

A numerical model for efficient simulation of multiple landslide-induced tsunamis scenarios

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Research topic

ISSUE: Assessing the hazard related to the landslide-generated tsunamis

GREAT CHALLENGE: Taking into account uncertainties related to the geometric and kinematic characteristics of the tsunamigenic source.

POSSIBLE SOLUTION: Applying Monte Carlo method to perform many tsunami simulations by extracting some landslide properties from their estimated probability distribution functions (as proposed by Grilli et al., 2009).

THE IDEA: Developing a numerical methodology able to carry out with acceptable computational costs a large number of different landslide scenarios in a Monte Carlo approach framework.

The proposed methodology can be used to perform Probabilistic Tsunami Hazard Analyses (PTHAs).



Methodology and Numerical Model

GREEN'S FUNCTIONS

From an analytical point of view...

«...response to unit forcing at a point, along a line, or at an instant.» (Mei, 1995)

From a numerical point of view...

Basic "brick" to construct tsunami solutions → Tsunami triggered by a bottom uplift of unitary magnitude over a small rectangular area

Numerical Green's function method

Two steps method (following the approach proposed by Ward, 2001):

1. Creation of a numerical Green's functions database → Numerical simulations
2. Generation of a generic tsunami scenario → Superposition of effects

$$\int_a^b \delta(x-\xi) dx = \begin{cases} 1 & \text{if } \xi \in (a,b) \\ 0 & \text{if } \xi \notin (a,b) \end{cases}$$

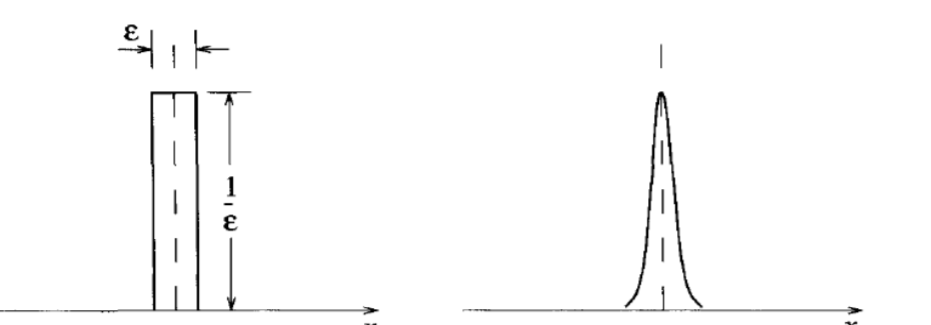


Fig1. Two examples of forcing function δ (Mei, 1995).

MILD SLOPE EQUATION

- Depth integrated → Propagation in the far field
- Fourier transform of the time-varying MSE: full frequency dispersive (inverse Fourier transform to recover the transient tsunami solution)
- Linearized: not for steep waves and not inshore

$$\nabla_n \cdot (c c_g \nabla_n N) + k^2 c c_g N = -\frac{\omega^2 Z}{\cosh(k h_b)} \leftarrow \text{Moving seafloor for the generation of underwater landslide tsunamis (Cecioni & Bellotti, 2010)}$$

- Reproduction of frequency dispersion of small amplitude tsunamis in the far field

Linearized numerical model → Superposition of effects

NUMERICAL ISSUES

Key point:
Rectangles size

- Balance between:
- Solution accuracy
 - Computational costs

Rectangle size selected according to the landslide characteristic dimensions

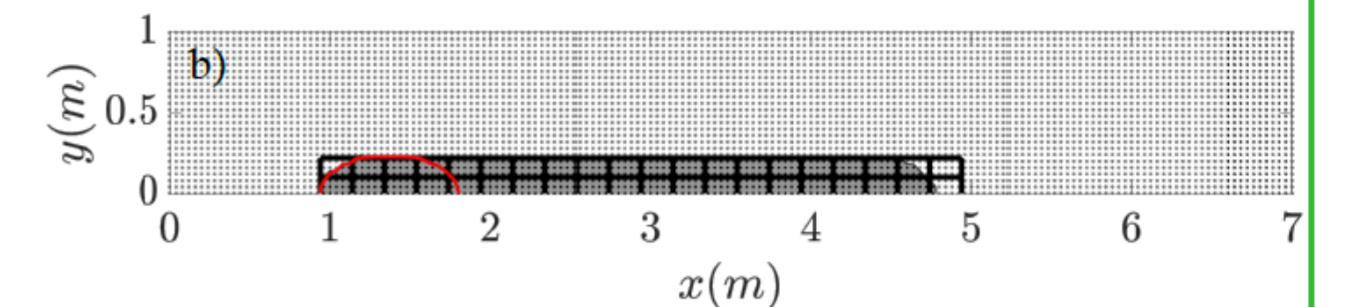
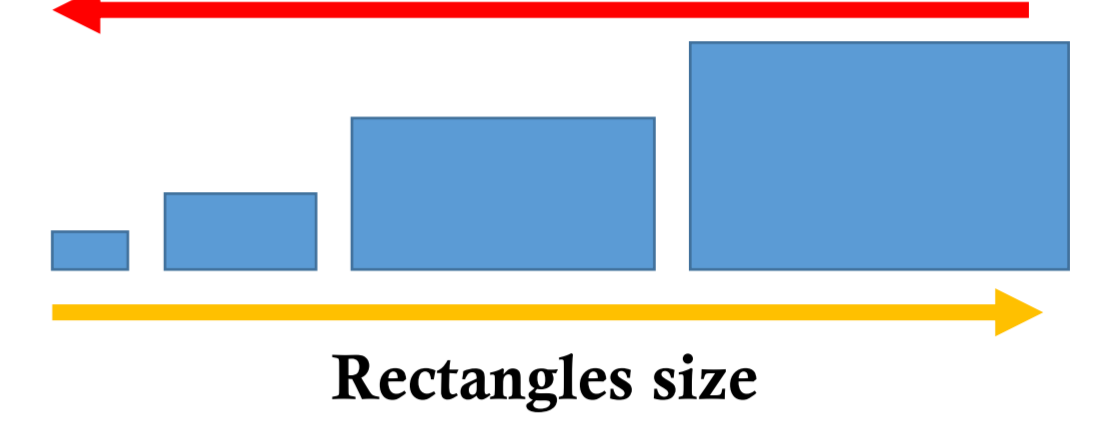


Fig2. Decomposition of the sliding area into small rectangles.

Accuracy & Comp. costs



Rectangles size

Parametric analysis

Tsunamis generated by a rigid underwater landslide (Enet and Grilli, 2007)

PARAMETRIC ANALYSIS

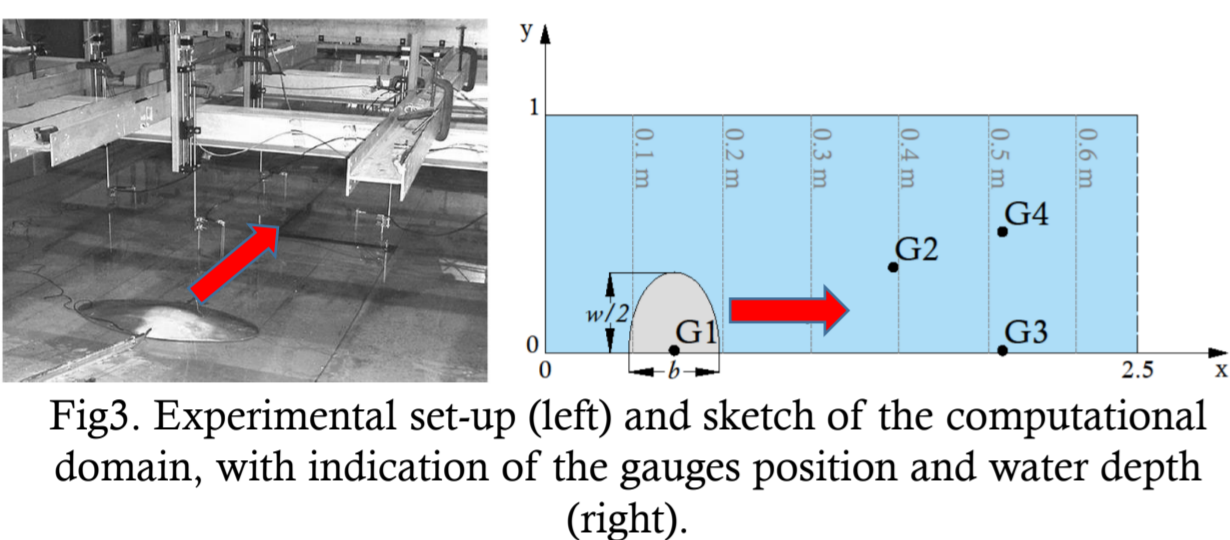
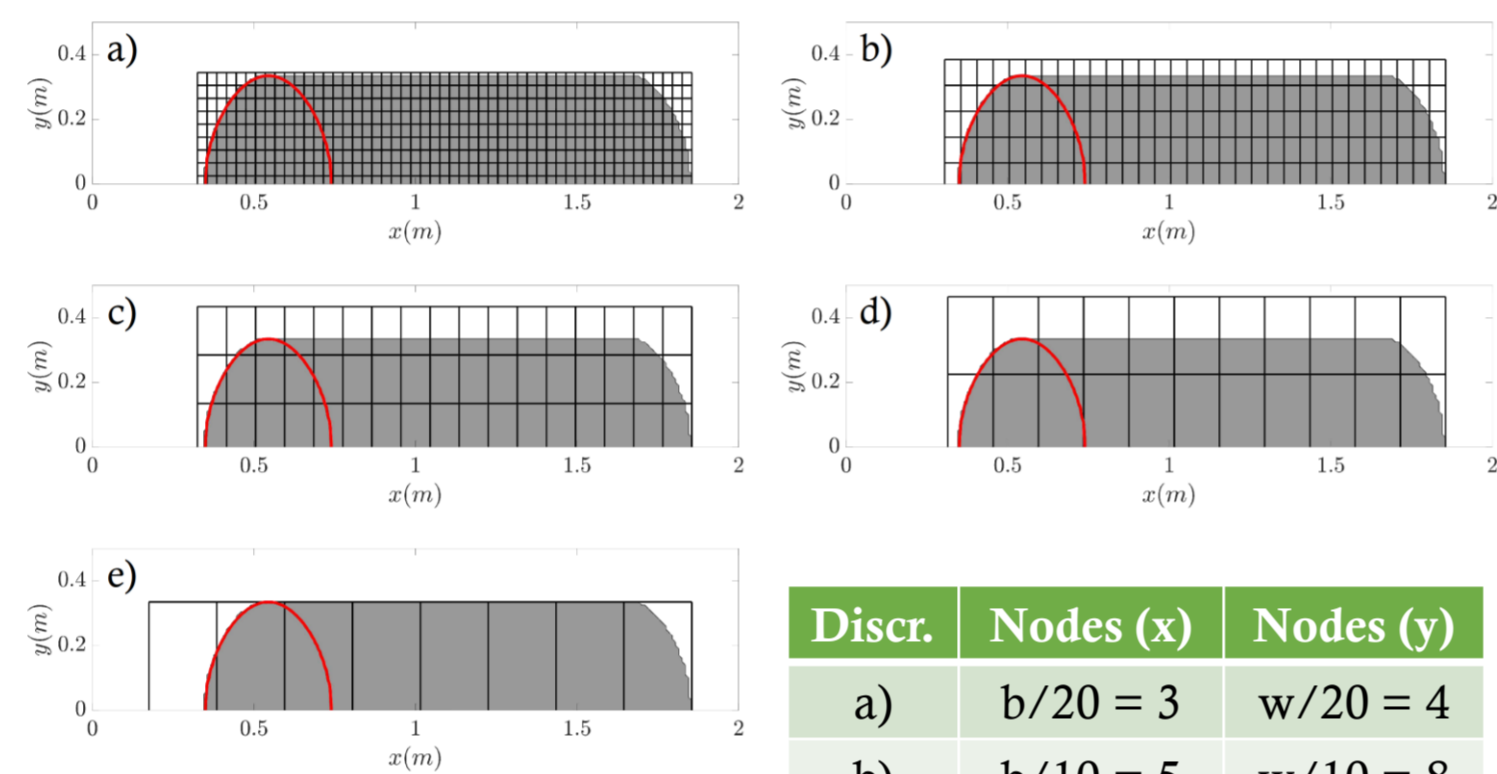


Fig3. Experimental set-up (left) and sketch of the computational domain, with indication of the gauges position and water depth (right).

Landslide dimensions

- Length: $b = 0.395$ m
- Width: $w = 0.680$ m
- Thickness: $T = 0.082$ m
- Numerical set-up
- Square mesh grid: $\Delta x = \Delta y = 0.01$ m
- Time step: $\Delta t = 0.01$ s
- Solved frequencies: $0 \leq f \leq 4.0$ Hz

Fig4. Sketch of the five decomposition of the generation area, in increasing order of rectangles size. Red line: initial position of the landslide. Gray: landslide motion area. Black rectangles: unit source areas.



Discr.	Nodes (x)	Nodes (y)
a)	$b/20 = 3$	$w/20 = 4$
b)	$b/10 = 5$	$w/10 = 8$
c)	$b/5 = 19$	$w/5 = 15$
d)	$b/3 = 14$	$w/3 = 24$
e)	$b/2 = 21$	$w/2 = 35$

Rectangles size as multiple of the grid element size

RESULTS

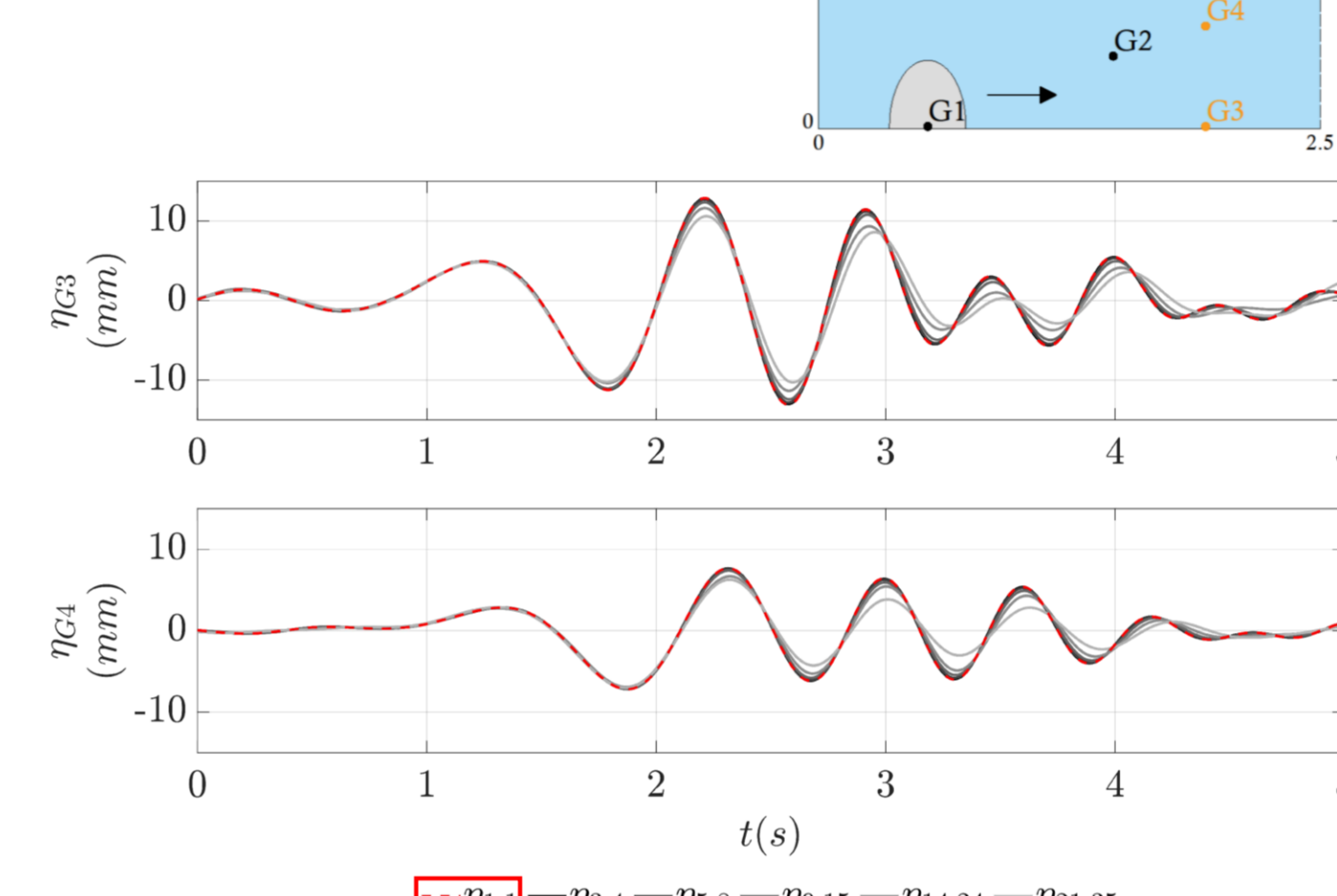
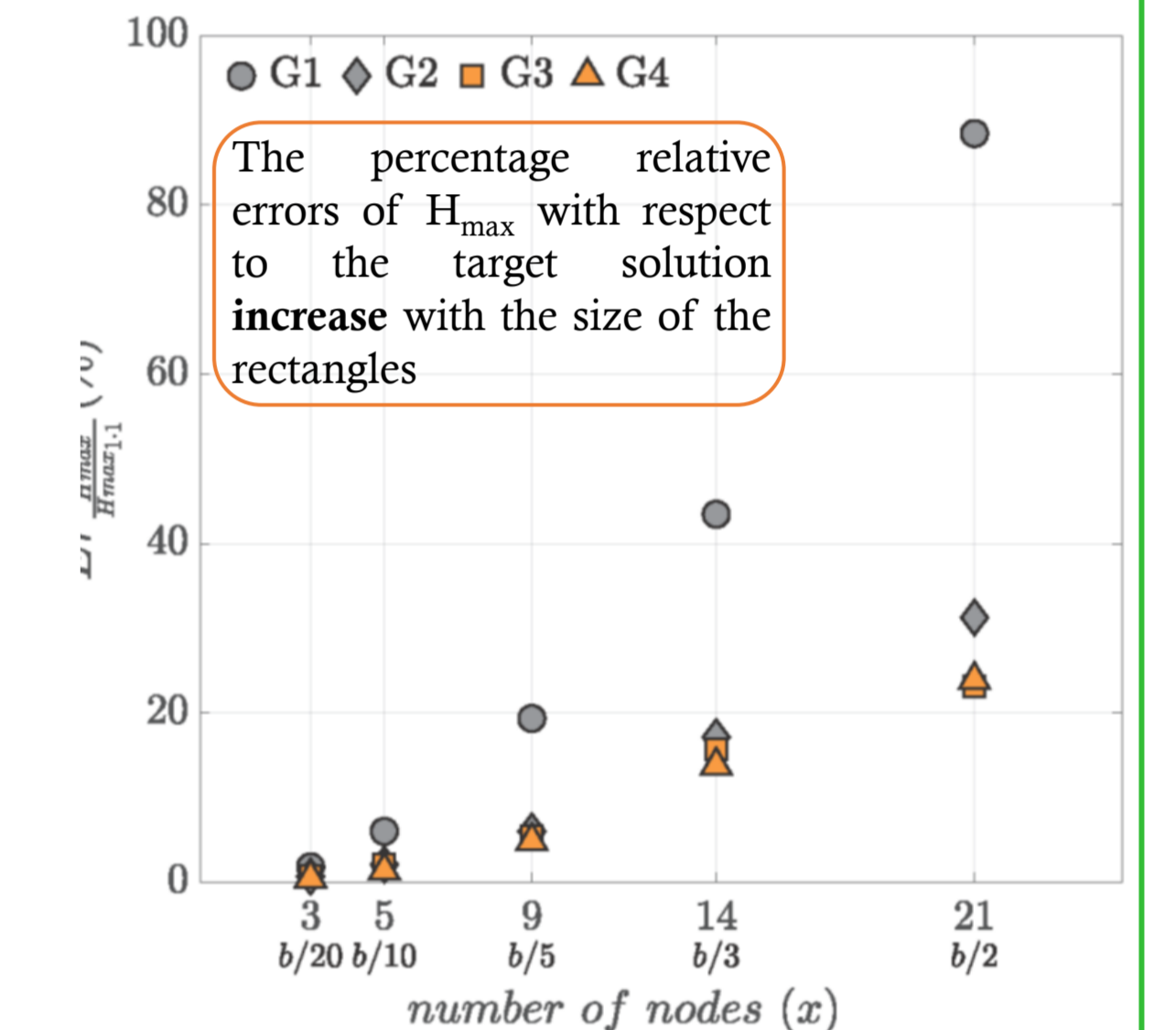


Fig5. Free surface elevations at the gauges G3 and G4 obtained by decomposing the generation area into rectangles of increasing sizes compared to the target numerical solution computed without applying the proposed method (red dashed line).



The percentage relative errors of H_{max} with respect to the target solution increase with the size of the rectangles

Fig6. Percentage relative error of the maximum wave height between each parametric solution and the target solution.

Tsunamis generated by sub-aerial landslide along the flank of a conical island (Di Risio et al., 2009)

PARAMETRIC ANALYSIS

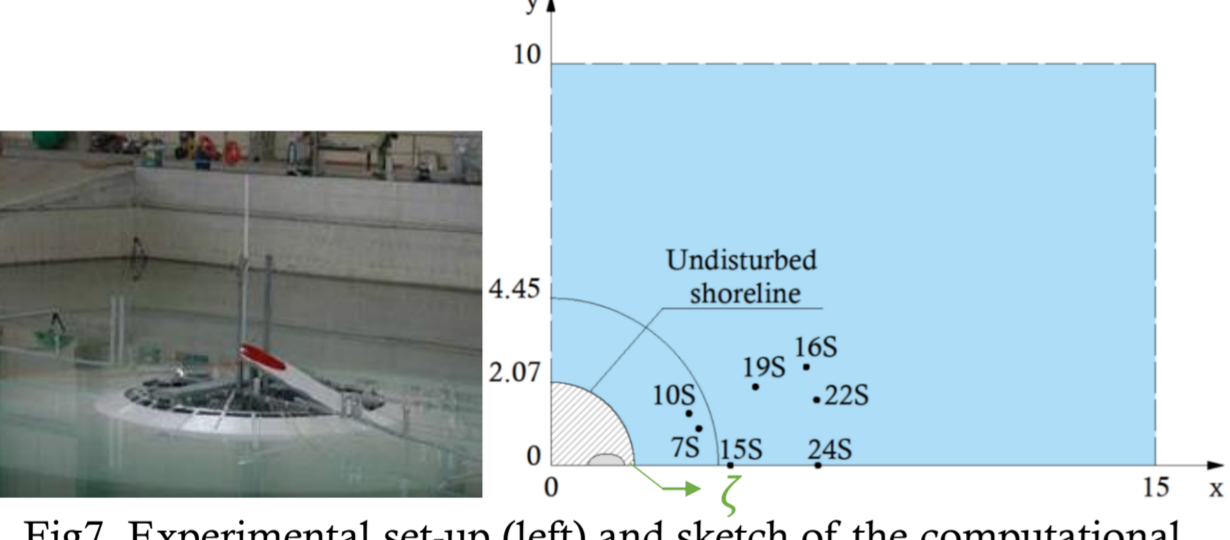
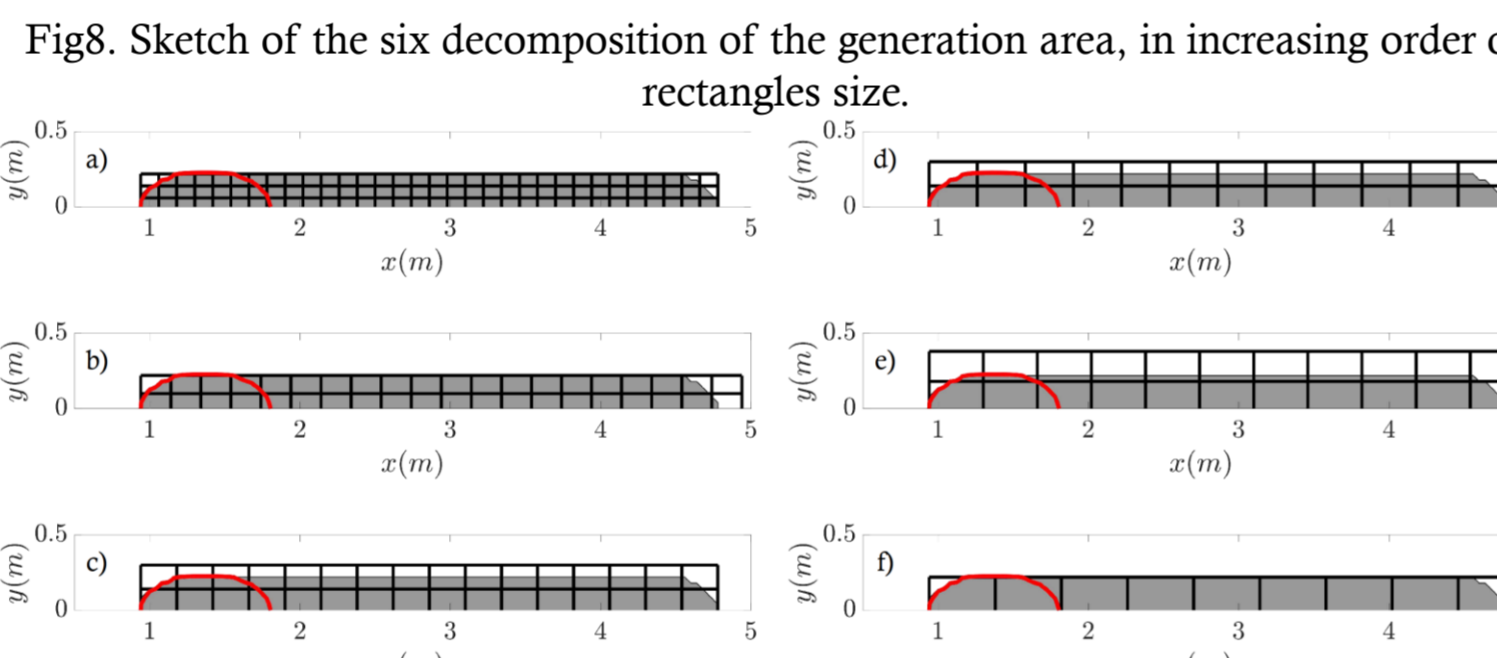


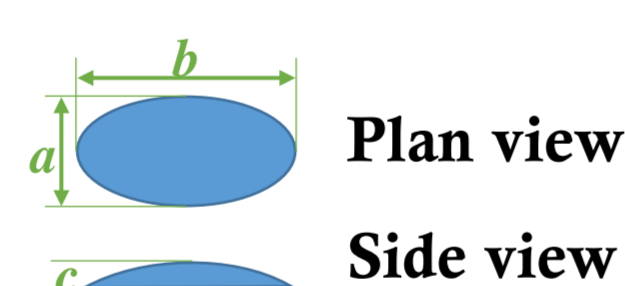
Fig7. Experimental set-up (left) and sketch of the computational domain (right).

Landslide parameters

- Length: $b = 0.8$ m
- Width: $a = 0.4$ m
- Thickness: $c = 0.05$ m
- Release distance: $\zeta = 0.3$ m
- Numerical set-up
- Square mesh grid: $\Delta x = \Delta y = 0.04$ m
- Time step: $\Delta t = 0.04$ s
- Solved frequencies: $0 \leq f \leq 1.4$ Hz



Discr.	Nodes (x)	Nodes (y)
a)	$b/10 = 3$	$a/10 = 2$
b)	$b/5 = 5$	$a/5 = 3$
c)	$b/4 = 6$	$a/4 = 4$
d)	$b/3 = 8$	$a/3 = 4$
e)	$2/5b = 9$	$2/5a = 5$
f)	$b/2 = 11$	$a/2 = 6$



RESULTS

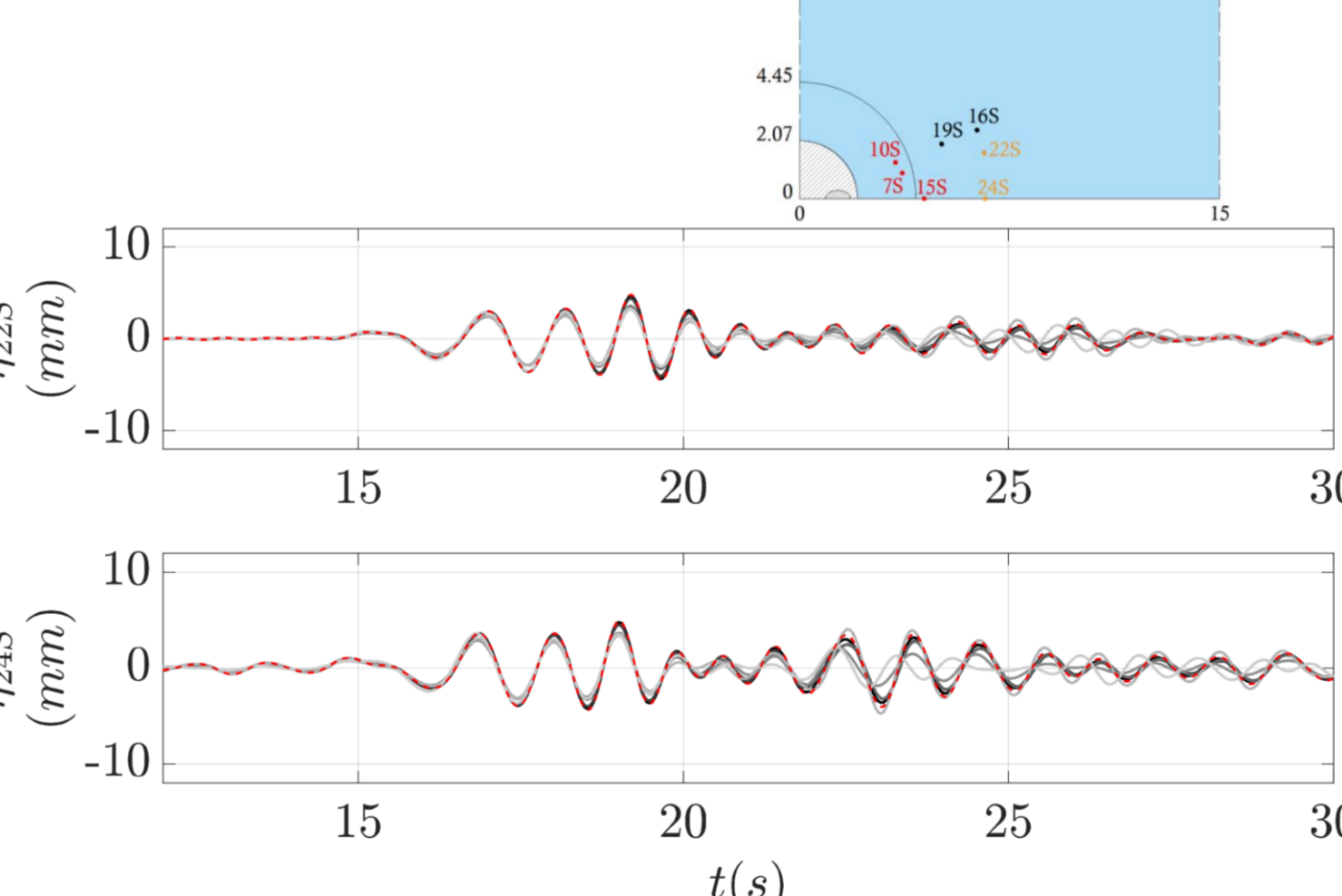


Fig9. Free surface elevations at the gauges 22S and 24S computed according to the proposed method compared to the target numerical solution (red dashed line).

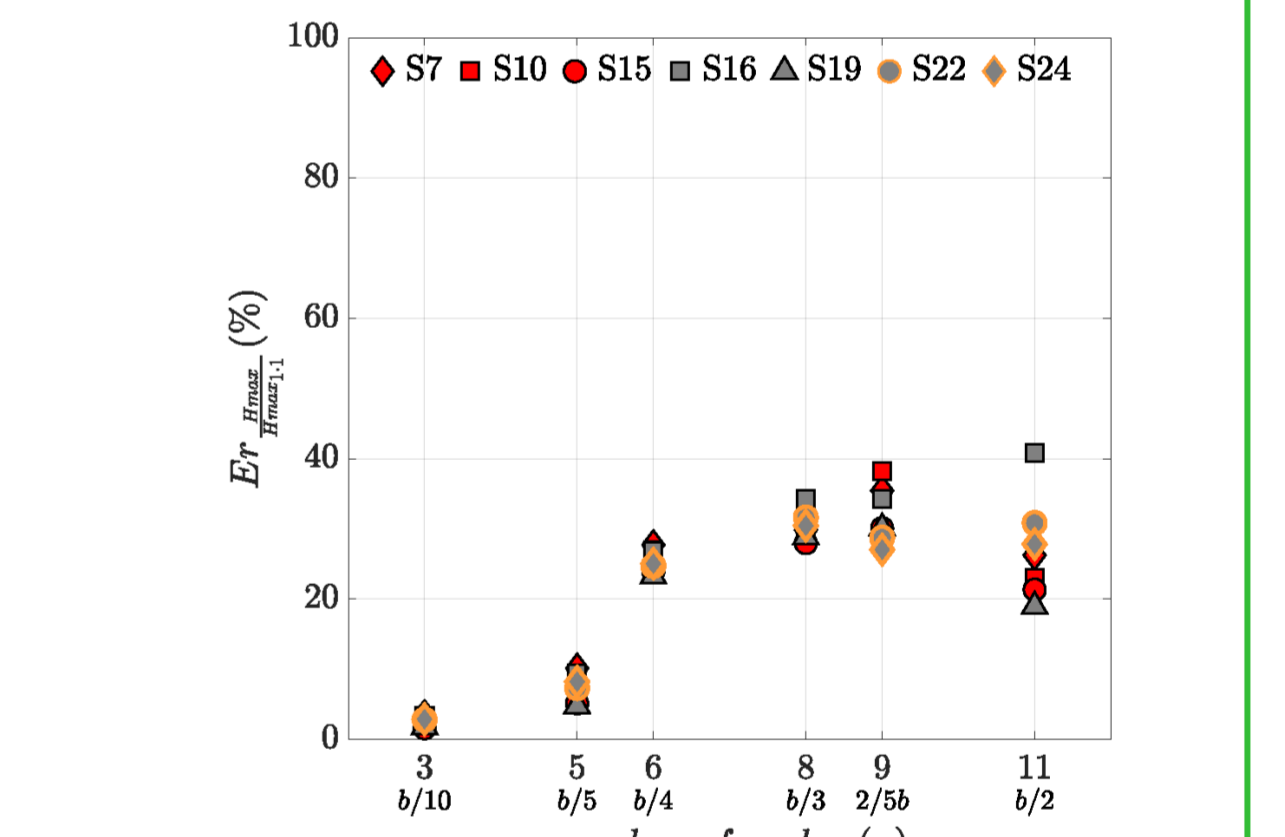


Fig10. Percentage relative error of the maximum wave height.

Efficiency of the method related to:

- Rectangles size
- The way the rectangles cover the generation area (because the source term magnitude is averaged in the rectangular areas)

Conical island – Monte Carlo simulation

NUMERICAL SET-UP

- Landslide parameters ranging from:
 - $b = 0.4 - 1.2$ m
 - $a = 0.2 - 0.6$ m
 - $c = 0.01 - 0.09$ m
 - $\zeta = 0.3 - 0.6$ m
- Numerical Green's functions database
 - Detection largest landslide area
 - Split into 51 rectangular areas
 - Numerical parameters: $\Delta x = \Delta y = 0.04$ m, $\Delta t = 0.04$ s, $0 \leq f \leq 1.4$ Hz

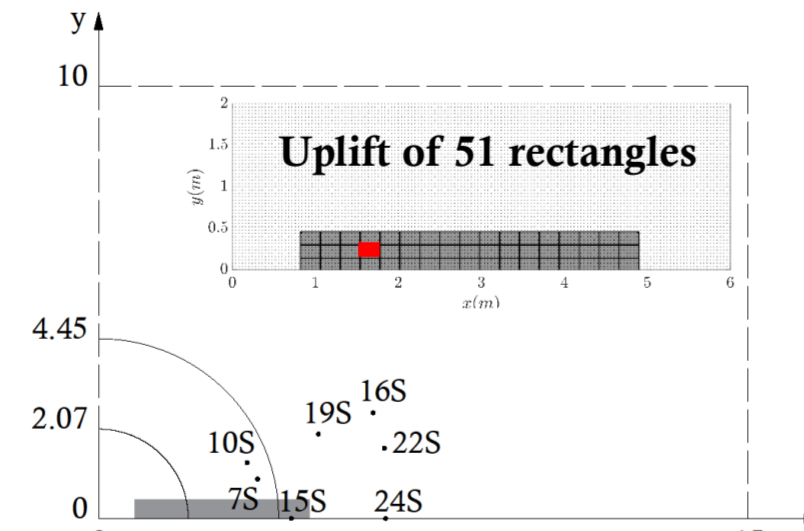
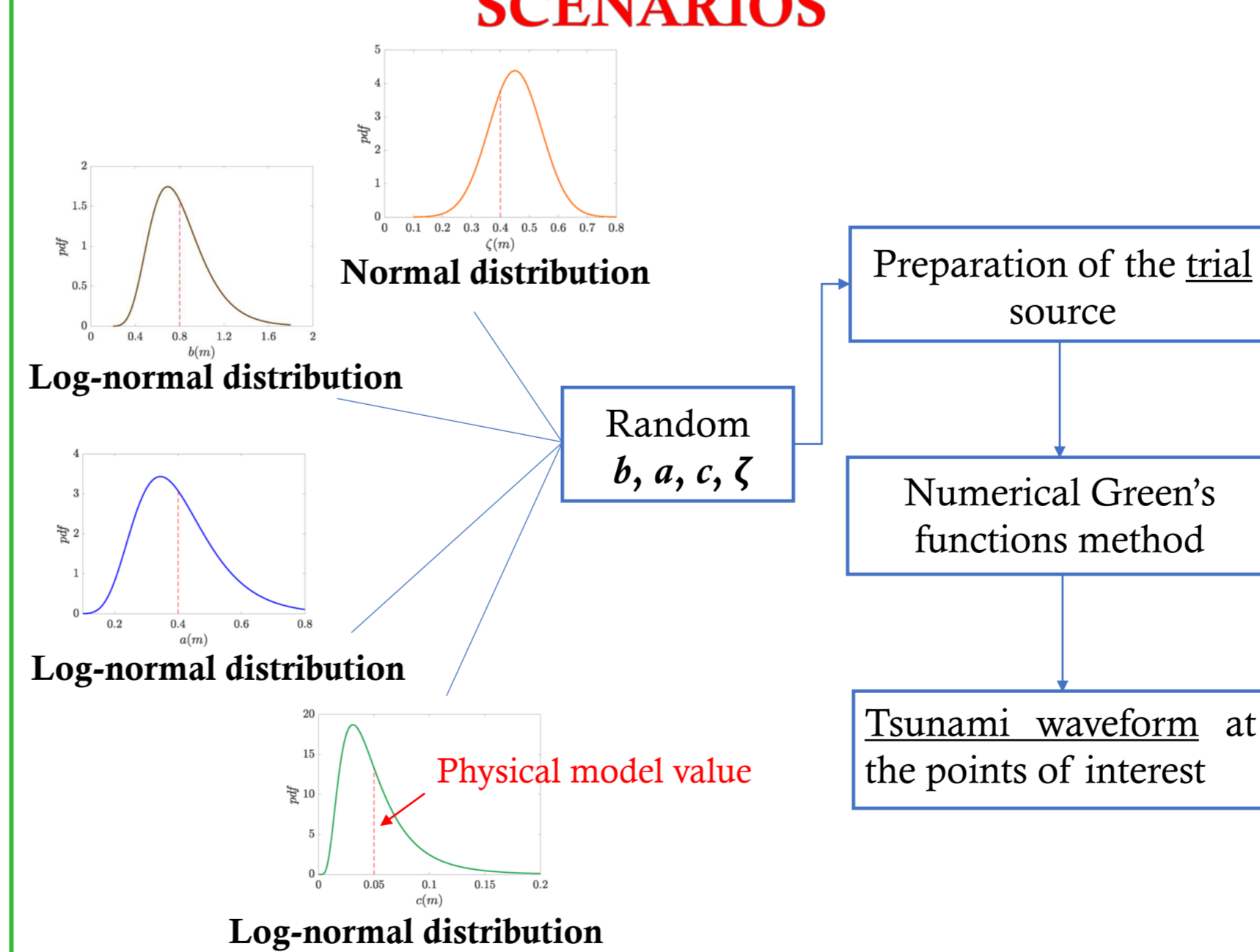


Fig11. Sketch of the computational domain, with the discretization of the hypothetical sliding area.

Discr.	Nodes (x)	Nodes (y)
a)	$b/10 = 3$	$a/10 = 2$
b)	$b/5 = 5$	$a/5 = 3$
c)	$b/4 = 6$	$a/4 = 4$
d)	$b/3 = 8$	$a/3 = 4$
e)	$2/5b = 9$	$2/5a = 5$
f)	$b/2 = 11$	$a/2 = 6$

Referred to the landslide parameters of the previous numerical test: $b = 0.8$ m, $a = 0.4$ m

CONSTRUCTION OF 1000 LANDSLIDE SCENARIOS



RESULTS

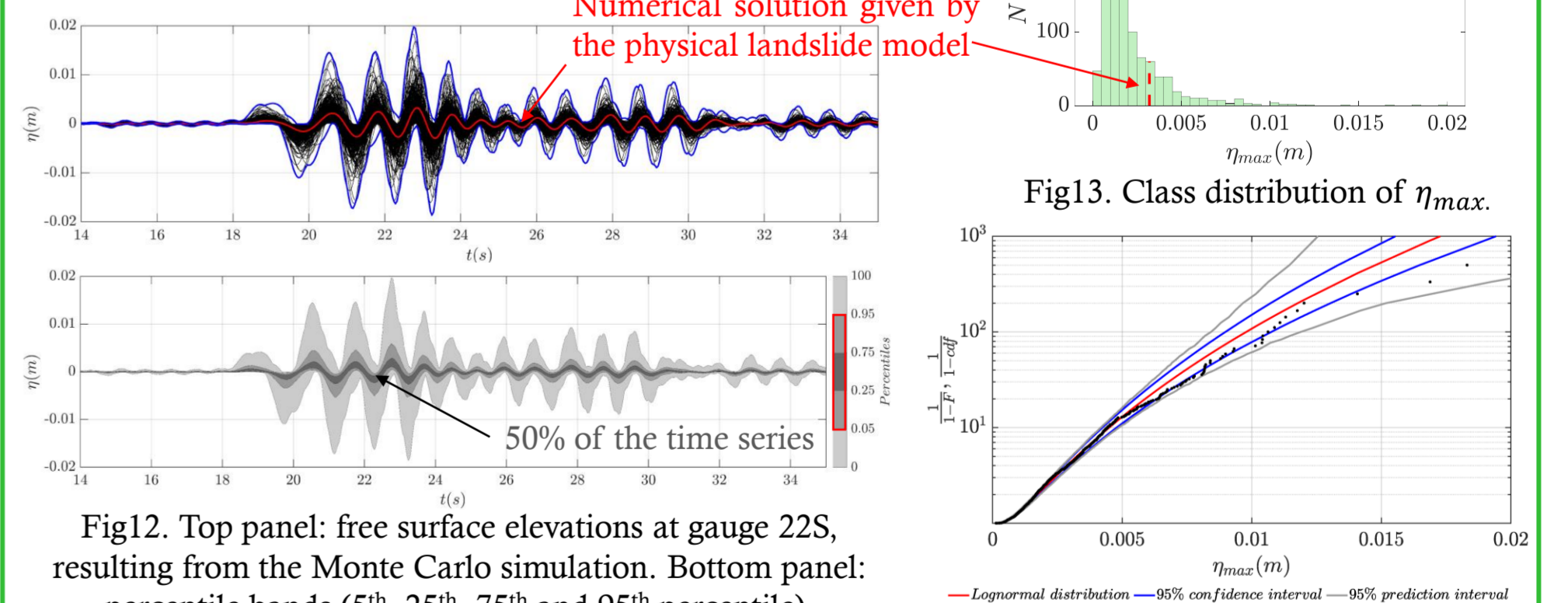


Fig12. Top panel: free surface elevations at gauge 22S, resulting from the Monte Carlo simulation. Bottom panel: percentile bands (5th, 25th, 75th and 95th percentile).

- Zero-crossing analysis → Sample of η_{max}
- Probability distribution fitting → The presence of a tail towards the higher sample values (positive skewness) suggests that the set could follow a log-normal probability distribution.
- Kolmogorov-Smirnov test

COMPUTATIONAL TIMES

- Single simulation approach → 46.50 h
- Numerical Green's function method (MSE solved only 51 times) → 5.68 h

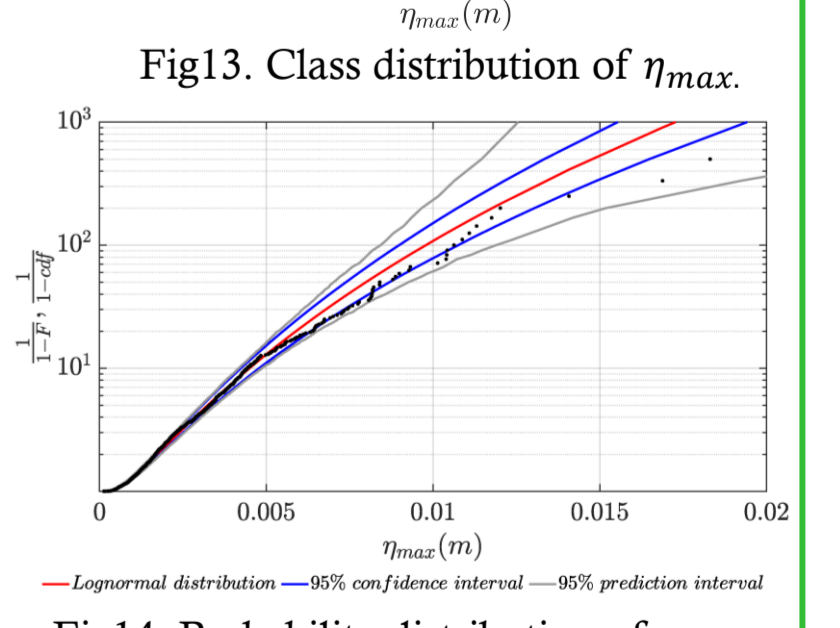


Fig13. Class distribution of η_{max} .

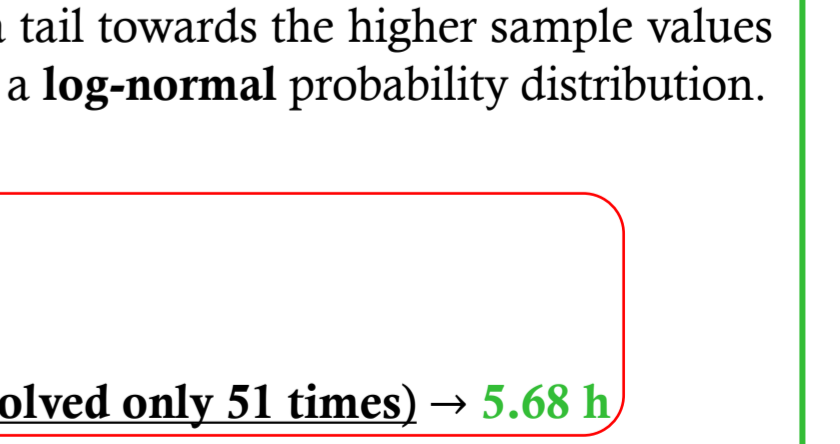


Fig14. Probability distribution of η_{max} .

References

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- Di Risio, De Giorlamo, Bellotti, Panizzo, Aristodemou, Molfetta, Petrillo (2009). Landslide-generated tsunamis runup at the coast of a conical island: New physical model experiments, Journal of Geophysical Research, vol. 114, pp. 1-16.
- Enet, Grilli (2007). Experimental study of tsunami generation by three-dimensional rigid underwater landslides, Journal of waterway, port, coastal and ocean engineering, ASCE, vol. 133(6), pp. 442-454.
- Grilli, Taylor, Baxter, Marezki (2009). A probabilistic approach for determining submarine landslide tsunami hazard along the upper east coast of the United States, Marine Geology, vol. 264(1-2), pp. 74-97.
- Mei (1995). Mathematical Analysis in Engineering: How to Use the Basic Tools. Cambridge University Press.
- Ward (2001). Landslide tsunami, Journal of Geophysical Research: Solid Earth, vol. 106(B6), pp. 11201-11215.

Attended courses

- Metodi numerici e statistici per l'Ingegneria Civile (2019), Prof. Giorgio Bellotti, Università degli Studi Roma Tre.
- Machine Learning online course (2019), Prof. Andrew Ng, Stanford University.
- Introduction to geostatistical analysis, with applications using Mathematica (2019), Prof. Aldo Fiori, Università degli Studi Roma Tre.
- Scientific, grant writing and presentation skills (2019), Università degli Studi Roma Tre.
- Metodi numerici per l'Ingegneria Costiera (2019), Prof. Giorgio Bellotti, Università degli Studi Roma Tre.
- Smoothed Particle Hydrodynamics numerical methods (2020), Università degli Studi di Parma.

Publications

- Iorio, Bellotti, Cecioni, Grilli (2020). A numerical model for the efficient simulation of multiple landslide-tsunami scenarios. ICCE 2020 (submitted).
- Franco, Pepi, De Finis, Iorio, Bellotti, Cecioni (2020). Roughness factor for multi-layer armour as overtopping estimator. ICCE 2020 (submitted).