4th International Workshop on Waves, Storm Surges, and Coastal Hazards
Incorporating the 18th International Waves Workshop
24th September 2025

Modelling of coastal wave dynamics during a storm on a macrotidal beach (Normandy, France)

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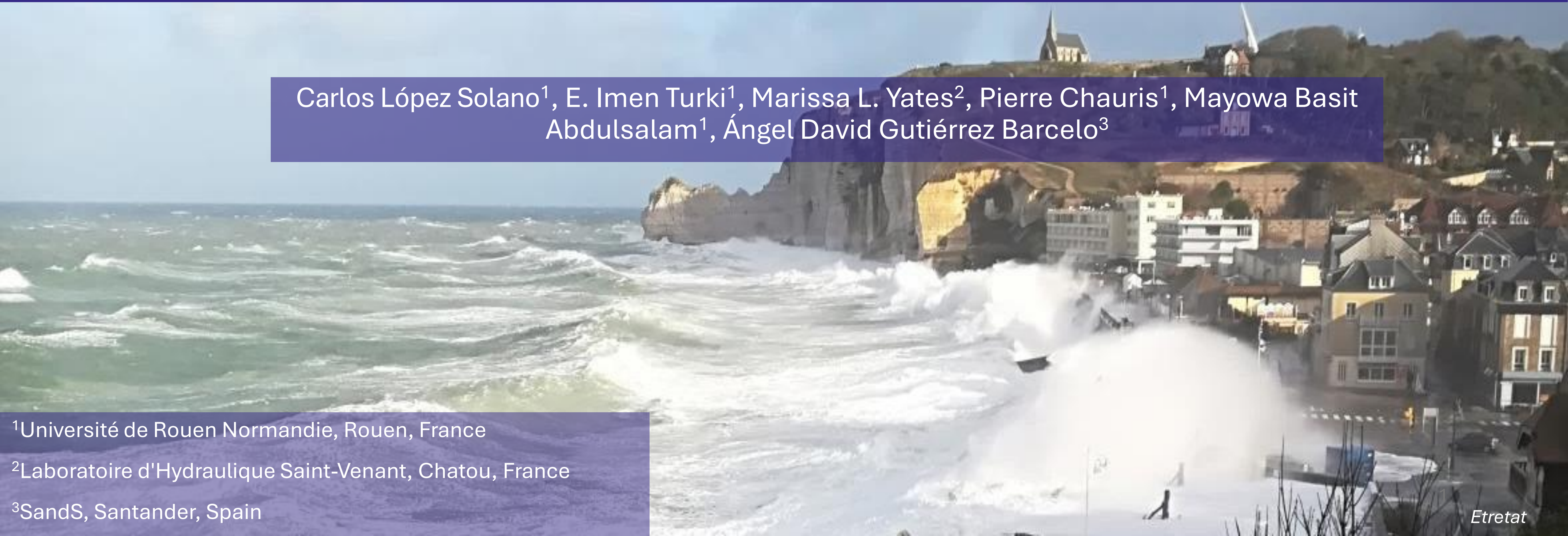
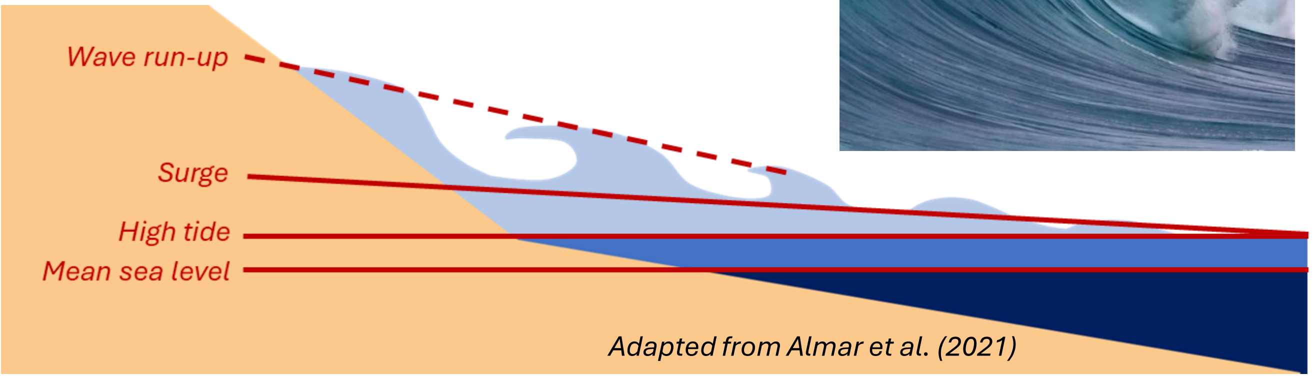


General context

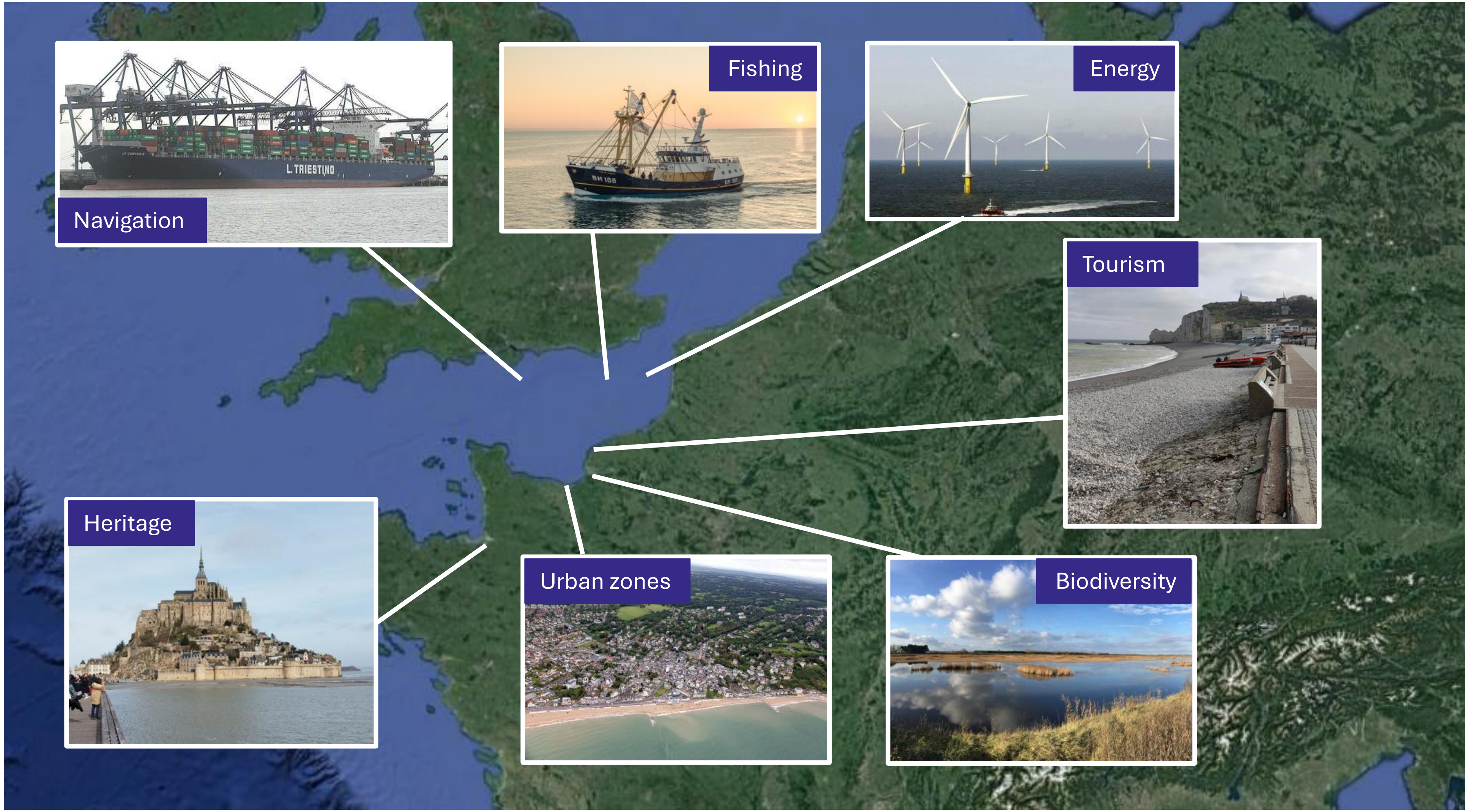
Coastal risks: flooding

Coastal wave dynamics

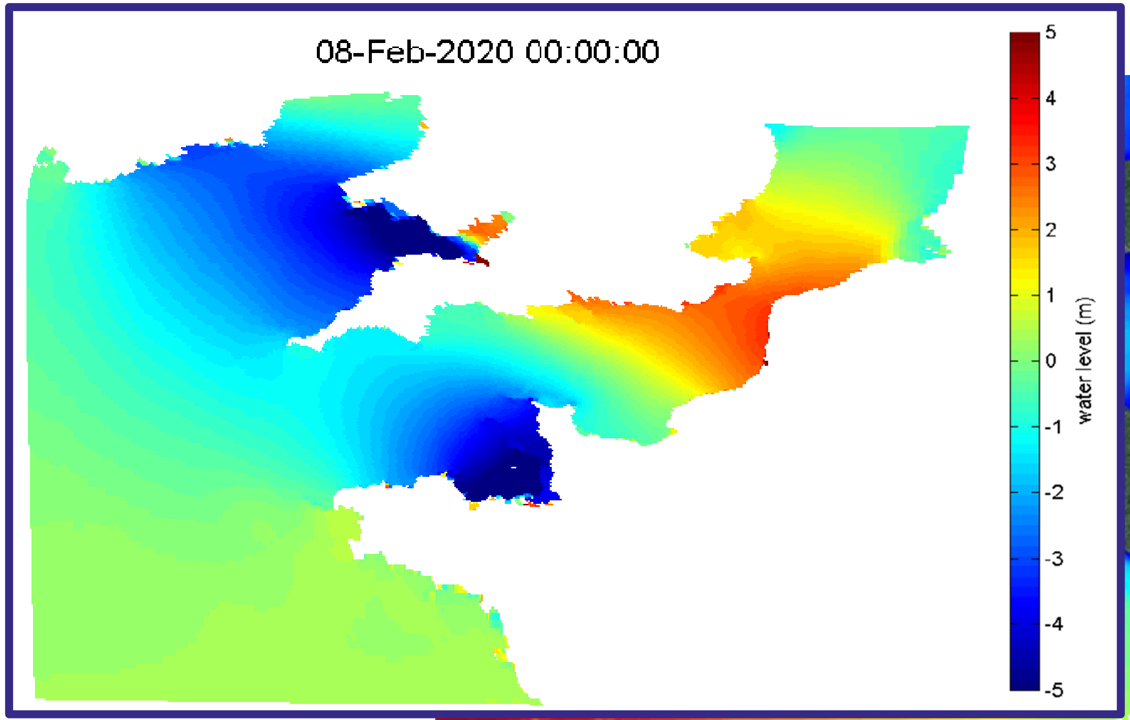
Wave run-up | Wave breaking

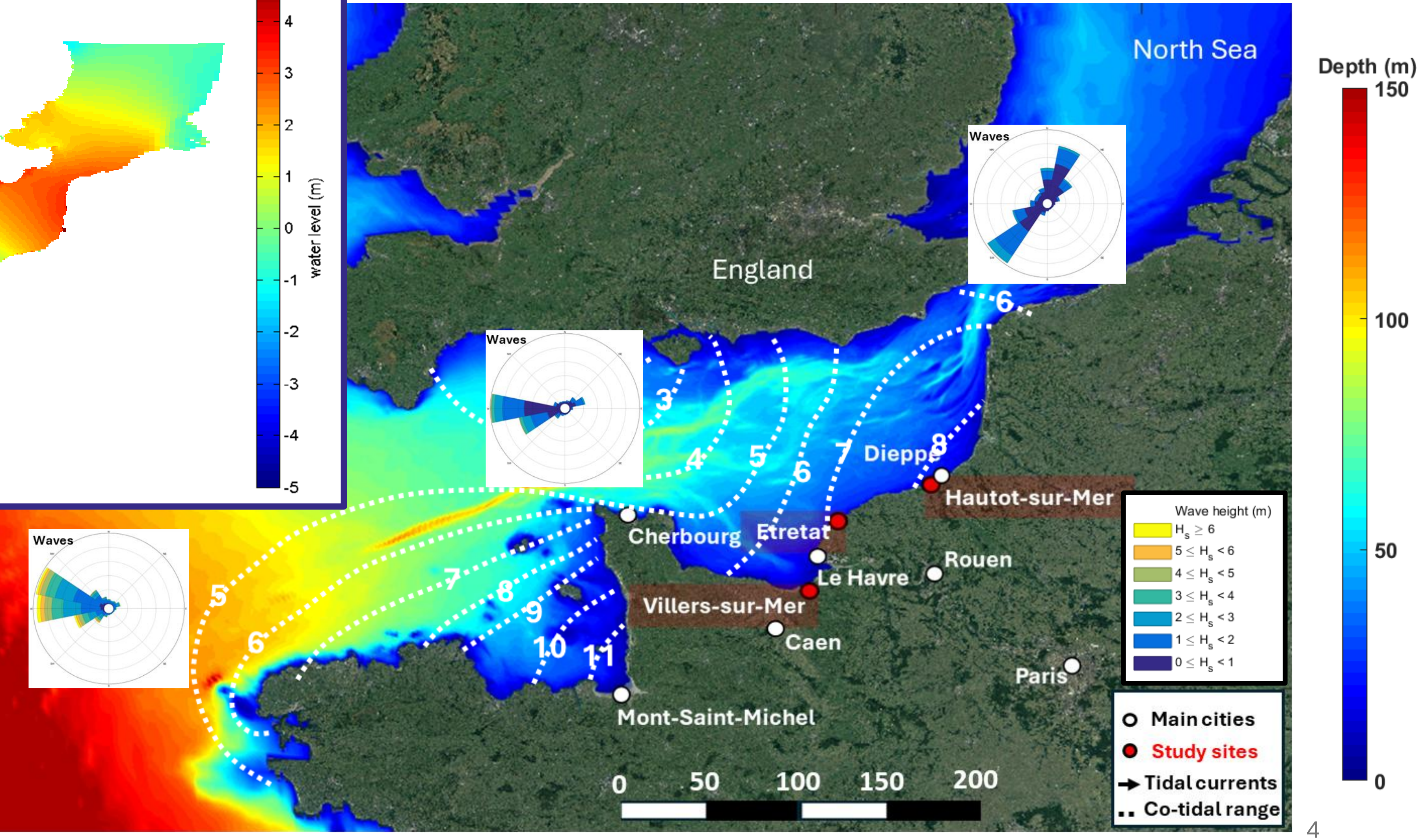


English Channel

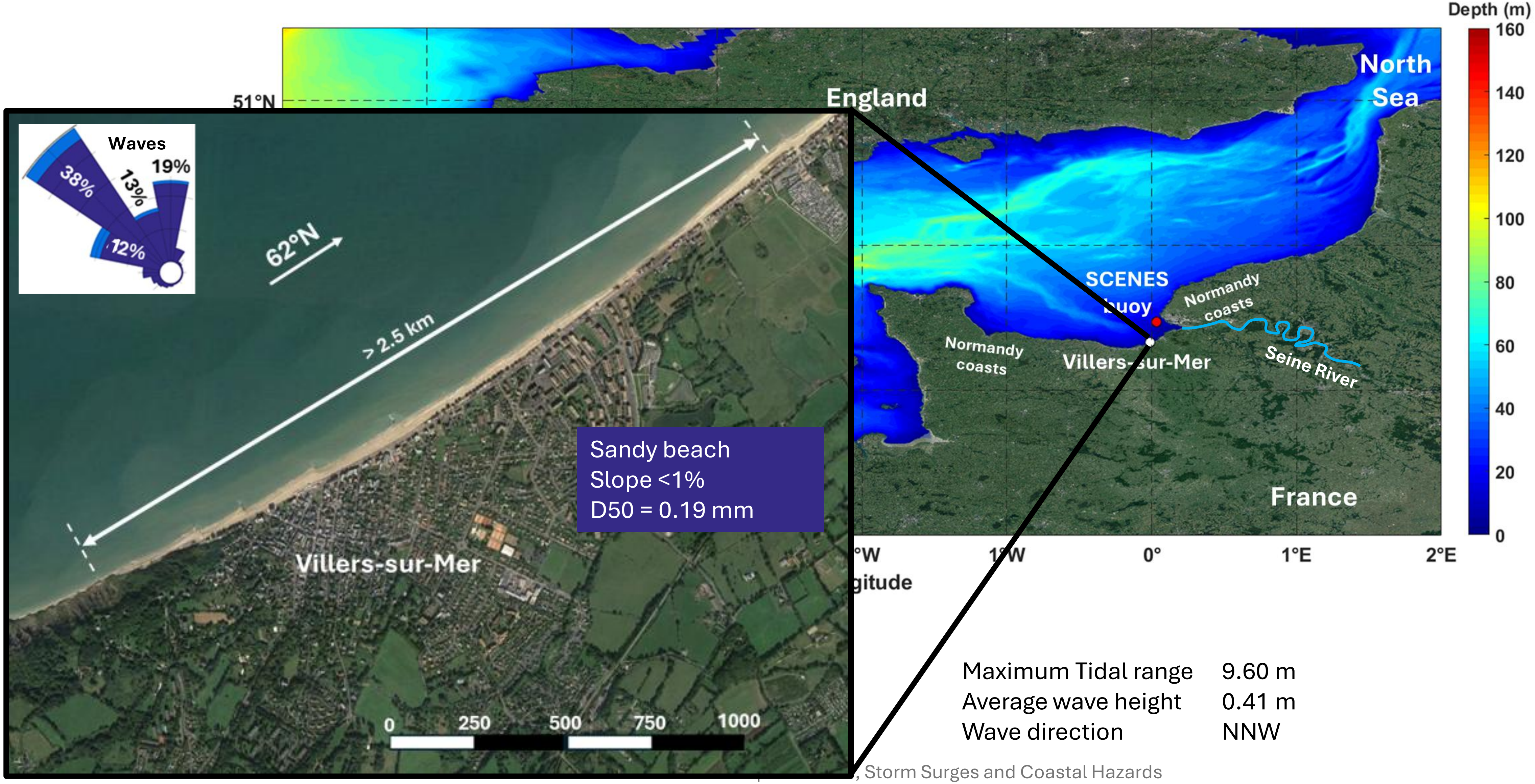


English Channel





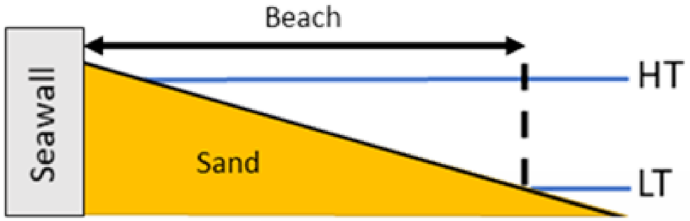
Villers-sur-Mer



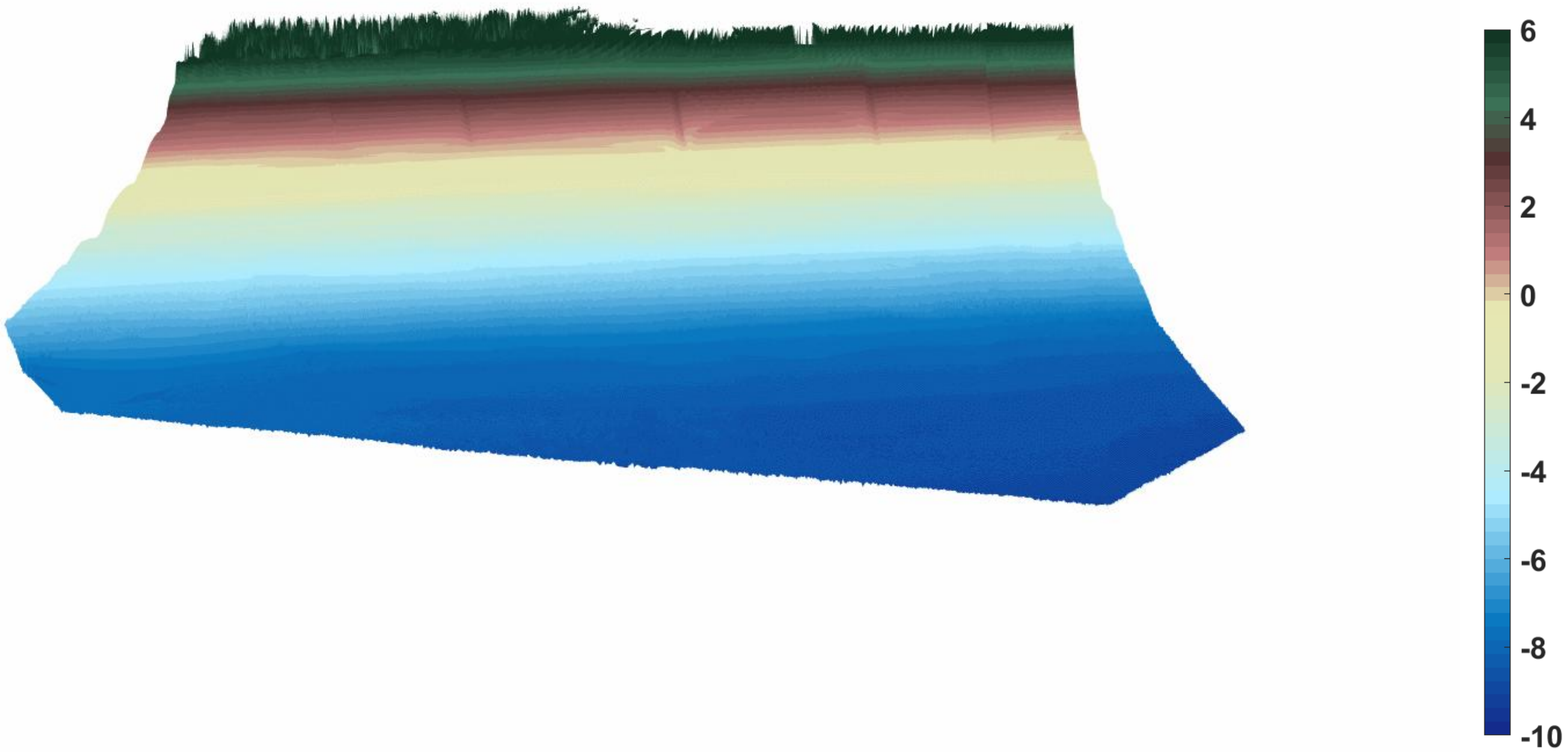
Sandy beach
Slope <1%
D50 = 0.19 mm

Maximum Tidal range	9.60 m
Average wave height	0.41 m
Wave direction	NNW

Villers-sur-Mer



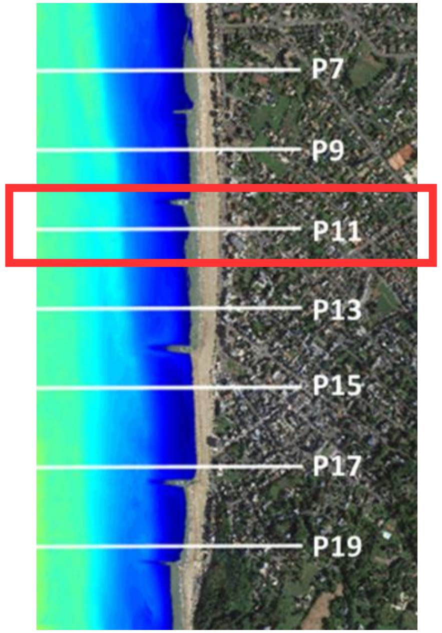
Smooth slope → dissipative beach



Bathymetry from LiDAR campaign (2019)

Numerical model: set-up

7 profiles selected along the beach each 100 m

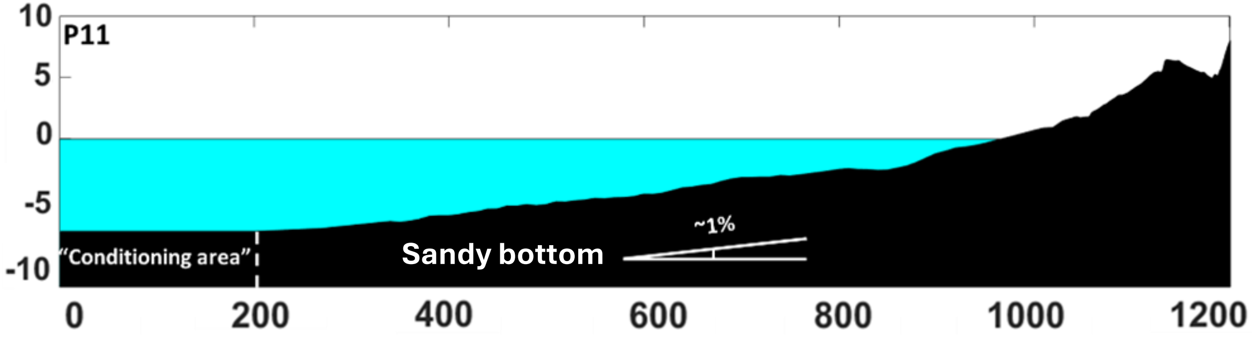


SWASH
Simulating WAves till SHore

SWASH (Ziljema et al., 2011):

- Interaction of nearshore hydrodynamics with coastal morphologies
- Governing equations (NLSW) equations include a non-hydrostatic pressure correction term
- Improves its frequency dispersion by increasing this number of layers

Set-up of the beach profiles

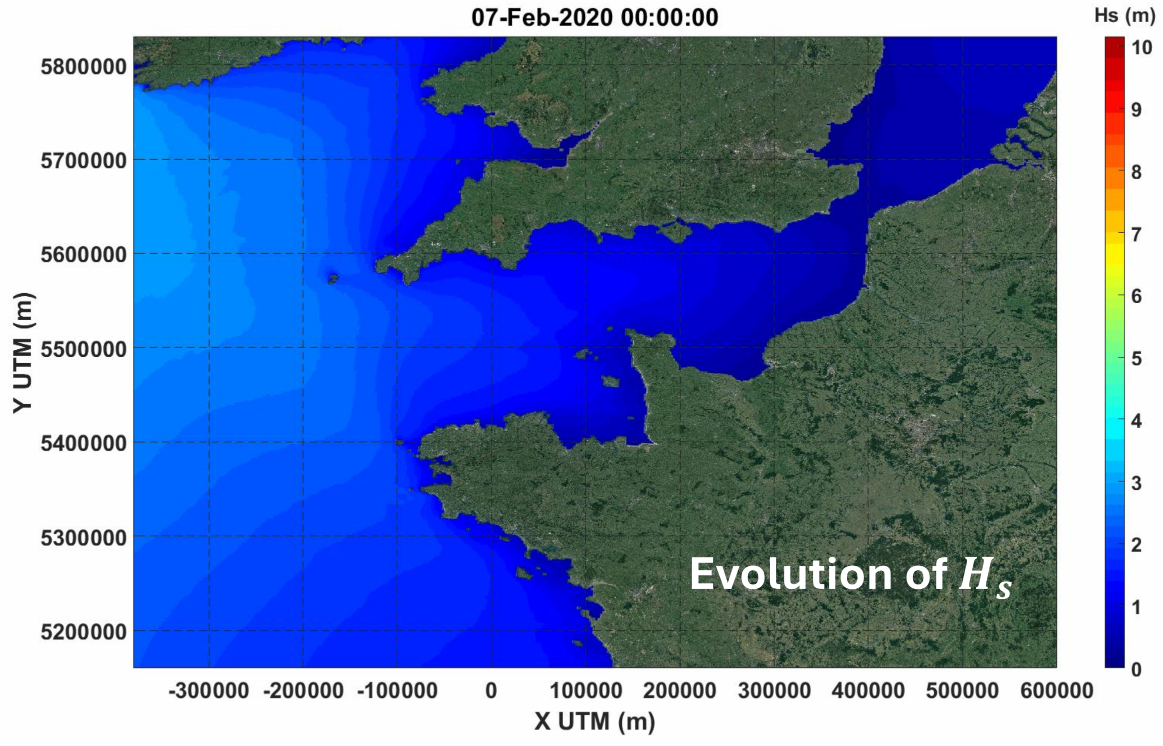


- Computational grid → 1200 cells of 1 m, with 1000 m of profile + 200 m of "conditioning area" for calibrating waves
- Timestep of 0.05 s
- 3h of simulation time for each sea state

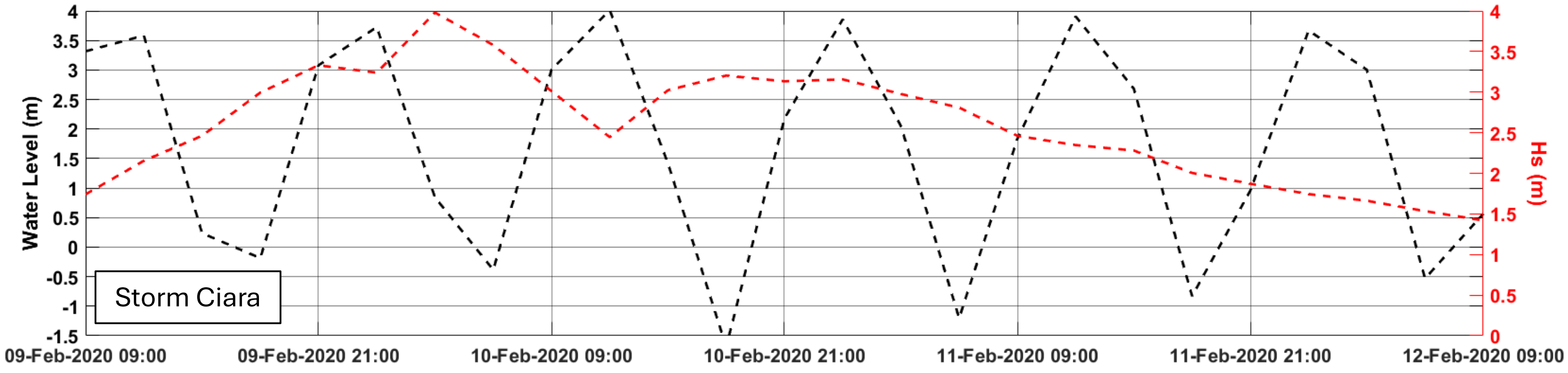
Numerical model: set-up

Storm Ciara
(09/02/2020 12h – 12/02/2020 12h) → 72h

One of the strongest event over the past few years



Forcings → 3-hour sea states of H_s (m), T_p (s), WL (m)



SWASH set-up:

- Non-hydrostatic
- 10 vertical sigma layers of 10% of the depth
- For run-up: wave breaking default

Solving breaking in SWASH

Wave breaking in SWASH

α : Breaking initiation criterion

β : Breaking stopping criterion

$$0 < \beta < \alpha < 1$$

Default values → α = 0.6, β = 0.3

- Across all grid cells: non-hydrostatic mode
- Breaking detection: appearance of steep wavefront

Detection criteria:

$$\frac{\partial \zeta}{\partial t} > \alpha \sqrt{gh}$$

$\frac{\partial \zeta}{\partial t}$: vertical velocity of the free surface

α: maximum local surface steepness

$\sqrt{gh}$: shallow water celerity

Criterion detected → cell enters hydrostatic mode → breaking starts

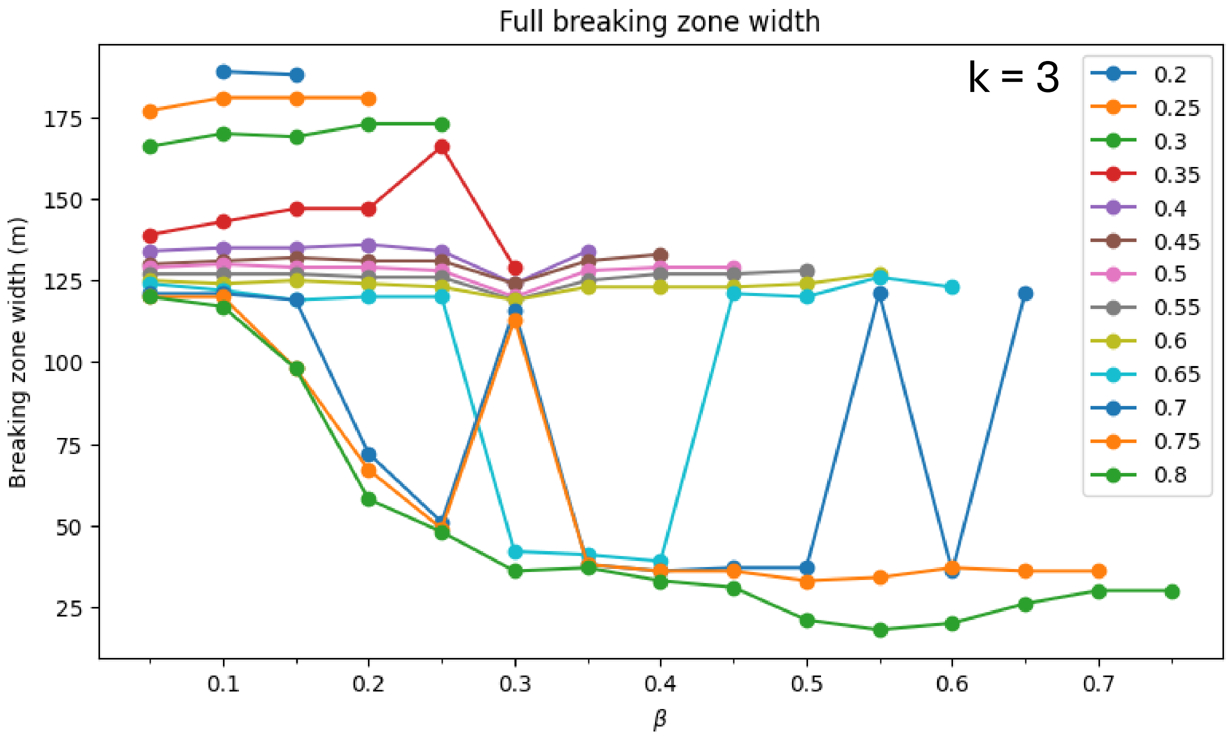
Persistence of breaking → Neighboring cells with local steepness high → cells enter hydrostatic mode

If $\frac{\partial \zeta}{\partial t} > \beta \sqrt{gh}$ (when $\frac{\partial \zeta}{\partial t} < \alpha \sqrt{gh}$)

Sensitivity of breaking

Sensitivity tests with → α, β and number of layers (k)

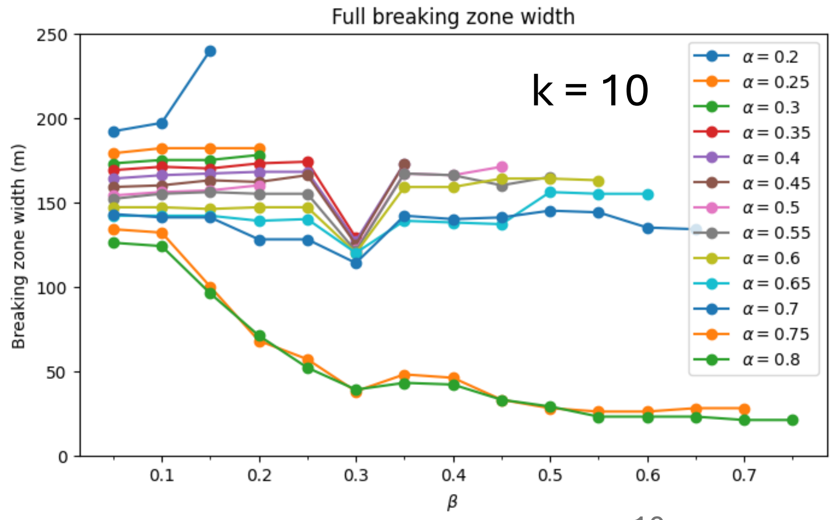
- α = [0.2 - 0.8]
- β = [0.1 - 0.7]
- k = 3, 8, 9, 10, 11, 12, 15 and 20



According to the manual:

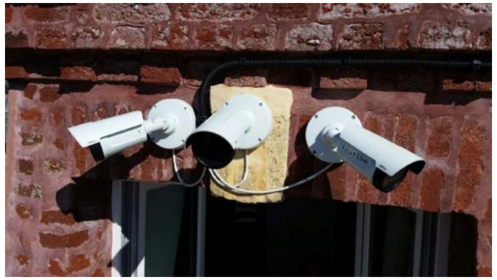
Note that by taking a sufficient number of vertical layers (10 or so) the phase velocity at the breaking front will be computed accurately enough and hence, this option should not be activated.

→ Correct for simulating run-up

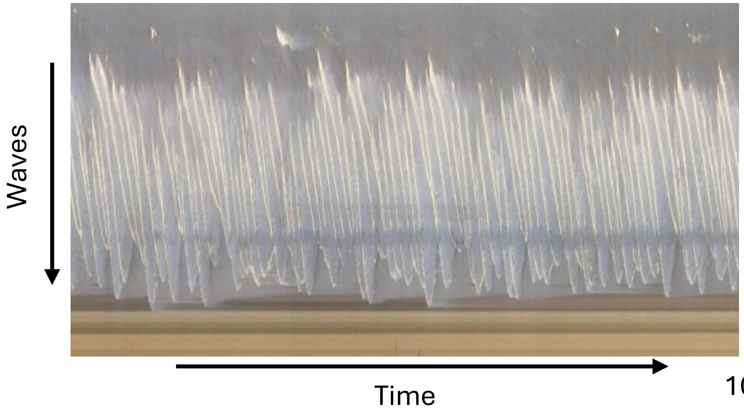


Timestacks for validation

Validation with Video Monitoring Systems (VMS)



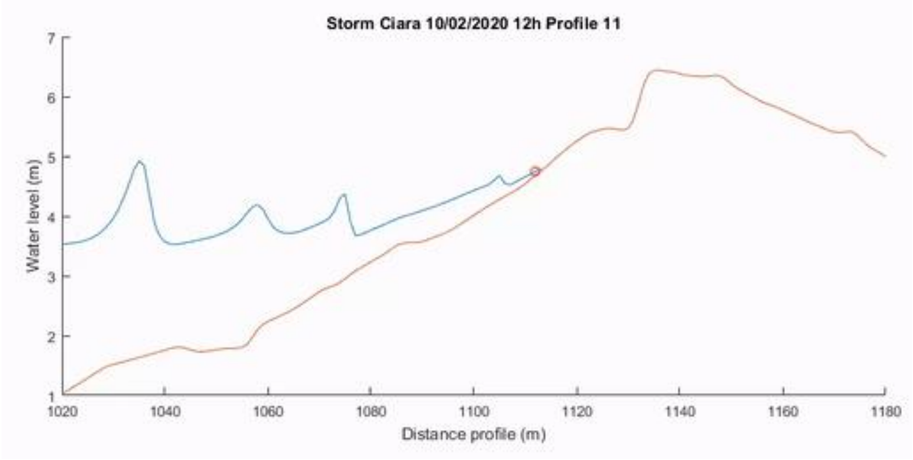
Generation of timestacks



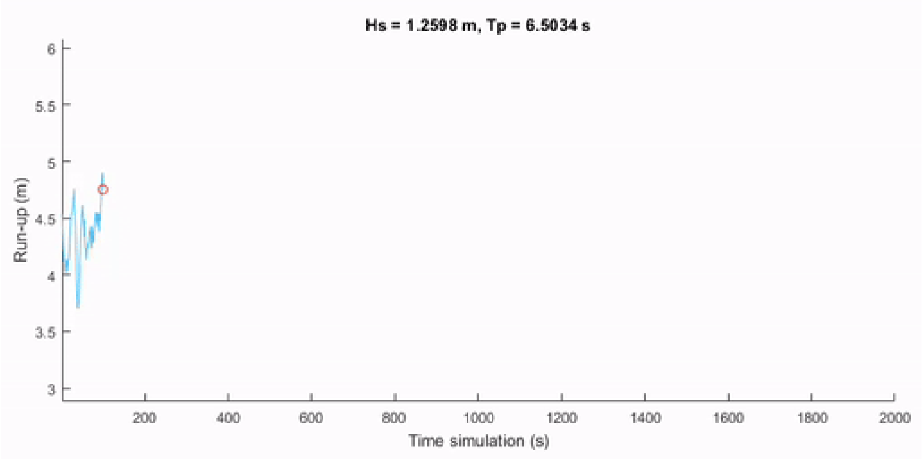
Timestack
10/02/2020 10:10

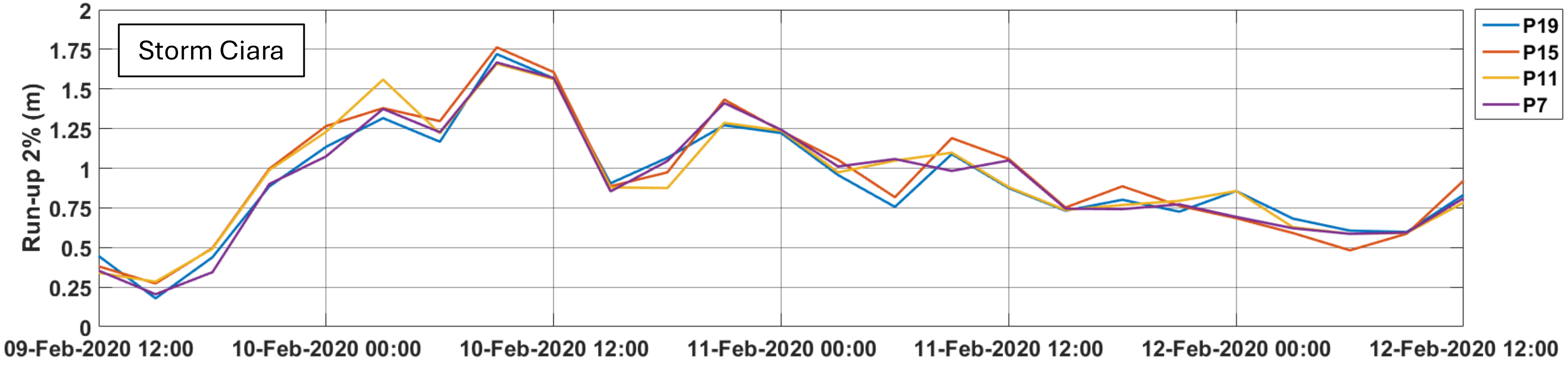
Results: wave run-up

Simulation of free surface



Run-up timeseries from the model



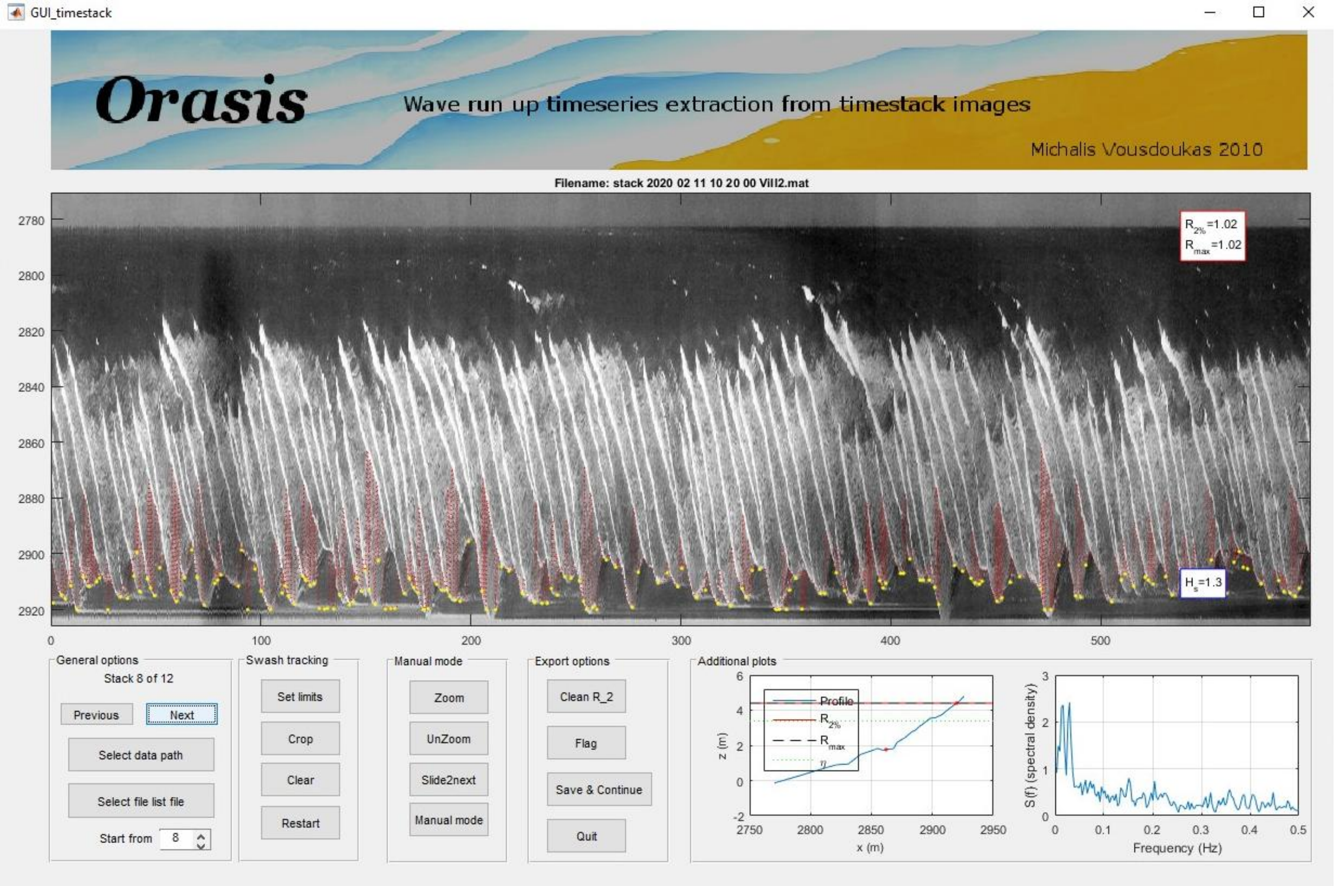


$R_{u2\%}$

Time		p11
09-févr	12h	0.34
09-févr	15h	0.284
09-févr	18h	0.492
09-févr	21h	0.988
10-févr	00h	1.23
10-févr	03h	1.559
10-févr	06h	1.221
10-févr	09h	1.659
10-févr	12h	1.562
10-févr	15h	0.879
10-févr	18h	0.875
10-févr	21h	1.286
11-févr	00h	1.237
11-févr	03h	0.974
11-févr	06h	1.048
11-févr	09h	1.098
11-févr	12h	0.881
11-févr	15h	0.736
11-févr	18h	0.768
11-févr	21h	0.794
12-févr	00h	0.856
12-févr	03h	0.628
12-févr	06h	0.586
12-févr	09h	0.592
12-févr	12h	0.783

Validation: run-up 2% ($R_{u2\%}$)

Validation with available timestacks (daylight, good visibility, not malfunctioning, …)



Forcings		Dates		$R_{u2\%}$
Water level (m)	Hs (m)	Time		p11
0.074346362	1.74889	10-févr	06h	1.221
3.8799665	1.49623	10-févr	09h	1.659
3.858417209	1.25978	10-févr	12h	1.562
0.164936157	1.45405	10-févr	15h	0.879
-0.825162853	1.50796	10-févr	18h	0.875
-1.30752263	1.33773	11-févr	06h	1.048
3.383381909	1.29469	11-févr	09h	1.098
3.767392107	1.22094	11-févr	12h	0.881
1.450040955	1.158	11-févr	15h	0.736
-2.418084773	1.01177	11-févr	18h	0.768

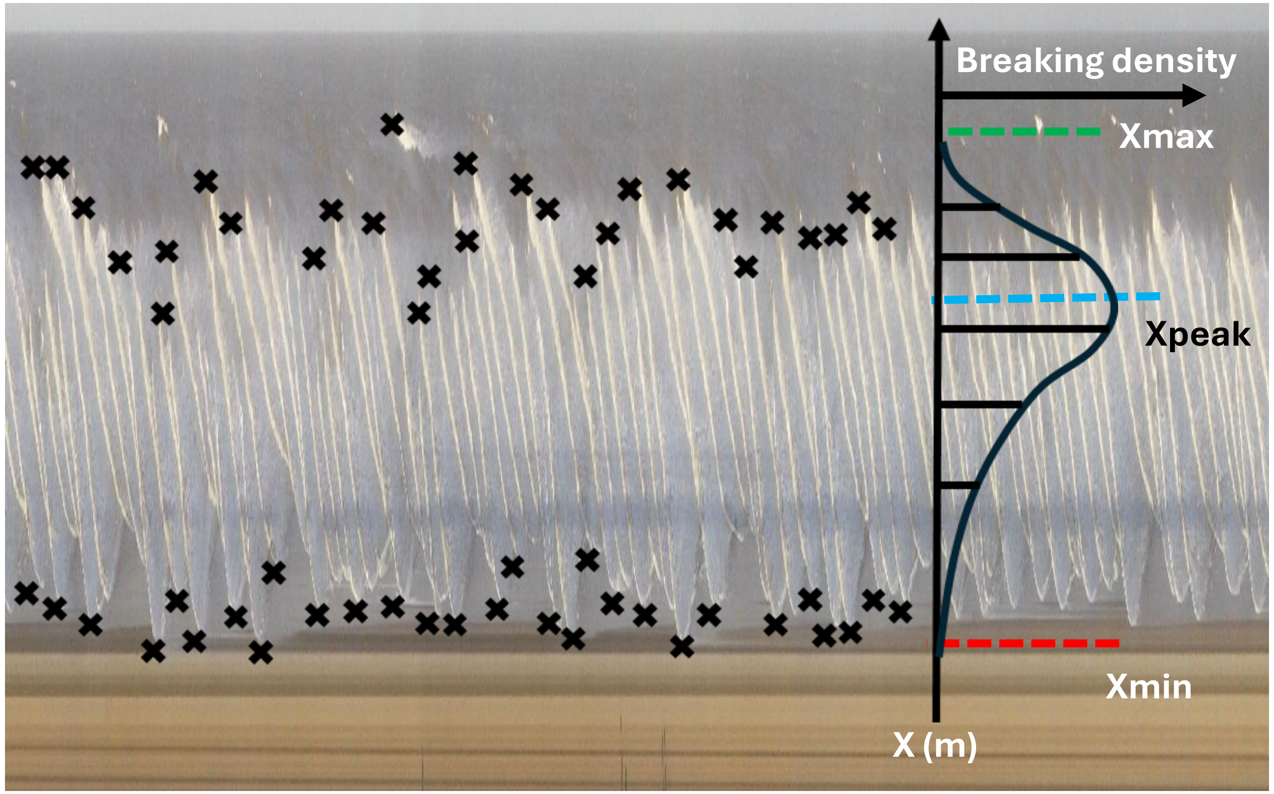
Date	Simulation		Timestack	
	Hour	$R_{u2\%}$ (m)	Hour	$R_{u2\%}$ (m)
10/02/2020	09h	1.659	10 :10	1.6613
10/02/2020	12h	1.562	10 :40	1.5881
10/02/2020	15h	0.879	13 :40	0.9097
11/02/2020	09h	1.098	10 :20	1.0178
11/02/2020	12h	0.881	12 :40	0.7807
11/02/2020	15h	0.736	14 :00	0.3584

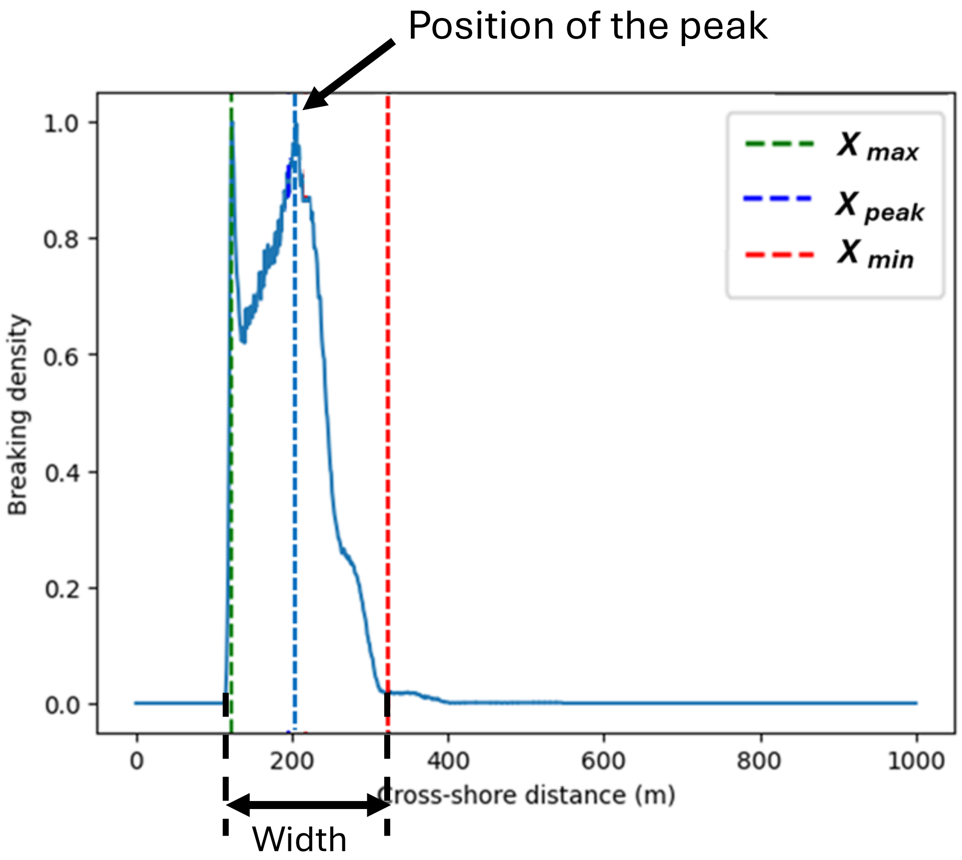
RMSE = 16 cm

Snapshot of the GUI of Vousdoukas et al. (2012)

Results: wave breaking

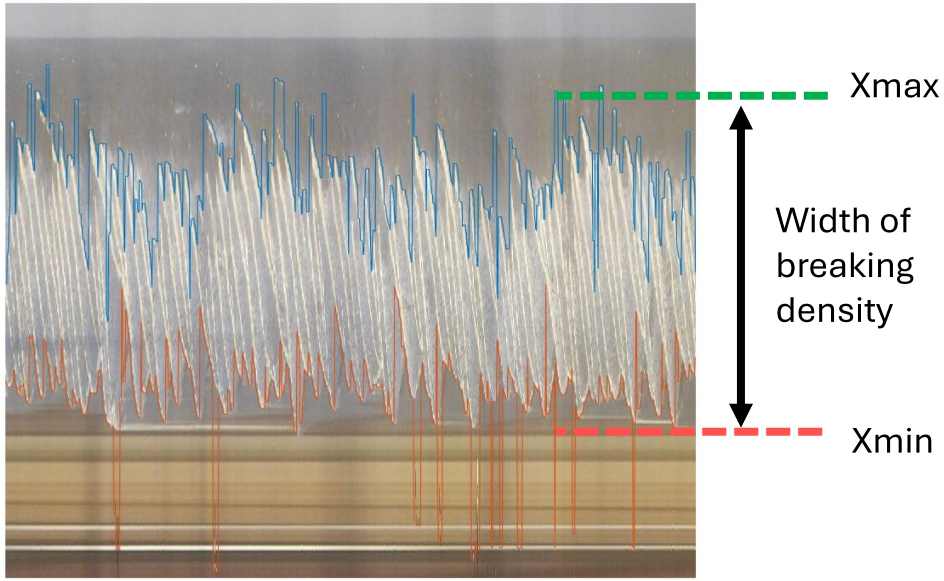
Breaking density along the profile



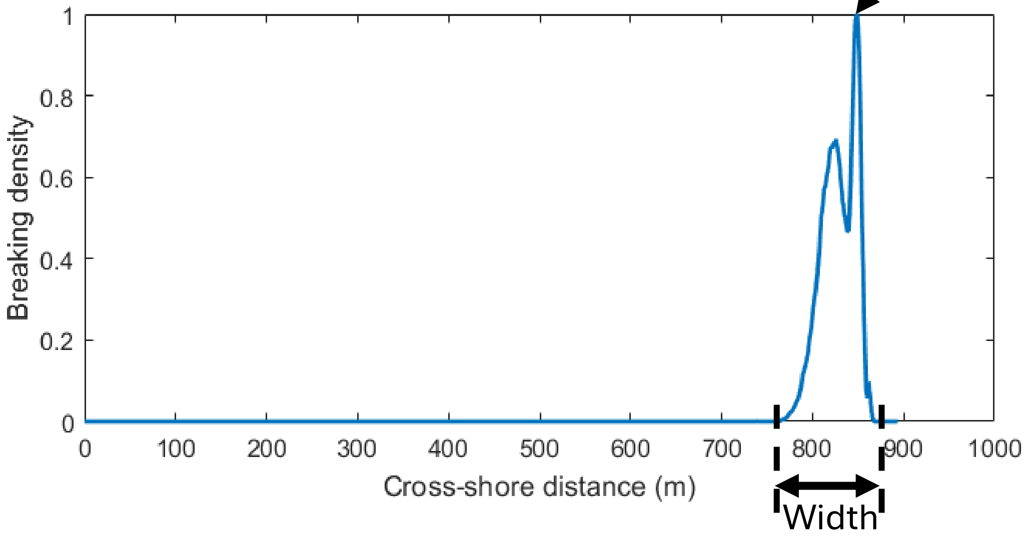


Simulation of the sea state 10/02 at 12h

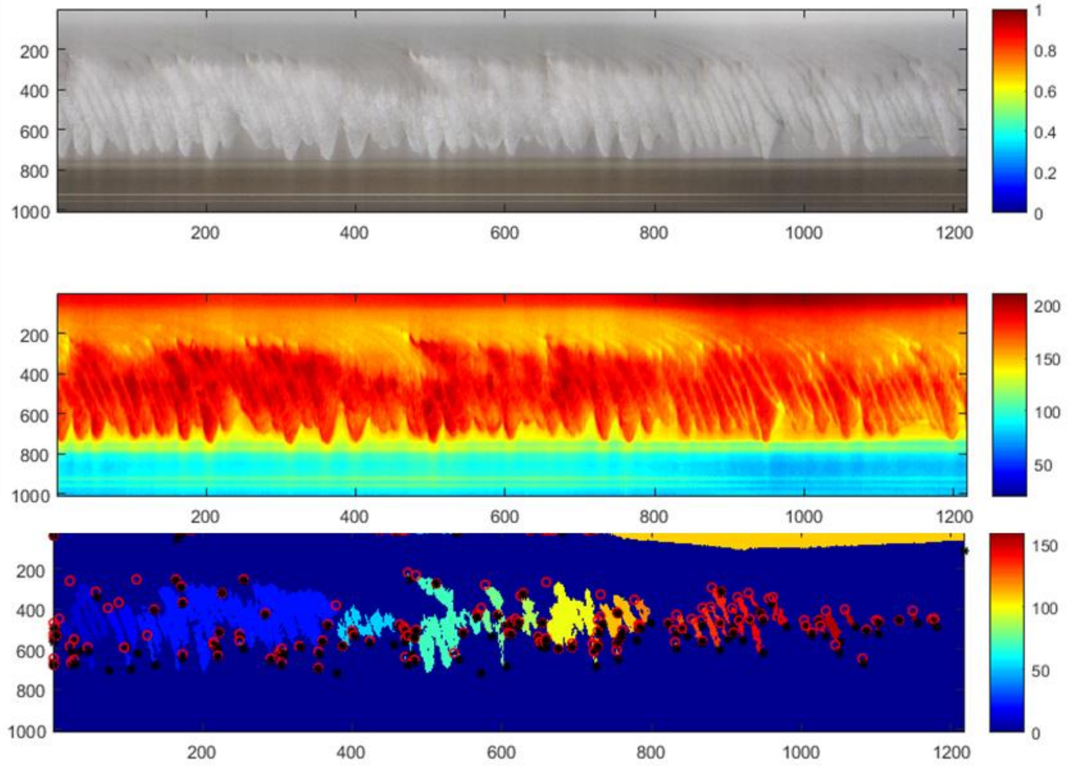
Validation: breaking zone



Position of the peak



From available timestacks → breaking density

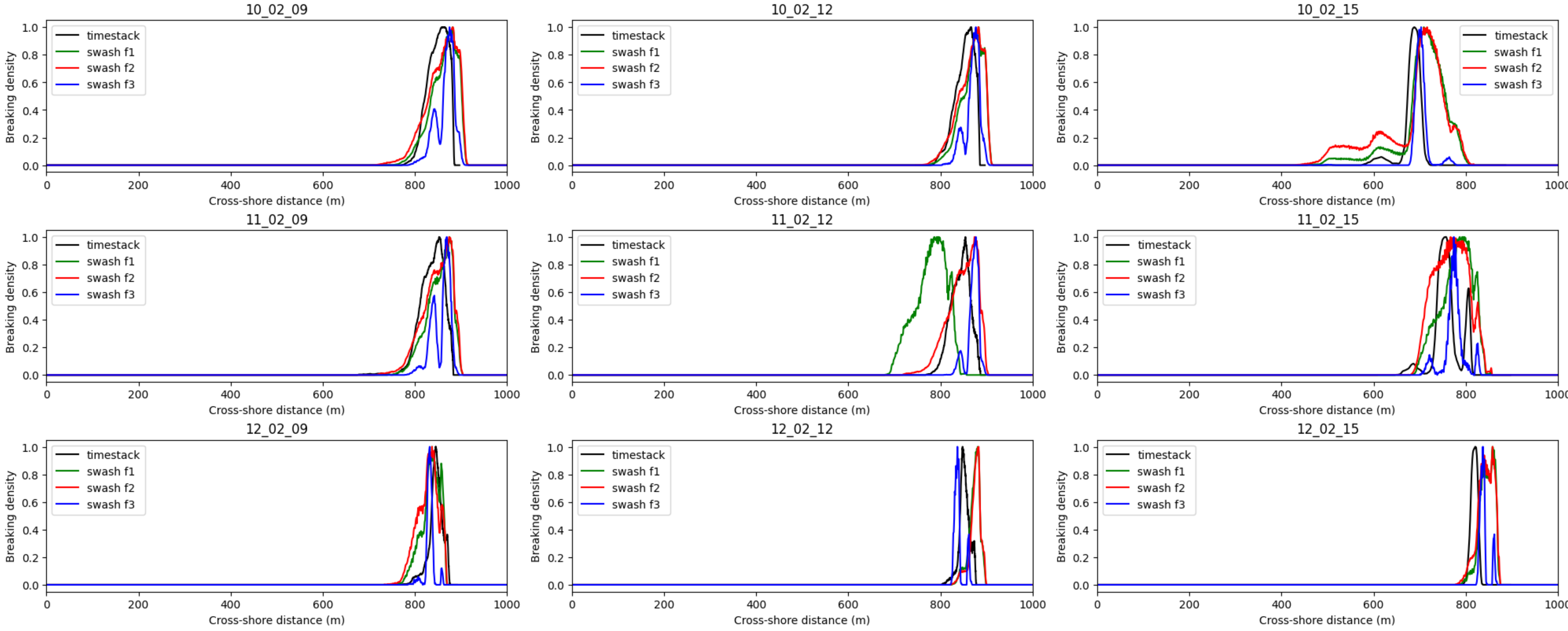


Validation: breaking zone

3 scenarios of simulation:

- f1 : k = 3, (α, β) = (0.3, 0.1)
- f2 : k = 10, (α, β) = (0.3, 0.1)
- f3: k = 3, (α, β) = (0.4, 0.3)

Time		Water level (m)	Hs (m)
10-févr	09h	3.8799665	1.49623
10-févr	12h	3.858417209	1.25978
10-févr	15h	0.164936157	1.45405
11-févr	09h	3.383381909	1.29469
11-févr	12h	3.767392107	1.22094
11-févr	15h	1.450040955	1.158
12-févr	09h	2.301449461	0.77696
12-févr	12h	3.554763822	0.81725
12-févr	15h	2.544465246	0.64144

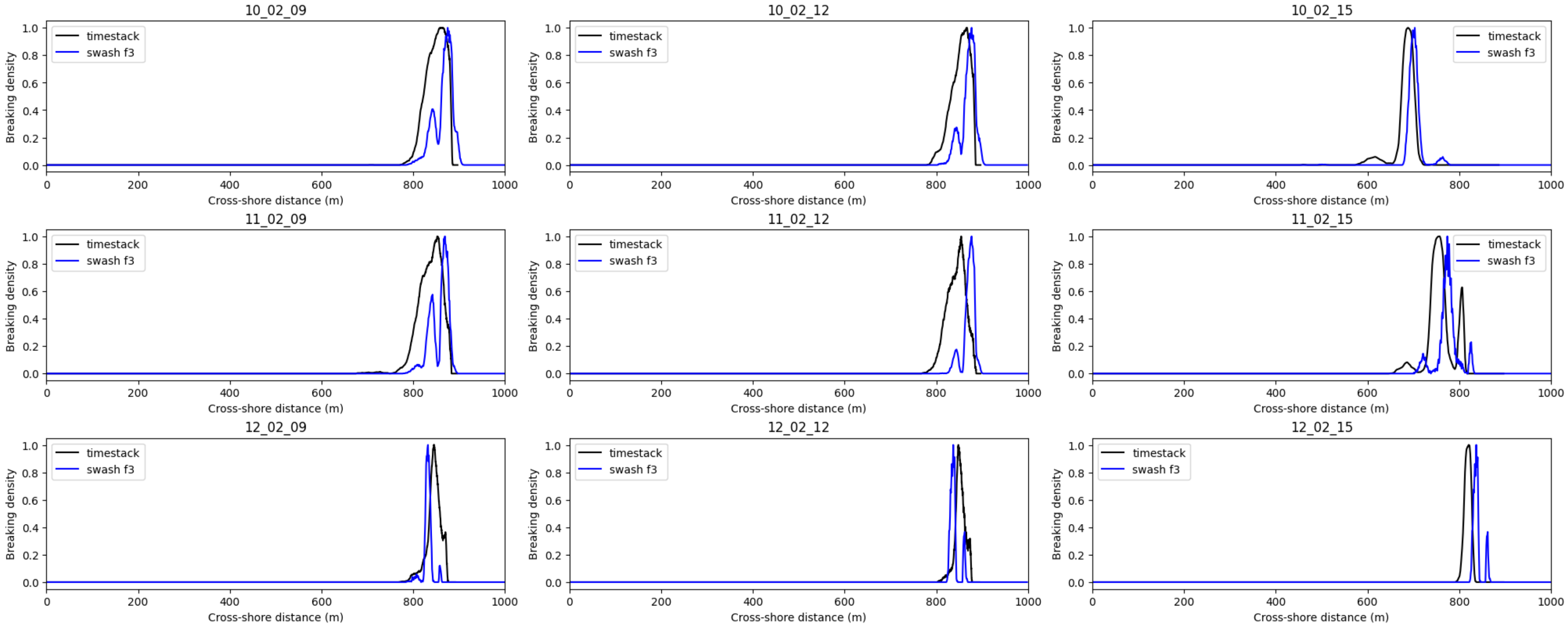


Validation: breaking zone

3 scenarios of simulation:

- f1 : k = 3, (α, β) = (0.3, 0.1)
- f2 : k = 10, (α, β) = (0.3, 0.1)
- f3: k = 3, (α, β) = (0.4, 0.3)

Date	Hour	Simulation			Timestack	Simulation			Timestack
		f1	f2	f3	Width (m)	f1	f2	f3	Position peak (m)
10/02/2020	09h	146	182	109	157.4	883	883	876	826.3
10/02/2020	12h	129	137	95	119.9	884	883	878	839.3
10/02/2020	15h	320	358	96	118.4	710	717	704	668.1
11/02/2020	09h	142	177	105	231.1	876	875	870	822.4
11/02/2020	12h	166	177	71	139	795	875	878	820.4
11/02/2020	15h	166	172	127	189.3	795	768	775	675.3
12/02/2020	09h	106	113	65	104.3	838	838	833	824.4
12/02/2020	12h	66	69	43	86.7	882	884	838	821.4
12/02/2020	15h	82	91	43	47	859	859	838	771.7



f3 provides the best overall results

To integrate run-up:

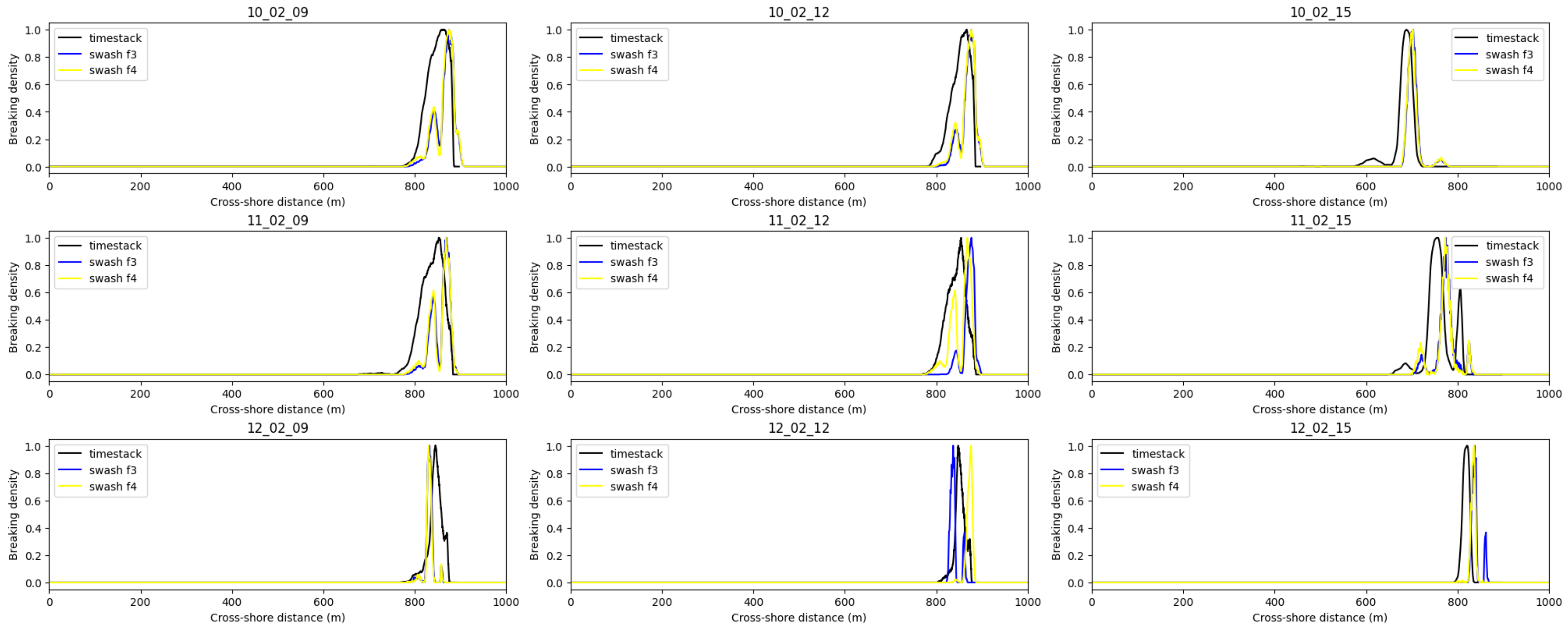
f4: k = 10
(α, β) = (0.4, 0.3)

Validation: breaking zone

f3 vs f4:

- f3: k = 3, (α, β) = (0.4, 0.3)
- f4: k = 10, (α, β) = (0.4, 0.3)

Date	Hour	Simulation		Timestack	Simulation		
		f3	f4	Width (m)	f3	f4	Position peak (m)
10/02/2020	09h	109	120	157.4	876	877	826.3
10/02/2020	12h	95	100	119.9	878	878	839.3
10/02/2020	15h	96	101	118.4	704	703	668.1
11/02/2020	09h	105	111	231.1	870	869	822.4
11/02/2020	12h	71	111	139	878	869	820.4
11/02/2020	15h	127	134	189.3	775	774	675.3
12/02/2020	09h	65	68	104.3	833	831	824.4
12/02/2020	12h	43	46	86.7	838	877	821.4
12/02/2020	15h	43	45	47	838	837	771.7



f4 improves slightly the results of f3

Final set-up

Agreement of run-up and breaking

f4: k = 10, (α, β) = (0.4, 0.3)

Validation of wave run-up

Date	Simulation		Timestack	
	Hour	$R_{u2\%}$ (m)	Hour	$R_{u2\%}$ (m)
10/02/2020	09h	1.791	10 :10	1.6613
10/02/2020	12h	1.703	10 :40	1.5881
10/02/2020	15h	0.998	13 :40	0.9097
11/02/2020	09h	1.163	10 :20	1.0178
11/02/2020	12h	0.942	12 :40	0.7807
11/02/2020	15h	0.854	14 :00	0.3584

⇨ RMSE = 23 cm

Validation of wave breaking

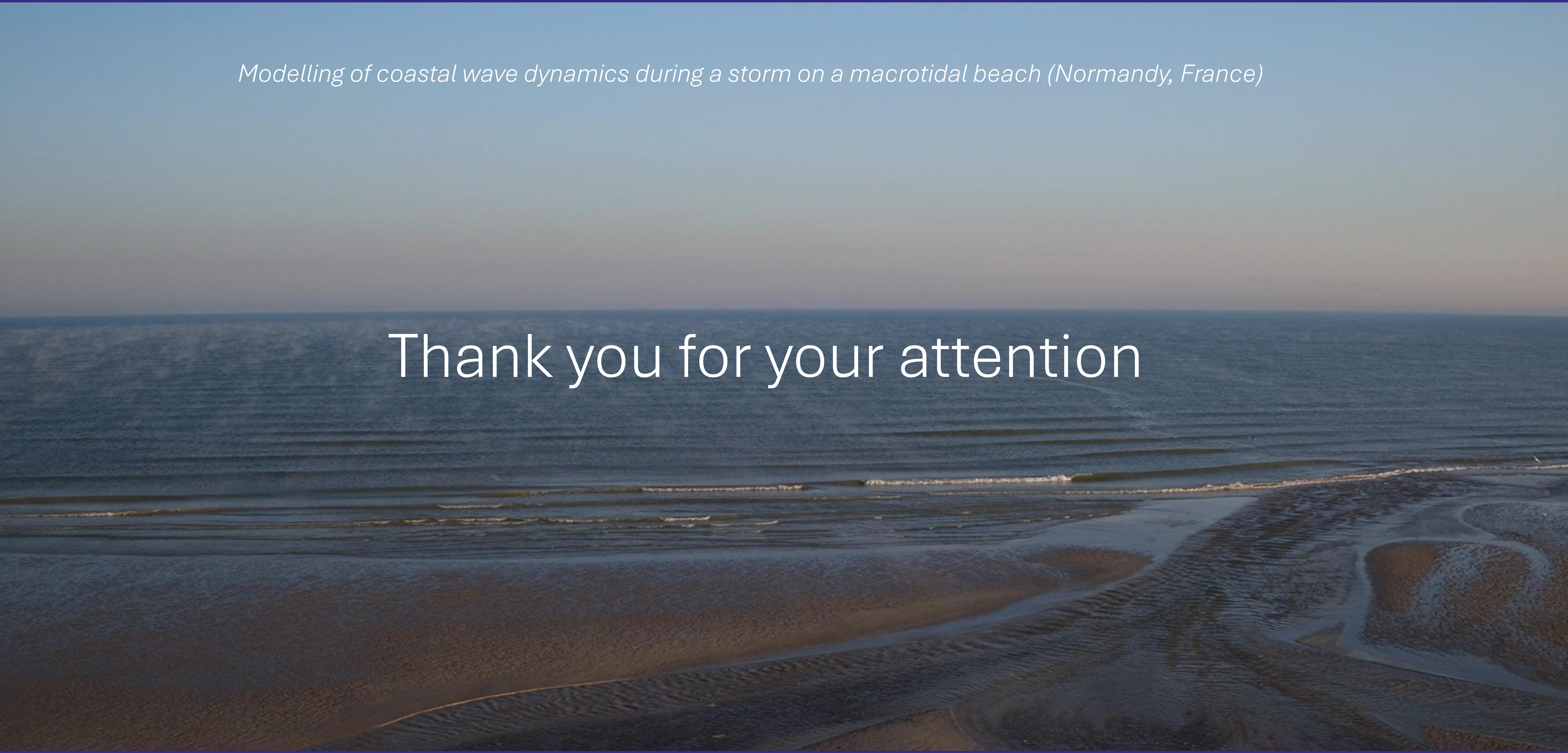
Date	Simulation		Timestack
	Hour	f4	Width (m)
10/02/2020	09h	134	157.4
10/02/2020	12h	114	119.9
10/02/2020	15h	192	118.4
11/02/2020	09h	121	231.1
11/02/2020	12h	121	139
11/02/2020	15h	139	189.3
12/02/2020	09h	81	104.3
12/02/2020	12h	55	86.7
12/02/2020	15h	57	47

⇨ RMSE = 50 m

Conclusions and perspectives

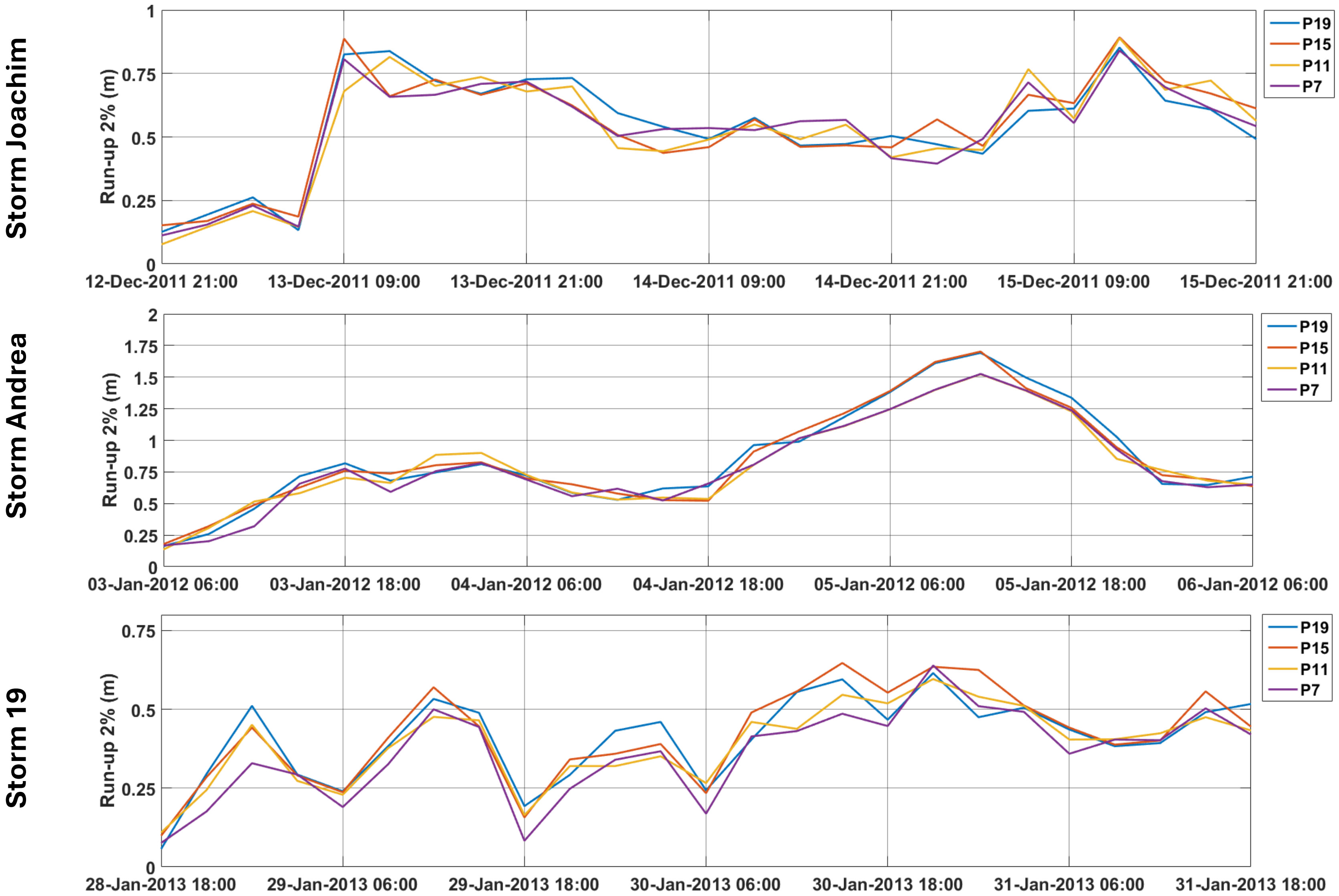
- SWASH is able to accurately represent coastal wave dynamics in dissipative beaches like wave run-up and wave breaking
- Timestacks from VMS are a useful tool to validate on-shore numerical simulations
- Next step: integrating an intertidal bathymetry obtained from altimetry (**SWOT**)
- On going work: OpenFOAM simulations of selected sea states to test accuracy of SWASH
- On going work: 2D SWASH simulations to compare transversal and longitudinal dynamics

Modelling of coastal wave dynamics during a storm on a macrotidal beach (Normandy, France)

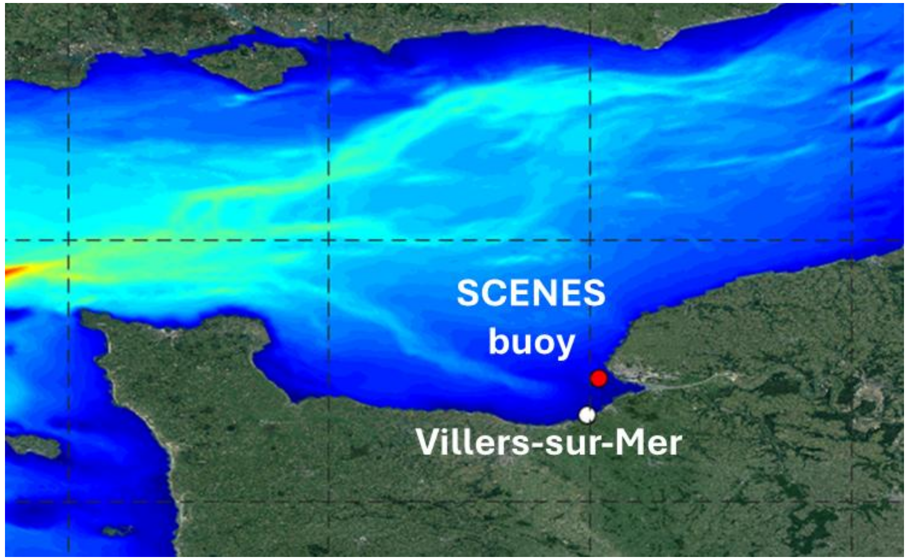


Thank you for your attention

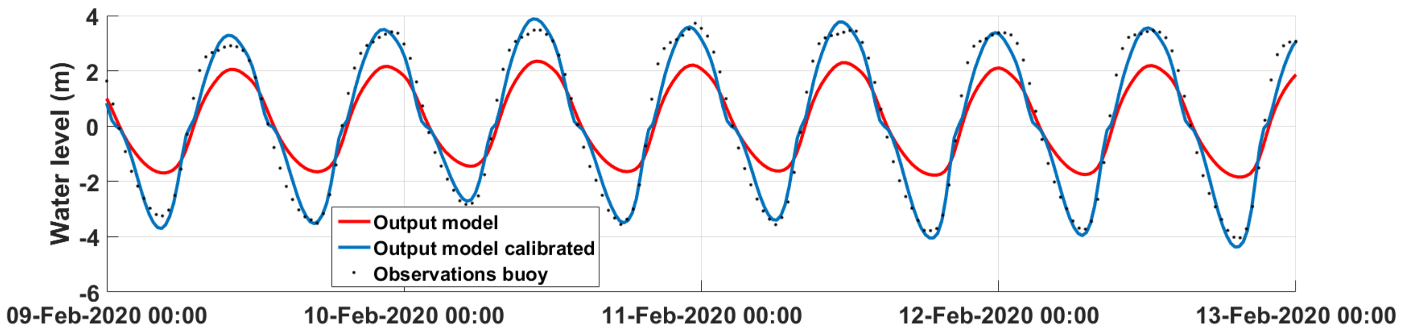
Other storms simulated



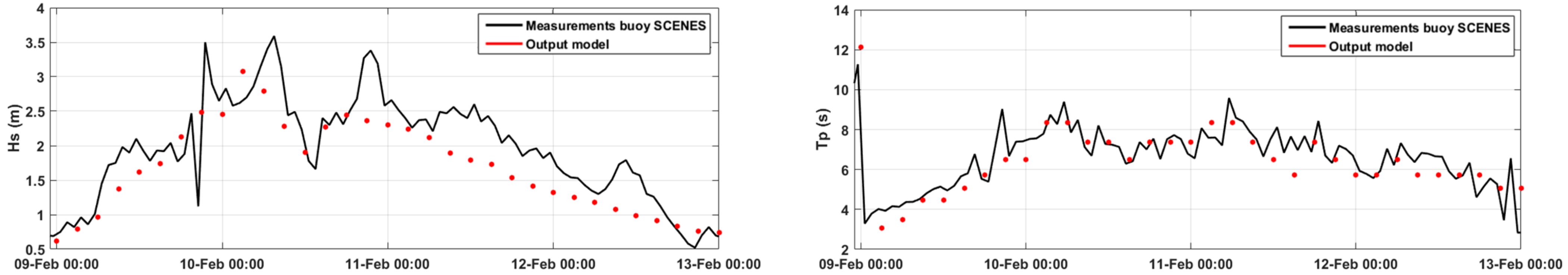
Numerical model: forcings



Correction of water level with measurements of SCENES buoy during storm Ciara



Validation of inputs of H_s (m), T_p (s) with SCENES buoy



Other support slides