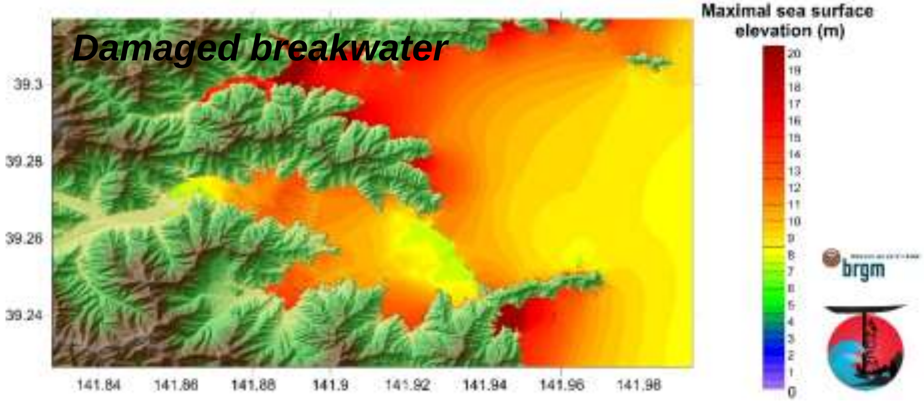
> Tests to integrate the breakwater collapse:

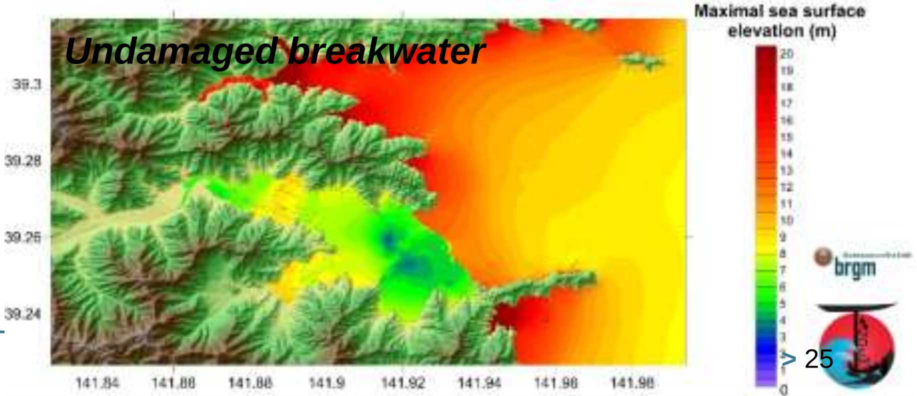
- Collapse supposed to be instantaneous
- 3 scenarios: collapse when the sea level is **maximal**, **1min after**, **2 min after**


Collapse at the maximal sea level

Collapse 1 min after

Collapse 2 min after


Damaged breakwater

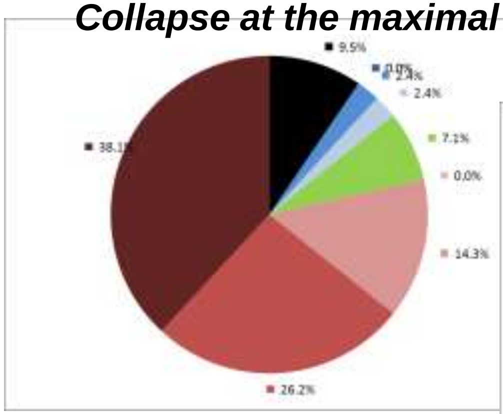

Undamaged breakwater

Role of the breakwater in Kamaishi

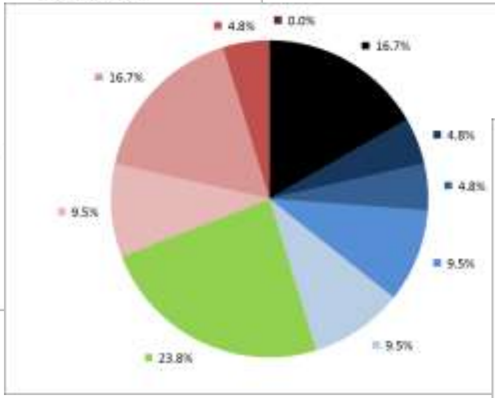
> Comparison to the field data from Mori et al. (2012)

- (42 points “Inundation”)

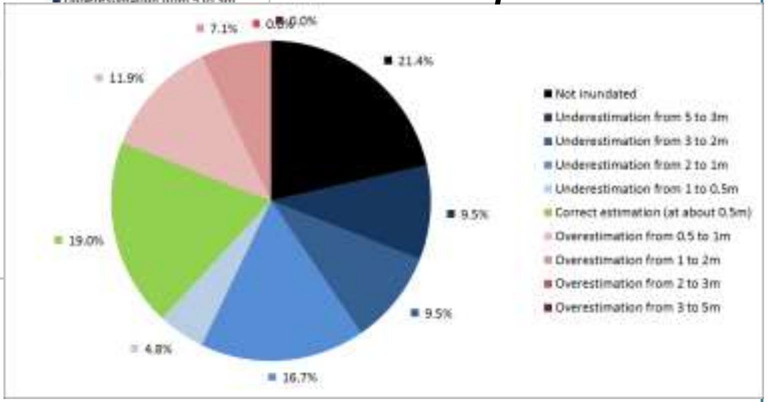
Collapse at the maximal sea level



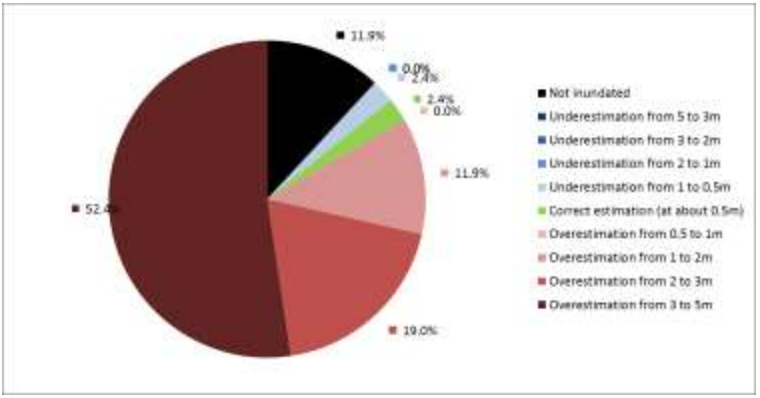
Collapse 1 min after



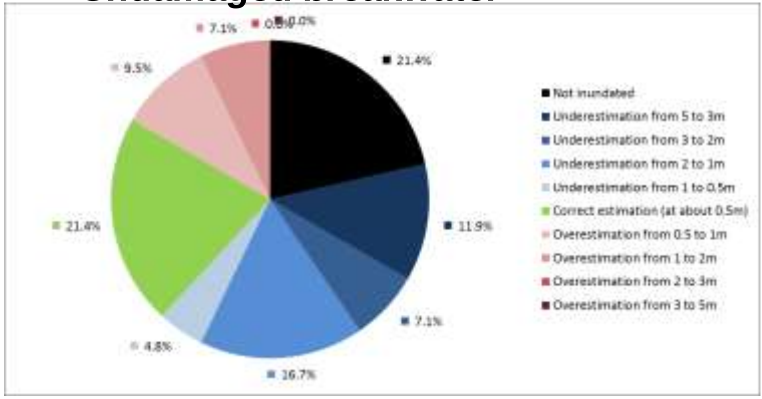
Collapse 2 min after



Damaged breakwater



Undamaged breakwater



How to integrate the whole complexity of such an event in simulations ?

> **According to available data, attempt to use the most adaptated approaches for each « step » of the simulation chain**

- Description of the source complexity
- Dispersive effects
- Role of the breakwater in Kamaishi
- very high resolution

Advantage of very high resolution

> Realization of a DEM with a very high resolution

- Grid mesh: 2.5m (re-interpolation from a 5m DTM)
- Buildings integrated in the topography (from OpenStreetMap, not exactly representative of the buildings during the event)
- Integration of some structuring elements:
  - Tsunami walls (supposed to be between 0.5 and 3 m hight)
  - Large structures (waste storage ?)

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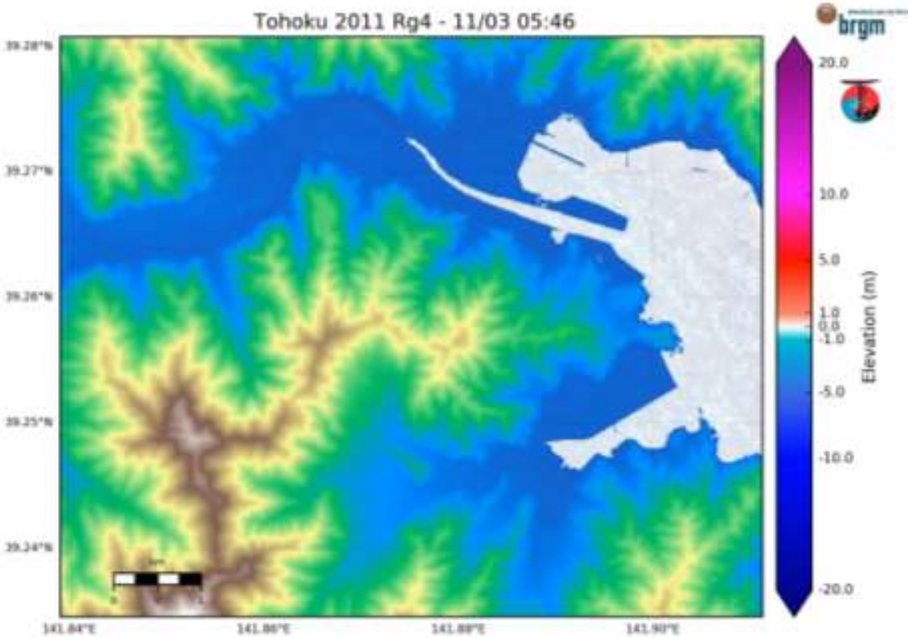
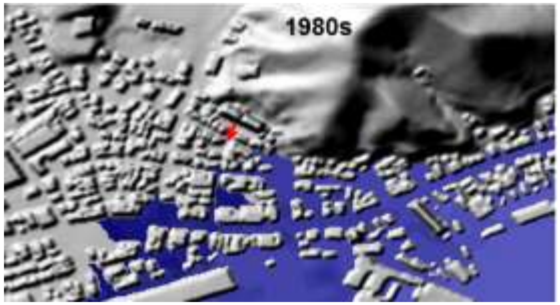
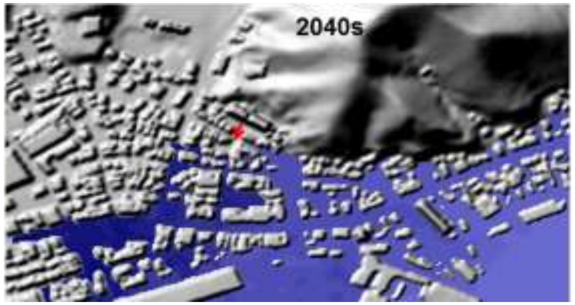
Advantage of very high resolution

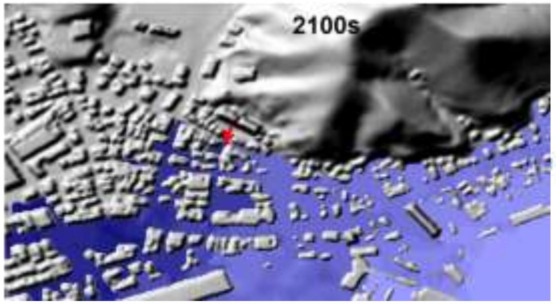
- **Realistic simulations of the flows in the streets**
- **Confrontation with available videos**



https://www.youtube.com/watch?v=aQj2zn5Axmk

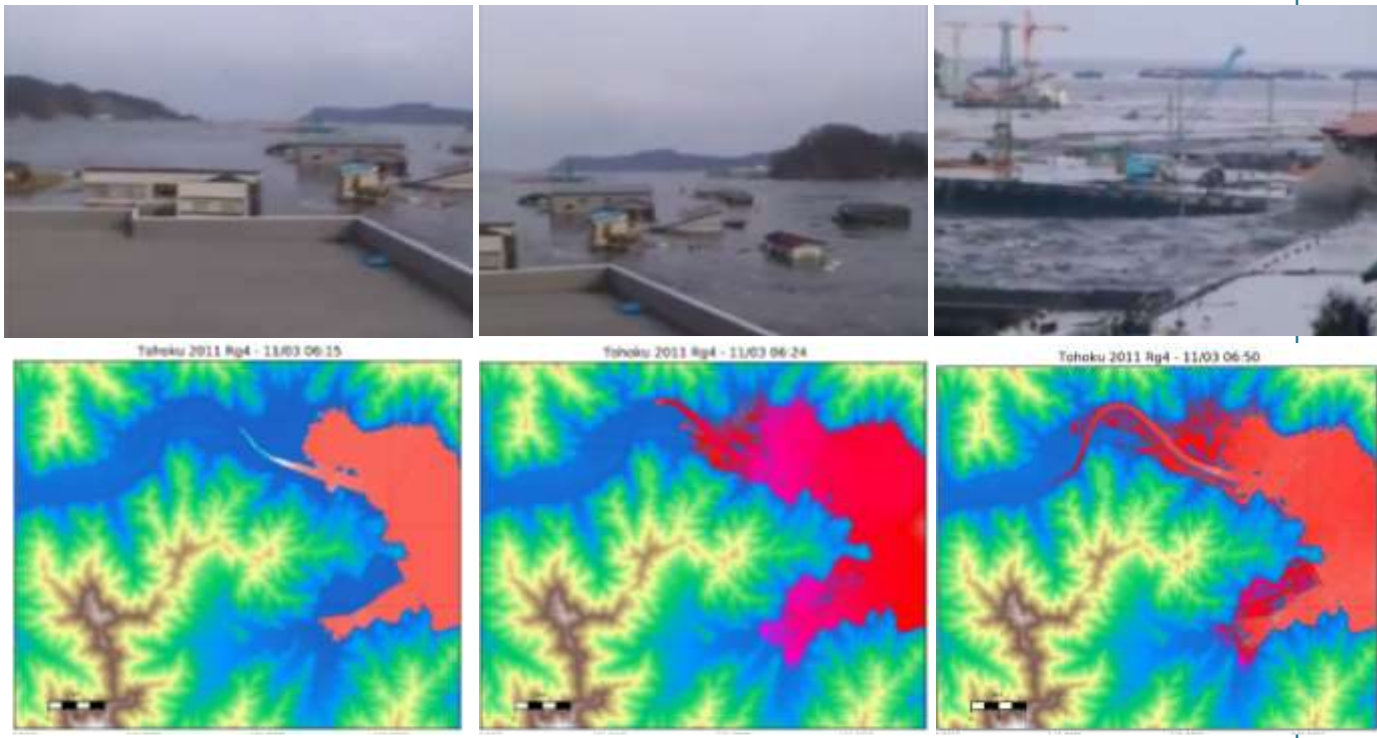






Advantage of very high resolution

> **Another example:** https://www.youtube.com/watch?v=629em0mPpUY



Event	Time in the video	Time from the first event in the video	Time of the event in the simulation	Time from the first event in the simulation
Beginning of the overflow	~20’	+0’	06:15 UTC	+0’
Max sea level and start of the withdrawal	~28’	+8’	06:24 UTC	+9’
Second wave	~45’	+17’	06:50 UTC	+26’

Conclusions

> **A very documented tsunami case**

> **Allow to quantify the consequences of various hypothesis**

- Description of the source complexity

  Importance to use a source description that gives back the whole complexity of the rupture, especially concerning the kinematiks and the horizontal contribution for very big events

- Dispersive effects

  Can be important in particular contexts, like in Sendai bay

- Role of important coastal defenses

  Their behaviour (collapse) can significantly influence the flood

- Advantage of very high resolution

  Allows a realistic simulation of the flood in complex areas (buildings…)

  Allows to validate the simulation with available elements (videos, photographies…)

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Projet ANR SPICy: La Réunion

Système de Prévision des Inondations côtières et fluviales en contexte Cyclonique

- Develop the next generation of cyclone-induced wave, surge (**regional scale**) and flood (**local scale**) forecasting system for the Reunion Island

- Investigate ways for better integration with emergency services to keep in mind the possible operational applications beyond the project

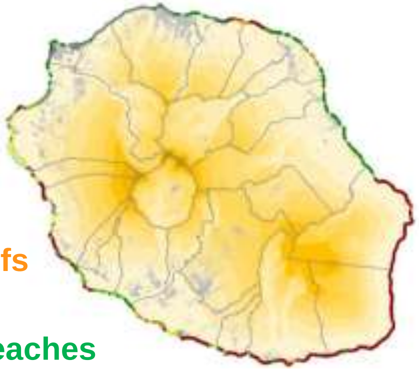
- Produce a demonstrator and inovative products that will be tested within two crisis exercices in 2016 (simulator) and 2017 (on site)

Reunion island presents specific issues ….

Artificial coast

Peeble beaches

Fragmented fringing reefs



Volcanic beaches

Cliffs

- **A small island (Ø ~ 50km)**
  - High uncertainties related to the track
- **No continental shelf associated to a microtidal regime (~0.5m)**
  - Storm surge is not the point
  - …. but waves are
- **Various coastlines types**
  - And as many different behaviours to account for
- **Coastal flooding due to wave overtopping only**
  - Local scale processes are essential

… that require suitable solutions

- **A probabilistic approach through ensemble simulations is required to account for the high uncertainties**

…. but at the same time :

- **Issue 1 :**

  Classical parametric wind and pressure fields (Holland, 1980) are not adapted to simulate waves because of large-scale environment influence

- **Issue 2 :**

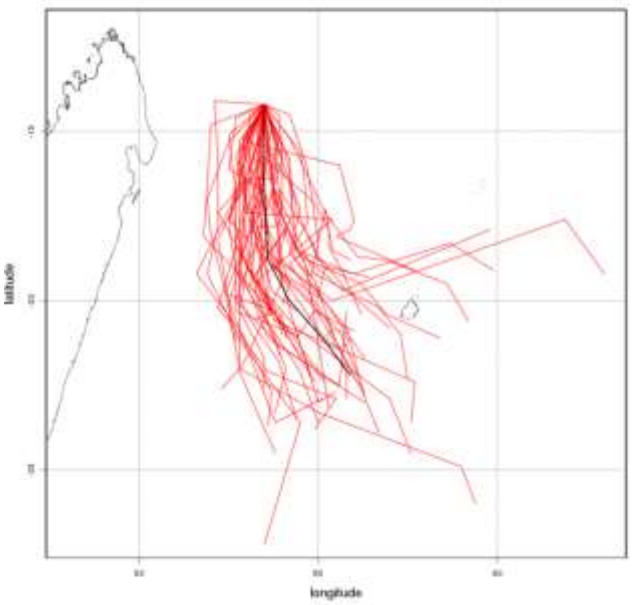
  Classical approaches with overflowing models used in forecast systems (like in the US) can’t be applied here

A problem of scale (processes) and computing times!

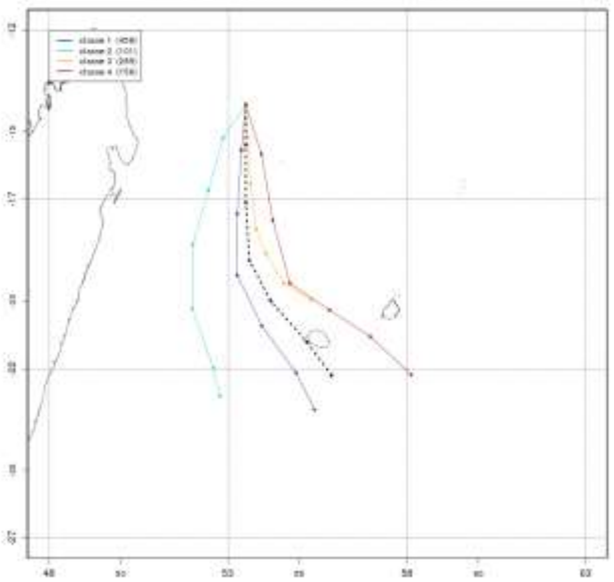
Our strategy for the meteorological data (1)

> Develop 2 methods to generate ensembles of scenarios accounting for both track and intensity uncertainty

- Option 1: Based on historical forecast errors statistics (DeMaria et al. 2009)
- Option 2: Based on the ECMWF ensemble forecasts



BEJISA prévision du 201312311200 (avec correction serial correlation)



trajectoires des moyennes de classe et traj reference

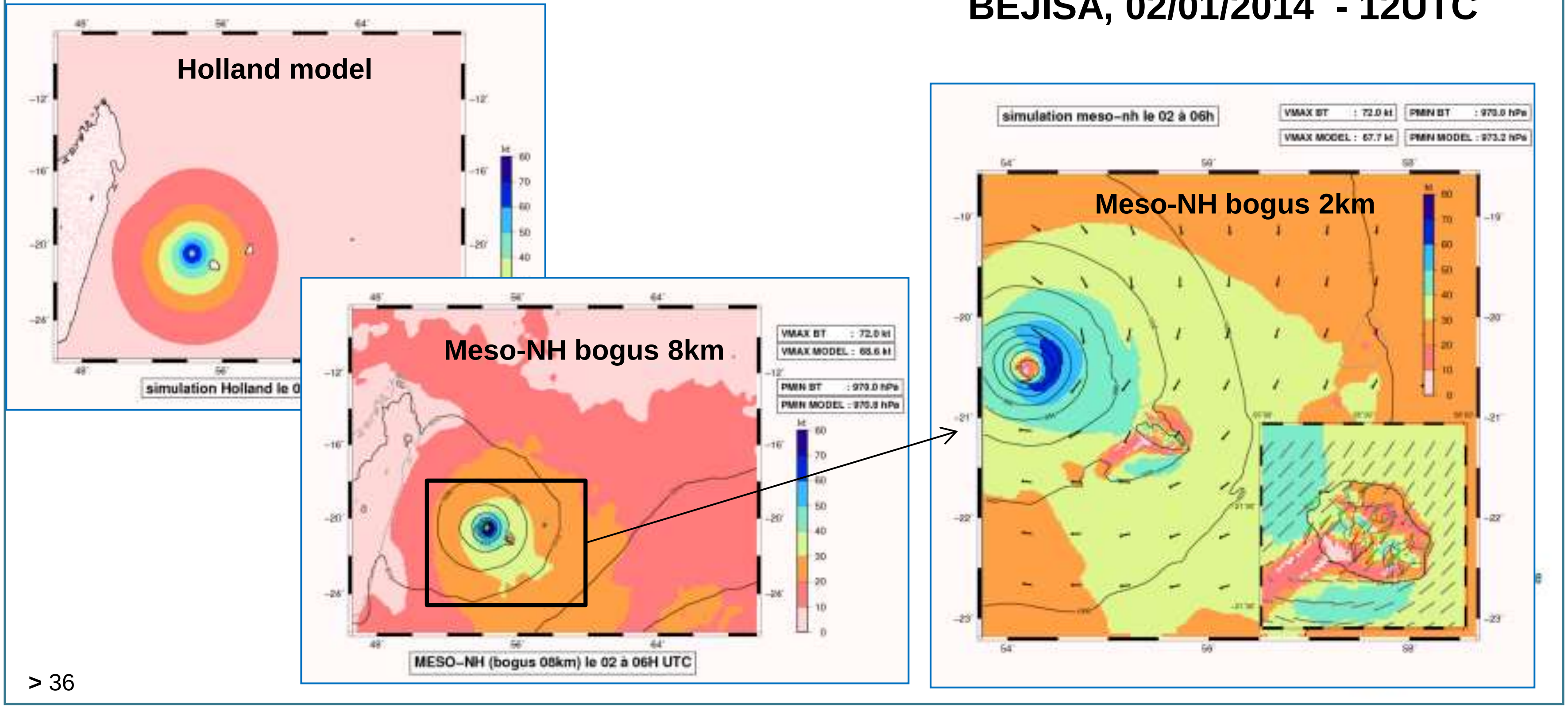
> Apply a clustering to the members to optimize the number of simulation and gain in computing times

Our strategy for the meteorological modelling (2)

> Create corresponding 2D wind and pressure fields by introducing the scenarios into the model **Meso-NH** (Global model coupling) through a bogusing scheme to :

- take into account the large-scale circulation in wave modelling applications
- reconstruct a wind circulation consistent with the local orography when the cyclone is in the vicinity of the Island

BEJISA, 02/01/2014 - 12UTC



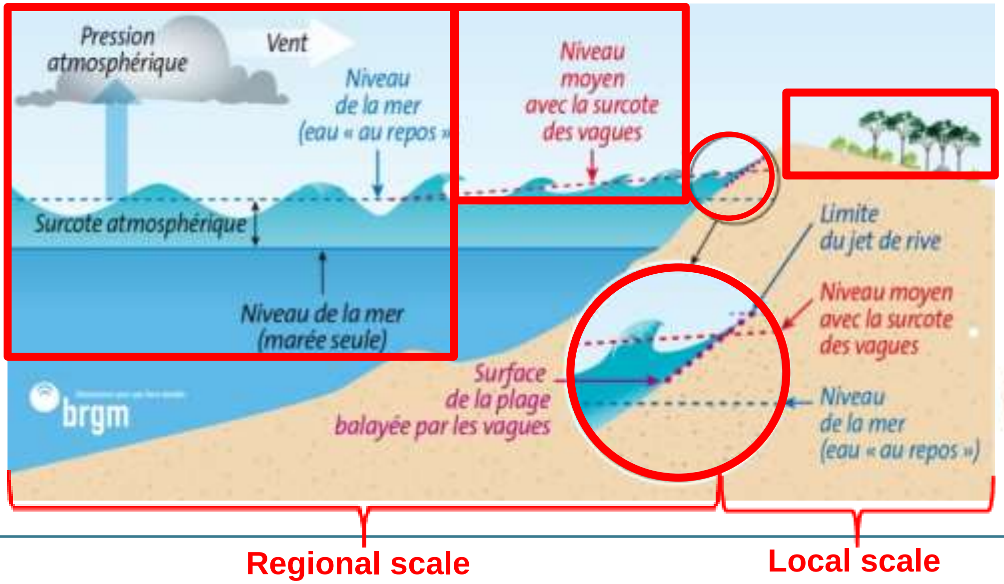
Our strategy for the hydrodynamic modelling (1)

> **Implement an optimized modelling platform comprising** :

- ✓ 2D spectral wave model (WW3) and NLSW model (MARS-2D: tide, storm surge, currents) until a resolution of 100-300m
- ✓ 1D spectral wave model profiles (SWAN) on homogeneous coastal segments to compute the wave-induced setup at 10m resolution all around the island
- ✓ 2DV non-hydrostatic free surface model profiles (SWASH) to fully simulate wave overtopping with at 1m resolution (topo-bathymetry lidar data)
- ✓ 2D NLSW model (MARS-Flood) to propagate the water flow with a resolution of 4m enabling a realistic representation of urban areas (wet-dry interface, spatial distribution of friction, river discharge, runoff, culvert and urban drainage)

Regional scale

Local site



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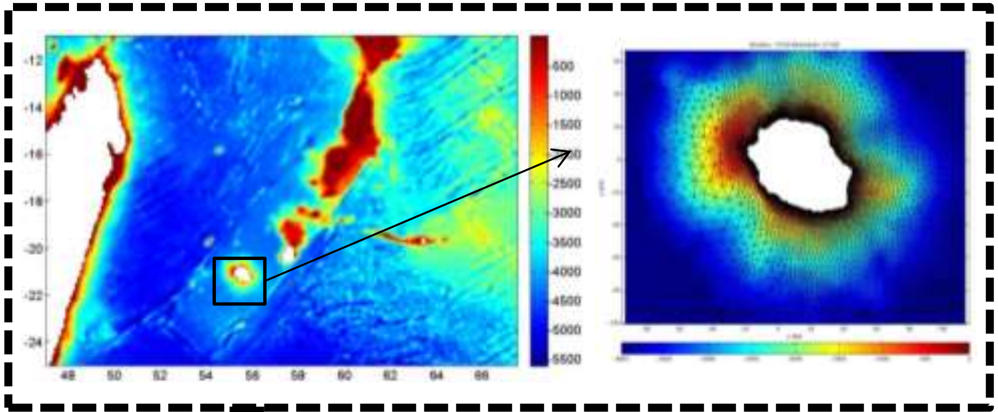
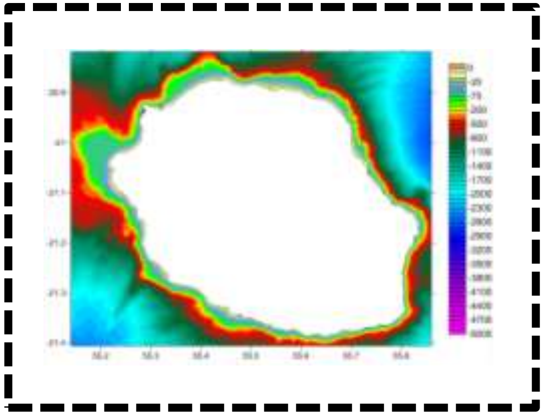
Our strategy for the hydrodynamic modelling (2) Regional scale

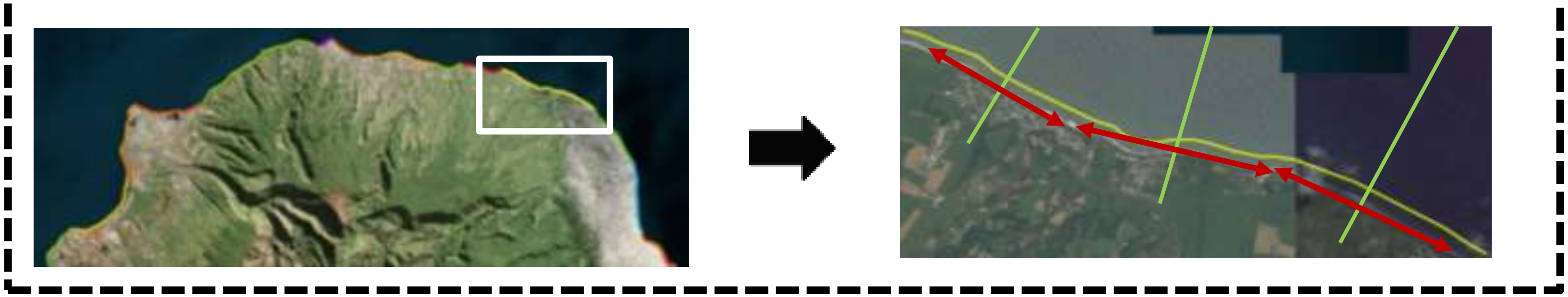
Wavewatch 3 two-way nested grids (10km => 300m)



MARS-2DH grid (100m)



Coastline segmentation and 10m resolution 1D SWAN profiles



Computing time ~ 25min on 24 CPU for 24h simulated : OK!

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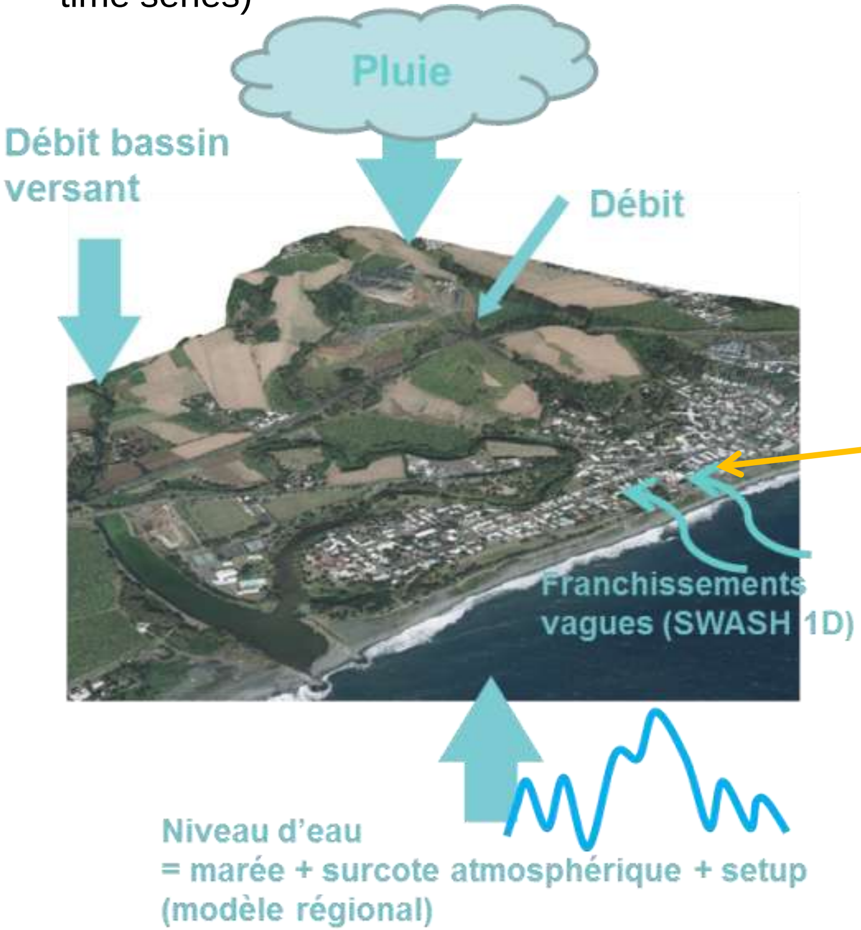
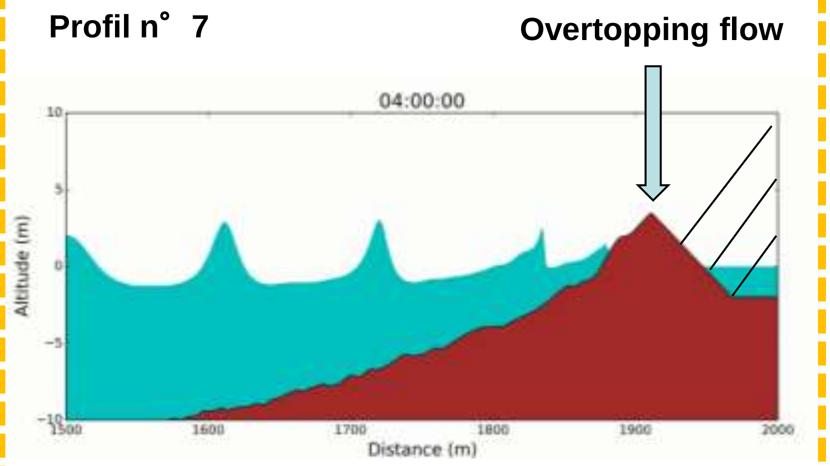
Our strategy for the hydrodynamic modelling (3)
Local scale

- Inputs from regional models (waves and waterlevels time series)



Sainte-Suzanne city

1m resolution SWASH profiles



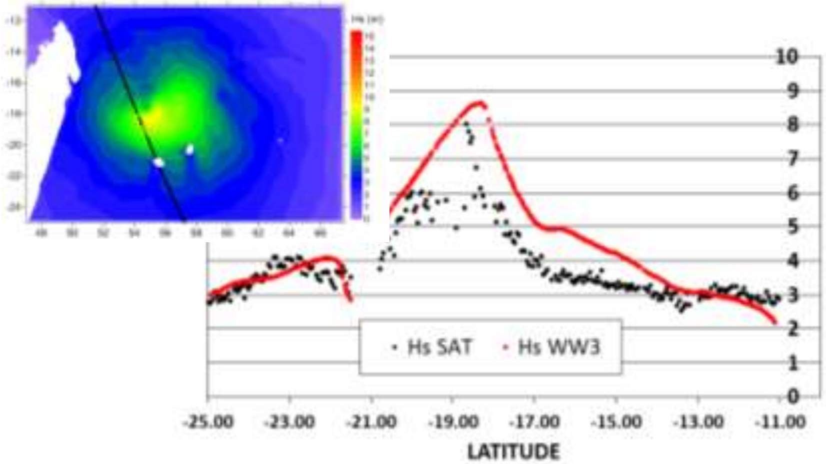
Computing time ~ 20 min on 24 CPU for 24h simulated : OK!

Computing time ~ 2h30 on 24 CPU for 24h simulated : Too long!

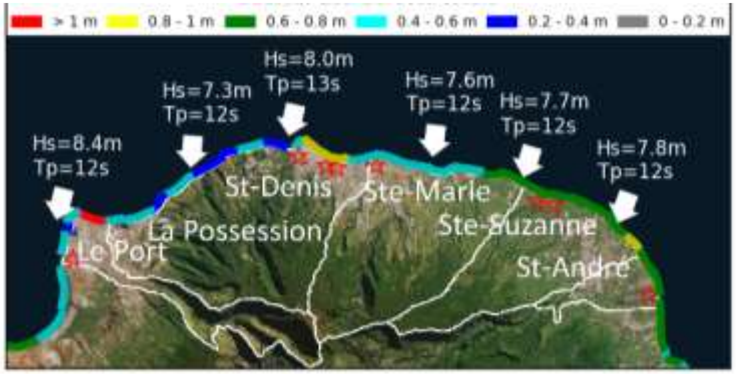
Example of reconstitution of historical events (2) The case of Dumile (Jan. 2013) at regional scale

- Input Data : Best-track Dumile+ bogusing in Meso-NH (8km-2Km)

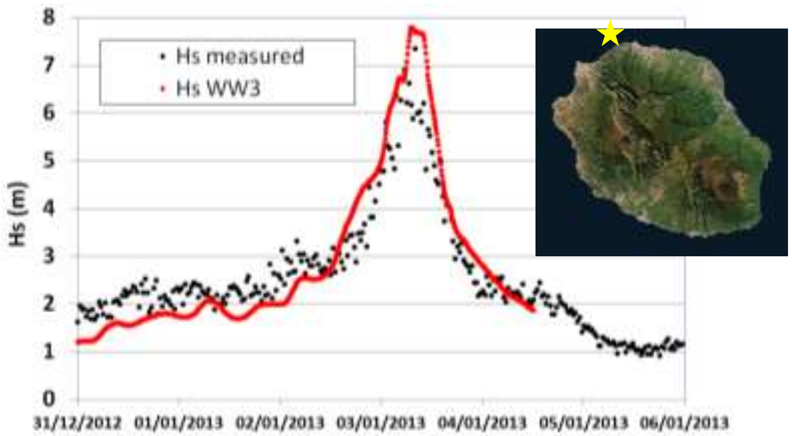
Comparison with satellite altimetry observations

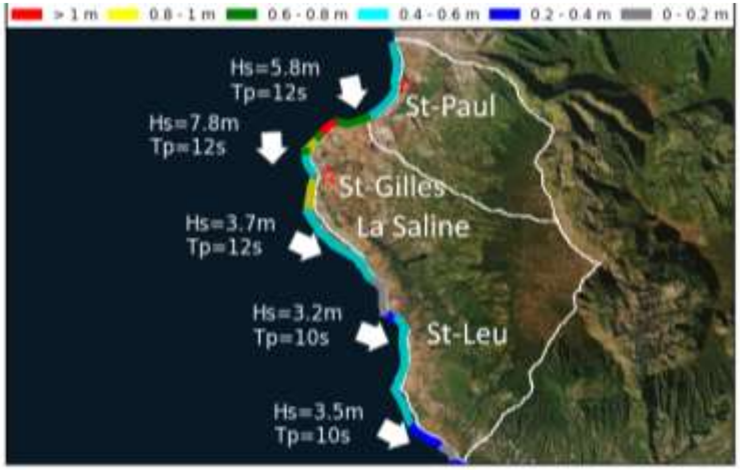


Storm surge (including wave setup)



Comparison with buoy measurements (AWAC)

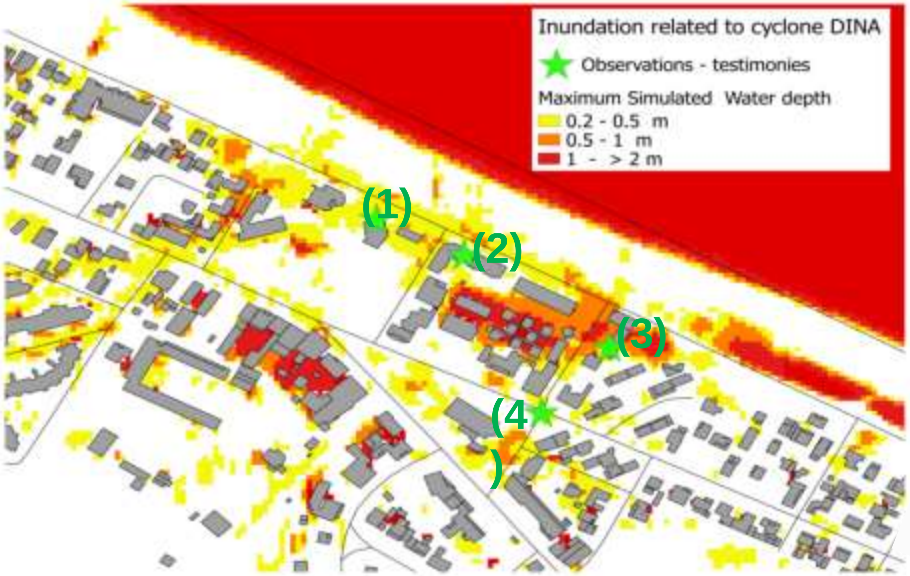




Example of reconstitution of historical events (3) The case of Dina (Jan. 2002) on Sainte-Suzanne

- Input Data : Best-track Dina + bogusing in Meso-NH (8km-2km)

SPICy « simplified » strategy (Zoom)



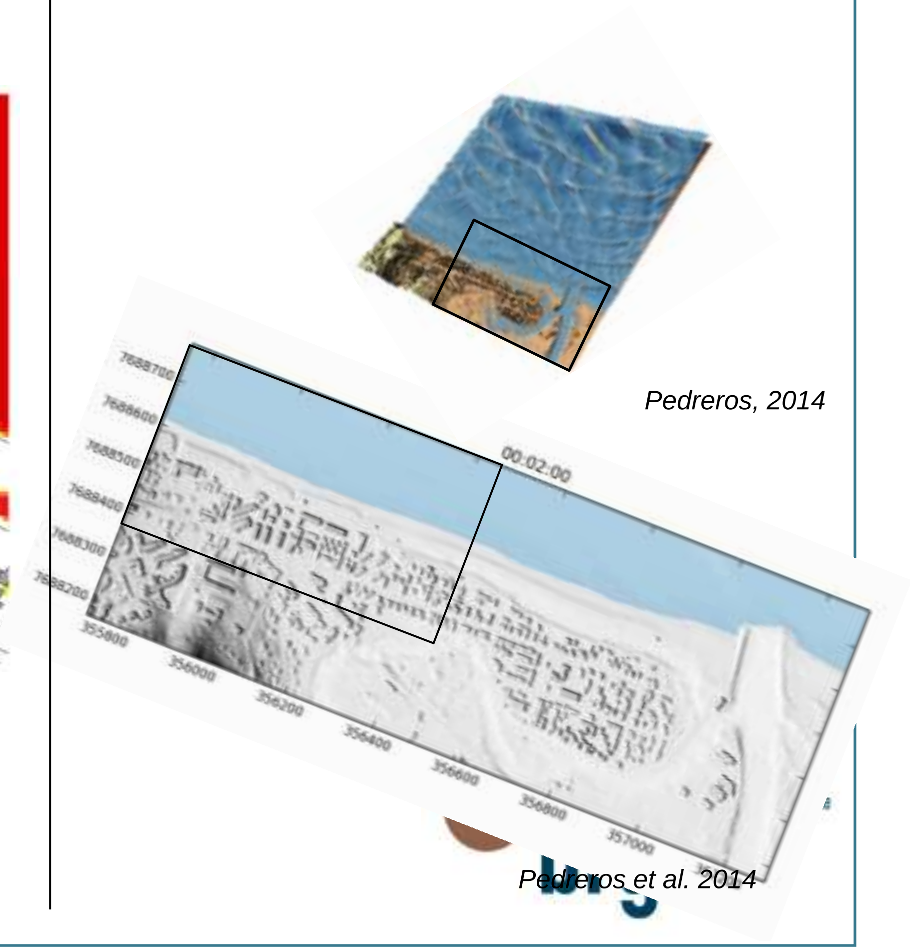
(1) **« Building collapsed by waves »**

(2) **« Six flats inundated at street level »**

(3) **« Firestation inundated »**

(4) **« Street Desprez and post station is inundated »**

Comparison with a « full processing modelling » (SWASH 3D, 2m resolution)



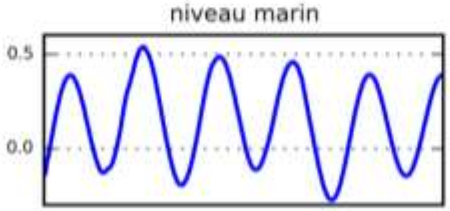
Pedreros, 2014

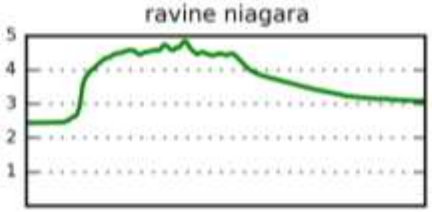
Pedreros et al. 2014

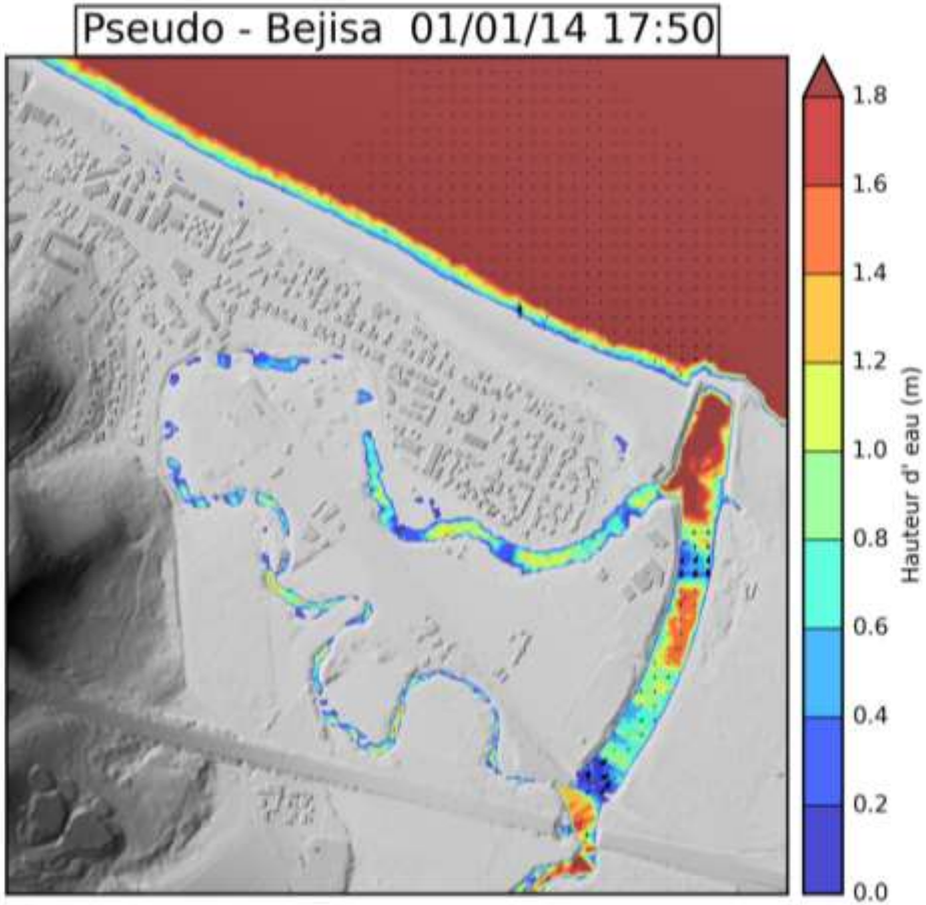
T1. Echelle locale (Ste-Suzanne): inondation

Utilisation du modèle MARS2DH-FLOOD

Prise en compte des franchissements et des débits fluviaux







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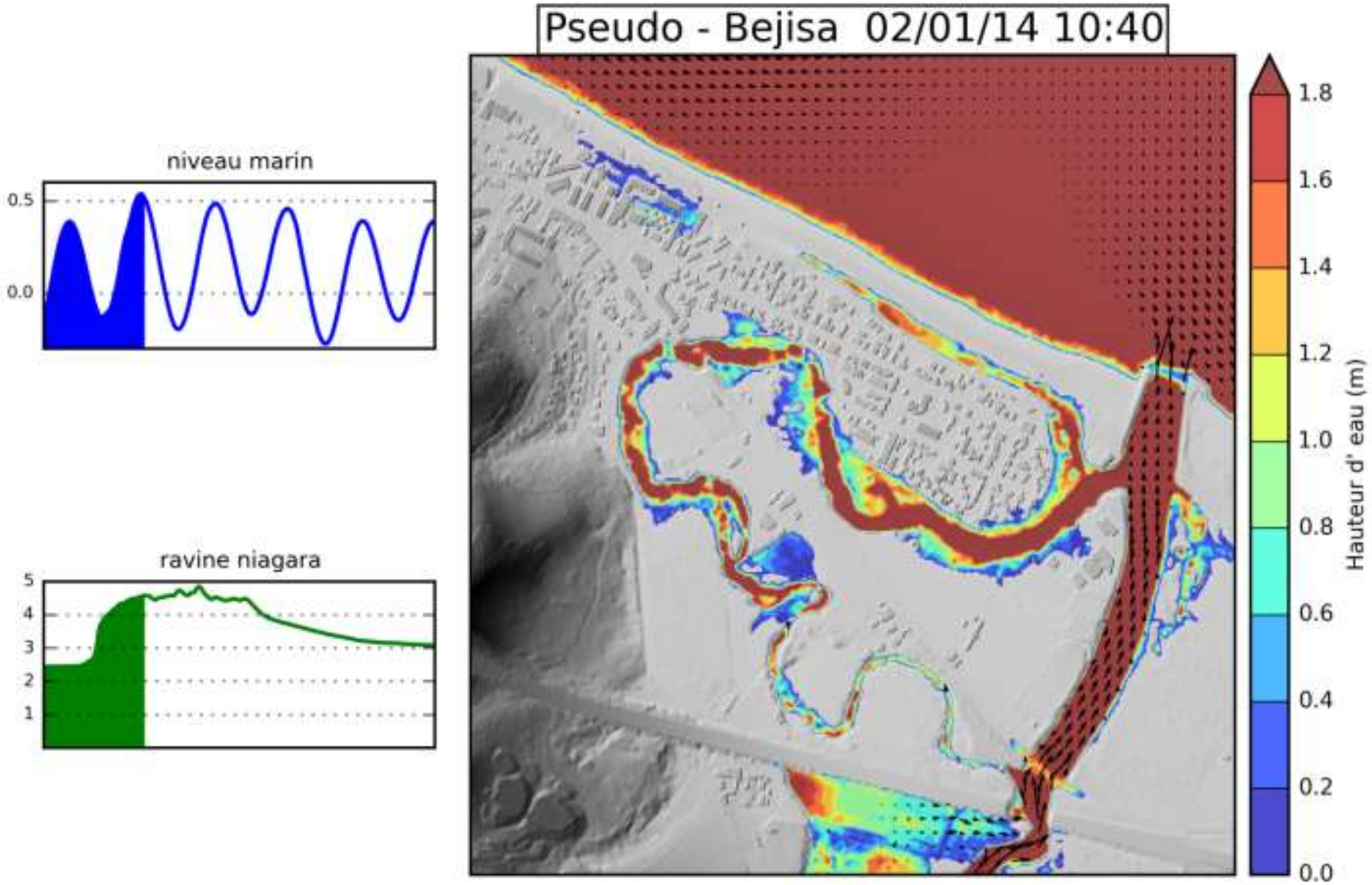

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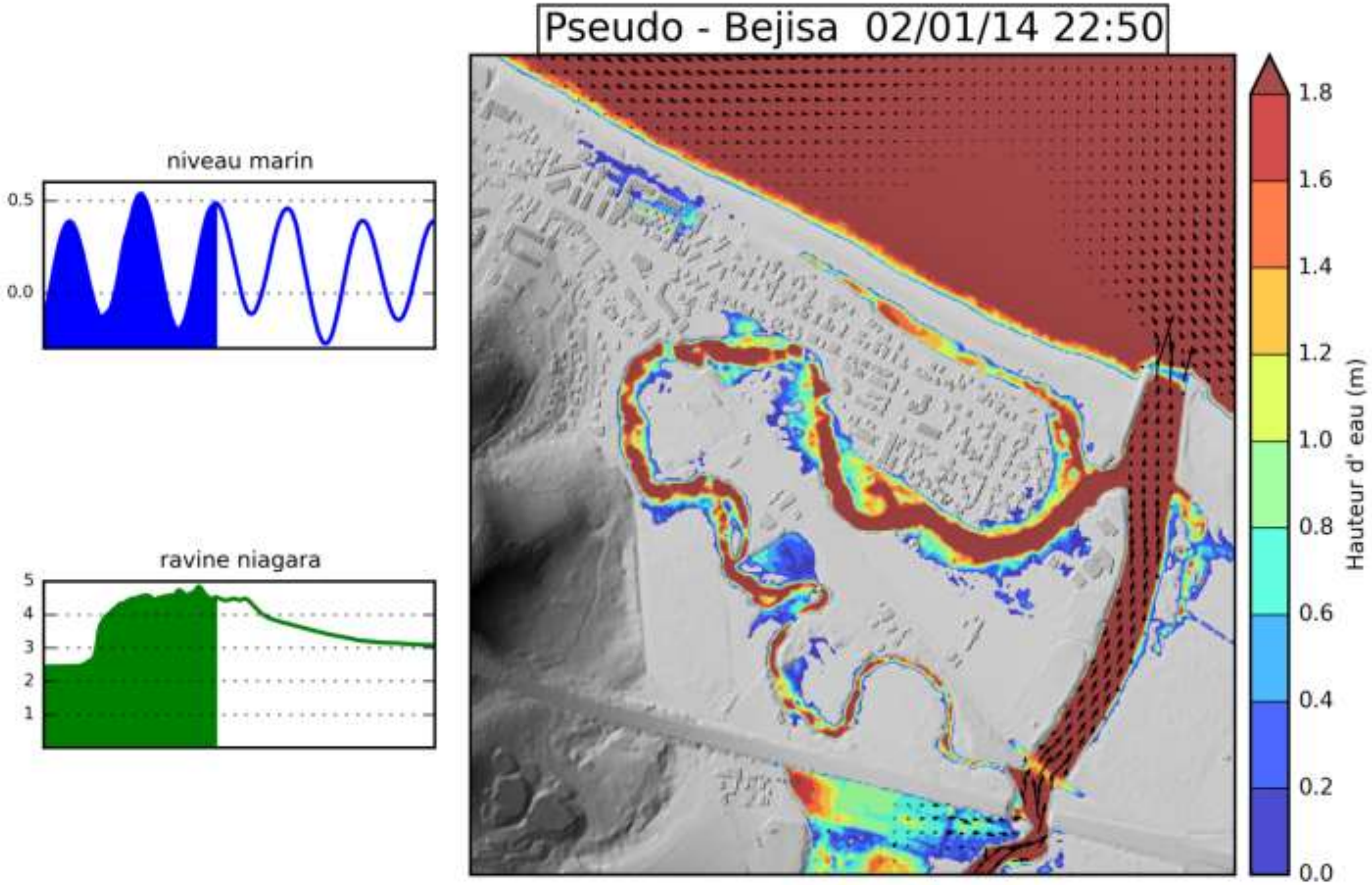

6- Modélisation de la submersion à Gâvres lors de la tempête Johanna (mars 2008)

> Cadre

- Projet JOHANNA (MAIF)
- UBO-BRGM
- Autour thèse C. André

> Questionnement

- Fonction coût des dommages
- Sous-questionnement : Vitesses et hauteurs d’eau autour du bâti → Capacité à reproduire la submersion par paquets de mer

Le Roy, S., Pedreros, R., André, C., Paris, F., Lecacheux, S., Marche, F., and Vinchon, C, 2015. Nat. Hazards Earth Syst. Sci., 15, 2497-2510, doi:10.5194/nhess-15-2497-2015, 2015.

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En résumé

- **Bancs découvrants**
- **Fortes pentes (bâtiments, digues, …)**
- **Propagation-> déferlement ->submersion**
- **Frottement**
- **Codes parallélisés**
- **Calculs emboités, grilles non structurées**
- **Ce qui implique des schémas :**
  - Capture de chocs
  - À l’équilibre (well balanced)
  - Positivité de la hauteur d’eau (reconstruction hydrostatique)
  - ….
- **Boussinesq: problèmes des conditions aux limites**

- **Attention aux données de forçage, MNT,…**

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Les défis…

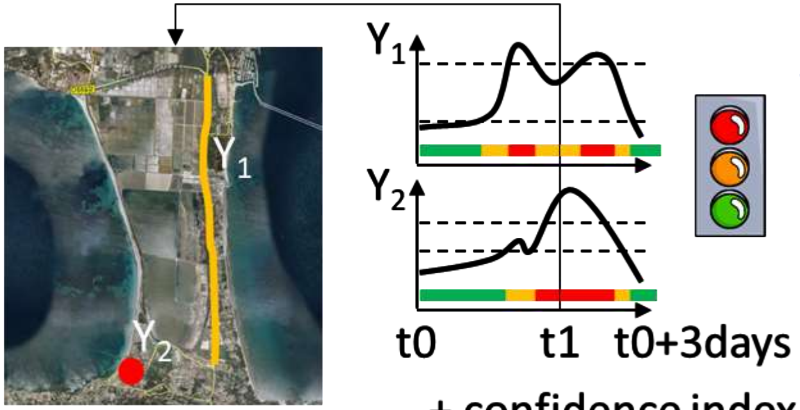
- **Risque inverse-métamodèles (prévision, prévention) -> ANR RISCOPE** (2017-2021)
- **Défaillance des ouvrages, destruction des bâtiments**
- **Couplage érosion submersion**

RISCOPE: objective & challenges

Contribute to forecast, warning & risk prevention of coastal flood

Forecast & Early Warnings

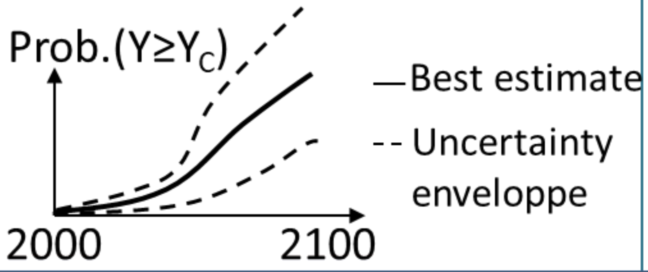
Spatio-temporal, till **3 days ahead**



+ confidence index

Prevention & Adaptation

Return period of flooding: present and future



Amongst the locks/challenges: computation time

> Real time ***minutes***

RISCOPE: objective & challenges

Explored solution in this research project:

Inverse approach & « meta-models »

> ~~Classical approach (direct)~~

- ~~What are the consequences if such scenario happens?~~

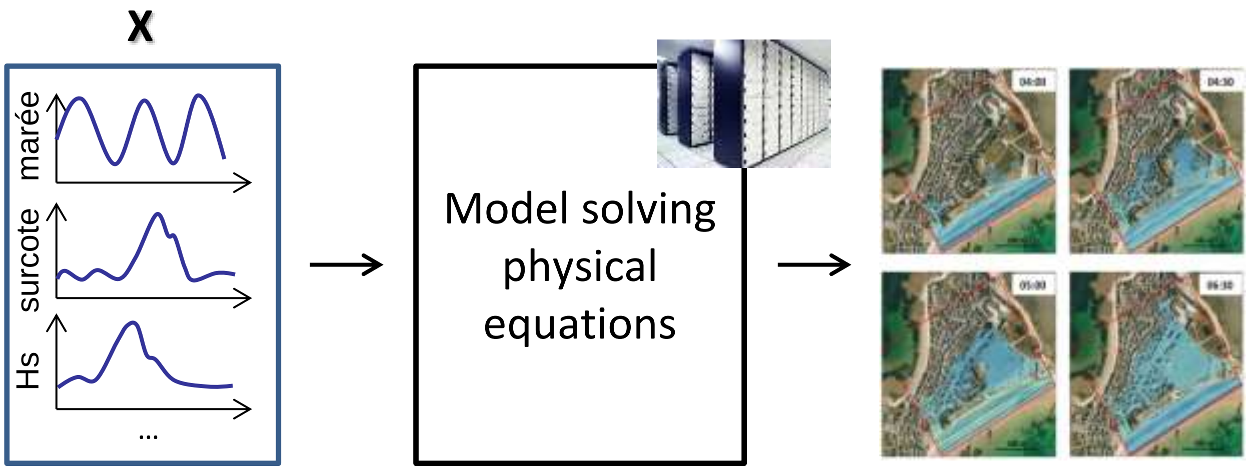
> Inverse approach

- Input: Which information is needed by stakeholders & decision makers on their territory?
- Output: What are the conditions leading to hazard / risk larger than a critical threshold (what is the threshold ?)

➡ **Stakeholders/decision makers: input of the inverse approach**

RISCOPE: objective & challenges

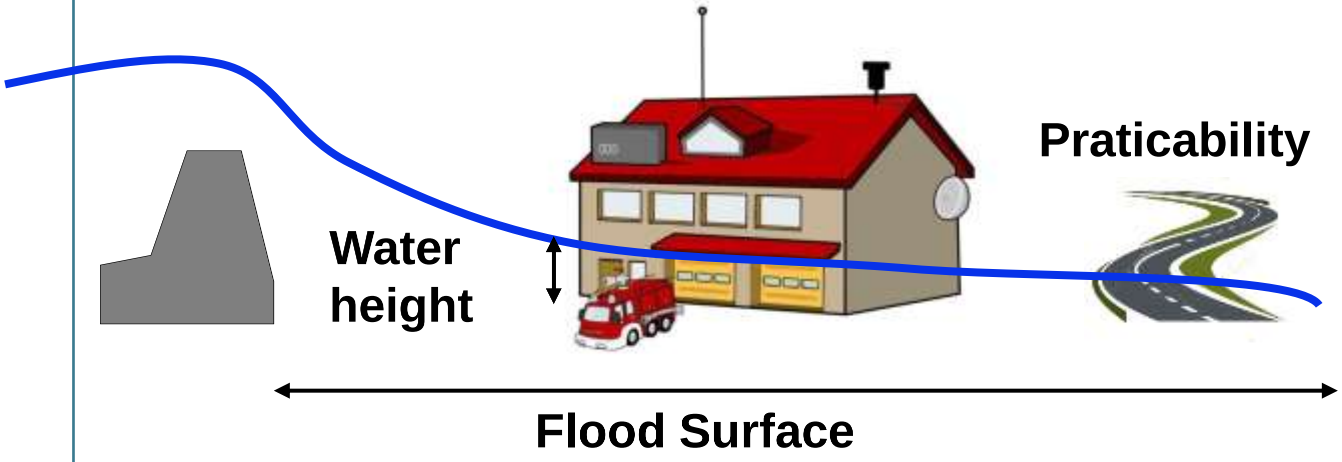
Explored solution: inverse approach & « meta-models »



Model solving physical equations

→ **Yi's**

Usefull informations for stakeholders / decision-makers

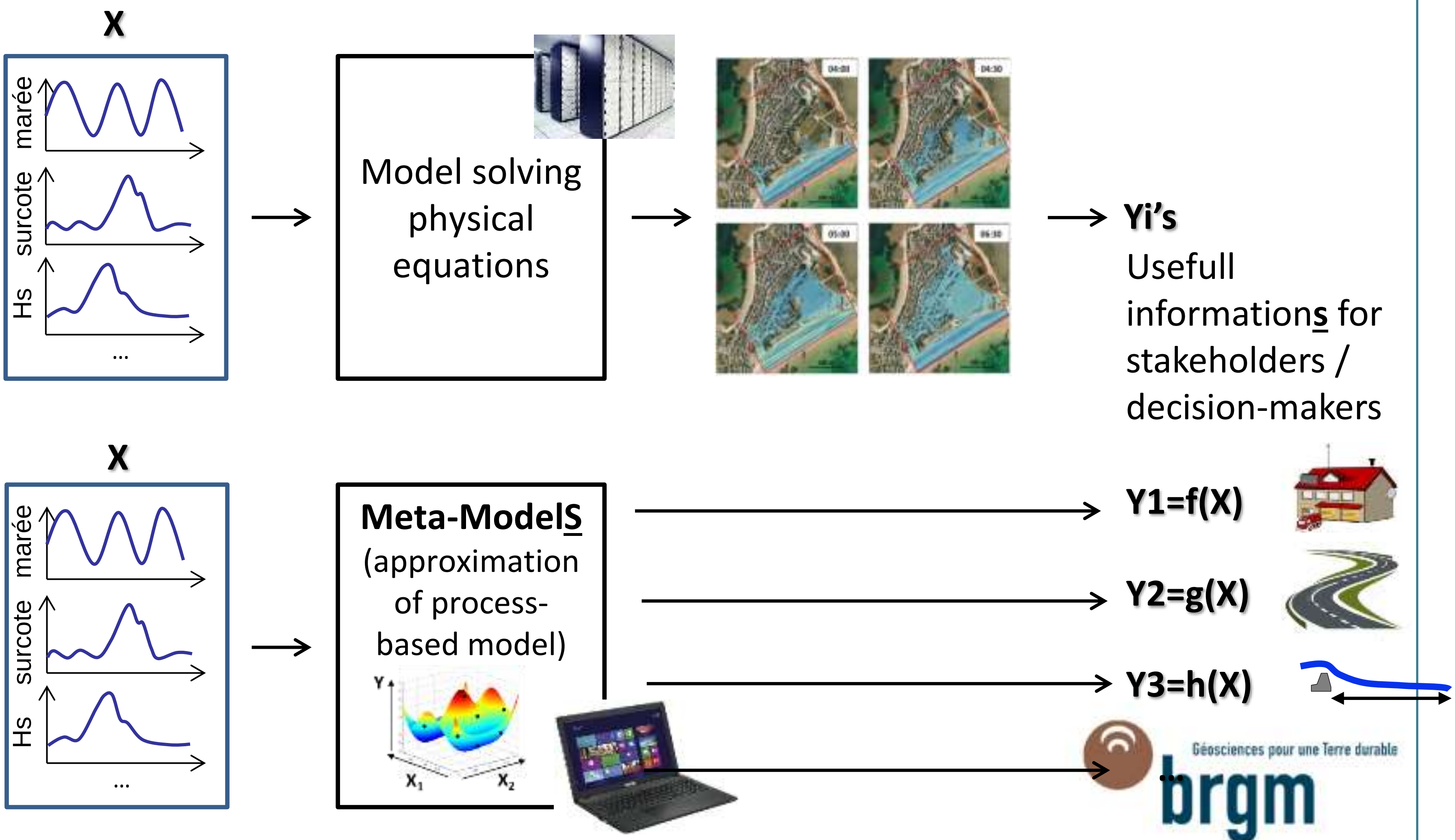


Ex: Application forecast – crisis managament

- **When?**
- **Critical thresholds?**

RISCOPE: objective & challenges

Explored solution: inverse approach & « meta-models »



X

Model solving physical equations

Yi's

Usefull informations for stakeholders / decision-makers

X

Meta-ModelS (approximation of process-based model)

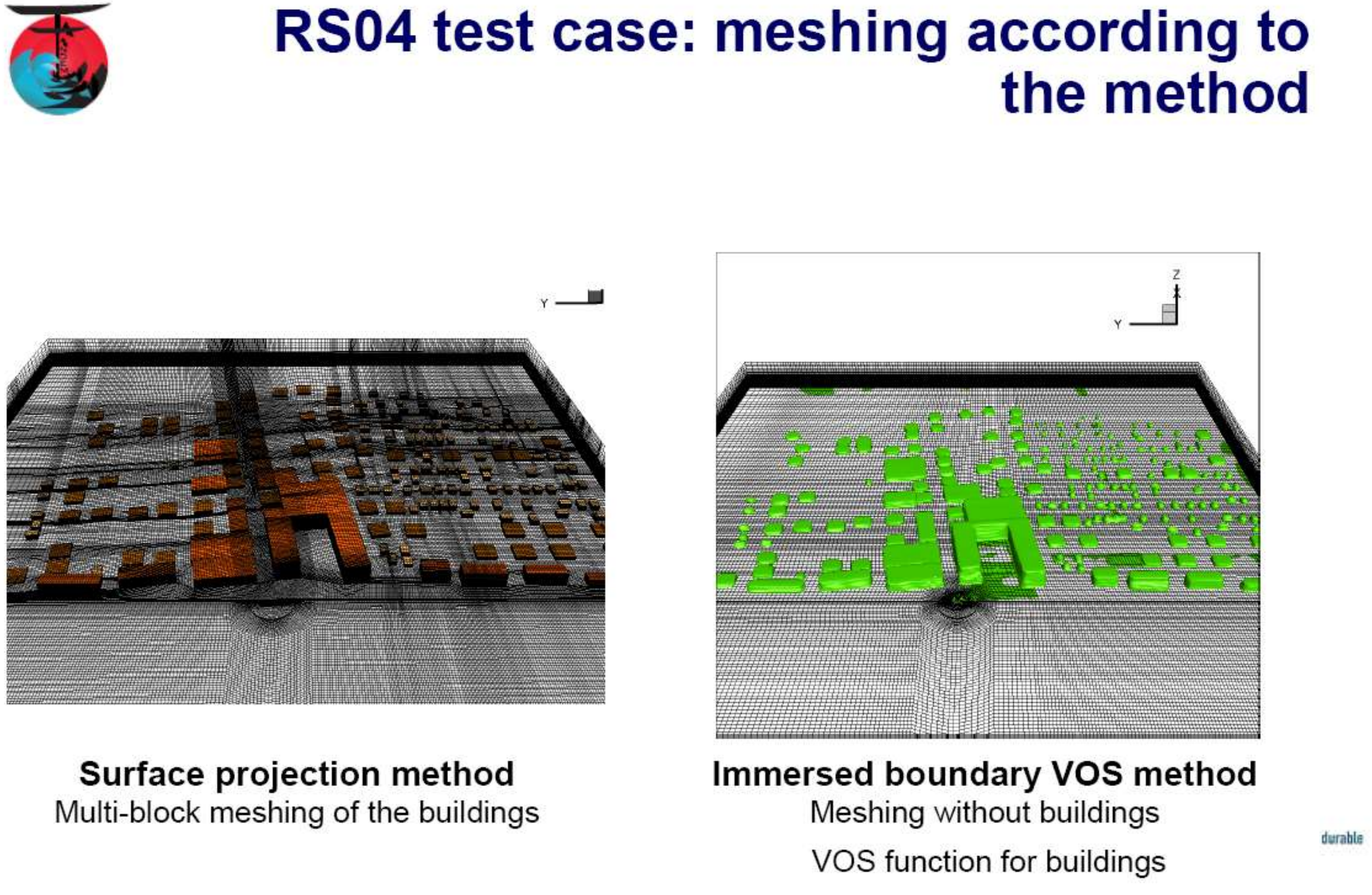
Y1=f(X)

Y2=g(X)

Y3=h(X)

…

Prise en compte des bâtiments



RS04 test case: meshing according to the method

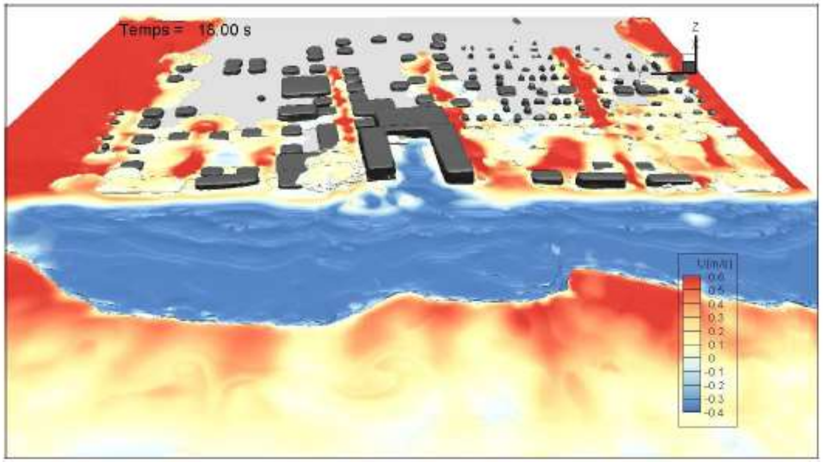
Surface projection method
Multi-block meshing of the buildings

Immersed boundary VOS method
Meshing without buildings

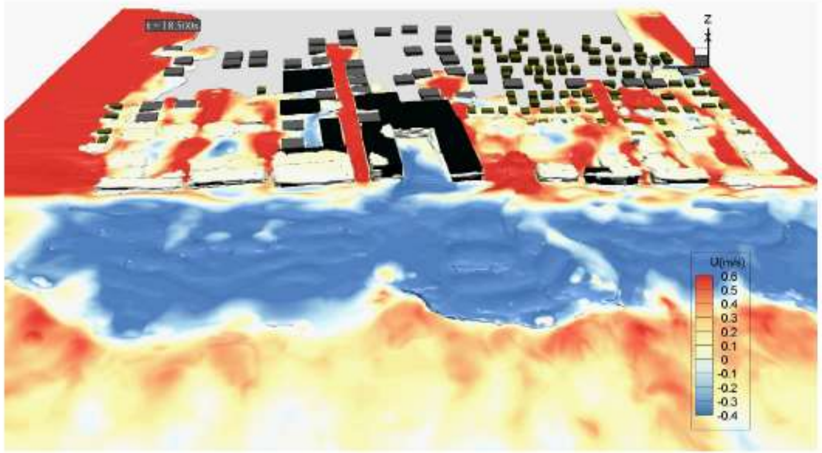
VOS function for buildings

Courtoisie de R. Marcer (PRINCIPIA, 2017)

Tsunami on a coastal urban area



VOS model



Model 1

DRP/R3C

Courtoisie de R. Marcer (PRINCIPIA, 2017)

Exemple Site d'étude: les Boucholeurs

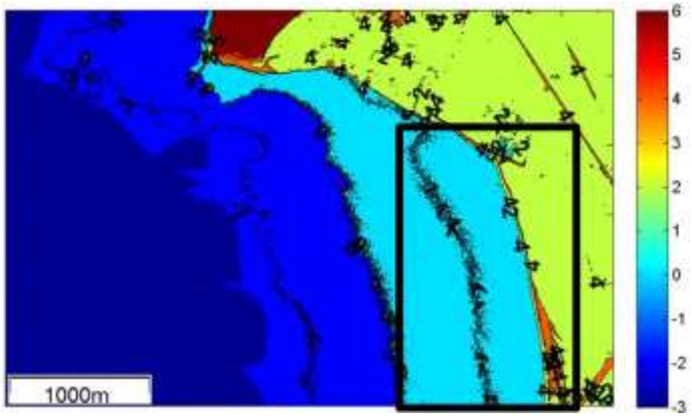
- Sandy dunes
- Protecting Yves marshland (natural reserve)
- On Xynthia trajectory

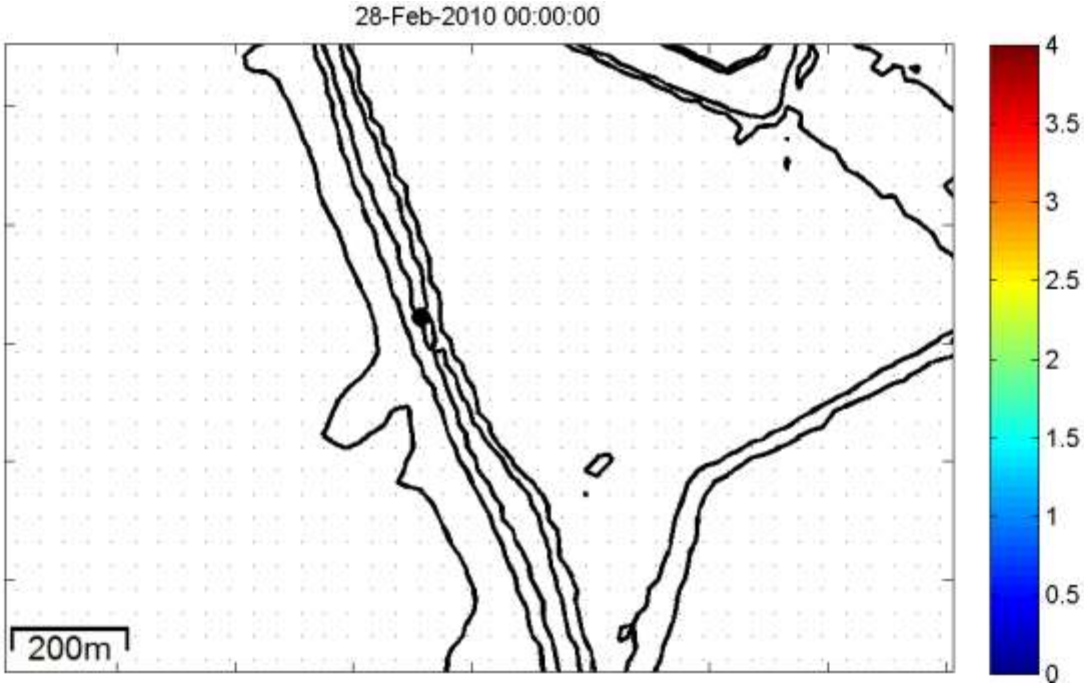
LPO

Erosion/submersion

DREAL Centre/ CETMEF

Modélisation de l’érosion et brèches des cordons dunaires





Müller H., Van Rooijen A., Idier D., Pedreros R., Rohmer J. (2017). Journal of Coastal Research

Merci de votre attention

AFP. Nice 08 Novembre 2011