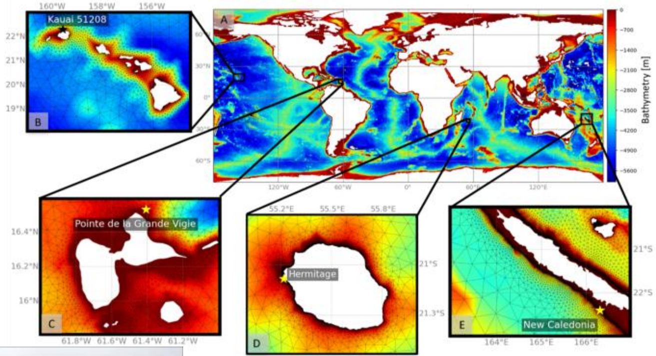
Improving the representation of nearshore wave processes on rocky/complex bottoms in Wavewatch III®

H. Michaud, D. Sous, M. Pézerat, A. Roland, A. Abdolali, T. Hesser, J. M. Smith, D. Honegger, T. Huxhorn

4TH INTERNATIONAL WORKSHOP ON WAVES, STORM SURGES, AND COASTAL HAZARDS
Incorporating the 18th International Waves Workshop

Latest developments in WW3



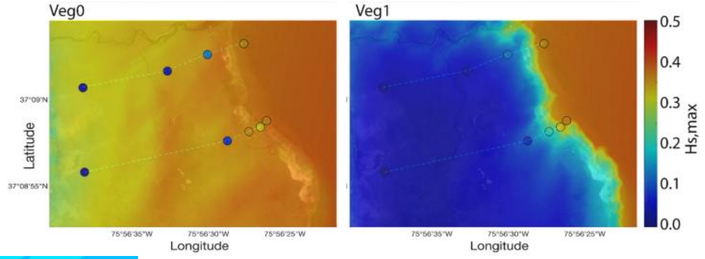
Solve and parallelization

- Domain Decomposition (SCOTCH, ParMetis)
- Implicit Solver
  - Jacobi
  - Block Gauss Seidel method

Gaffet et al., 2025 GMD , Abdolali et al Ocean Modelling in press

Shallow water

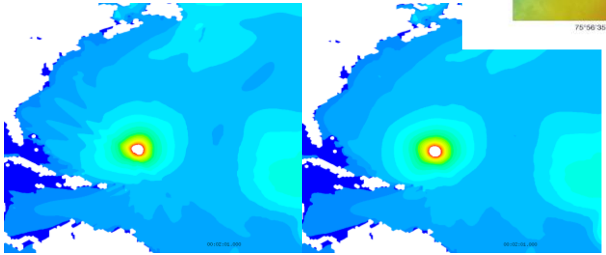
- Vegetation
- Diffraction
- IG Waves for moving boundary (wetting & drying) and implicit schemes
- Depth breaking & bottom friction parameterizations
- Triad interactions
- Wave setup on unstructured grids using elliptic solver



Abdolali et al 2022

Operational forecasting/Downscaling

- Limiter
- GSE alleviation
- Hybrid Open-MP
- Parallel coherency



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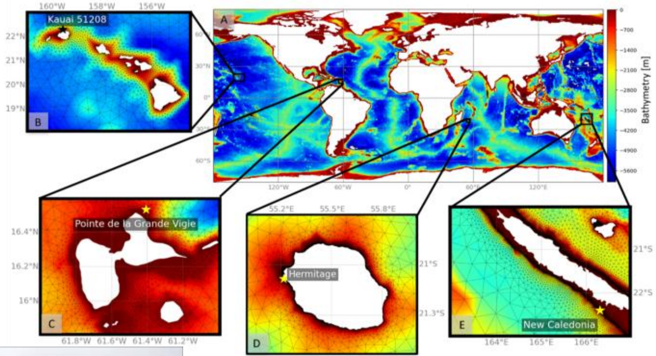

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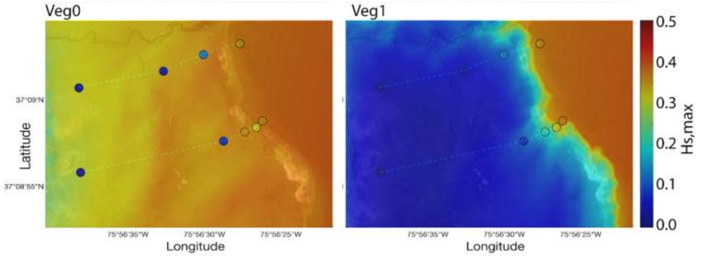

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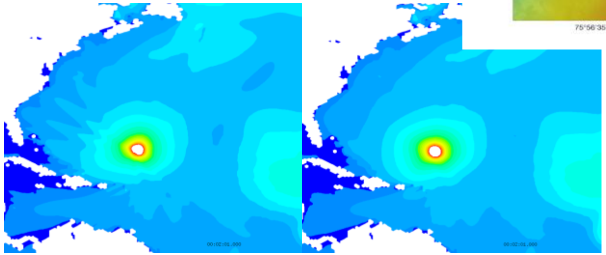


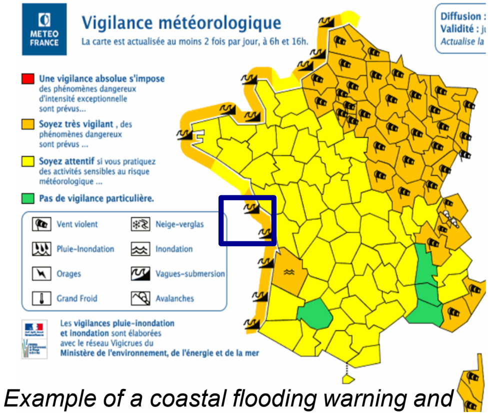
Motivations

Context and Importance

- Coastal flooding forecasts and climate adaptation policies require accurate wave modeling.
- Modeling: From km-scale resolutions to meter-scale expectations with low computational cost for ensemble predictions.
- 70% of the coastline has a complex bottom (rocky, coral) whereas standard spectral wave models are mainly tuned for sandy coasts.

Objectives

- Implement new developments in WAVEWATCH III ® to better capture small-scale nearshore processes over rocky bottoms
- Assess model skills on Ars-en-Ré rocky shore
- Investigate on the processes that control wave dissipation



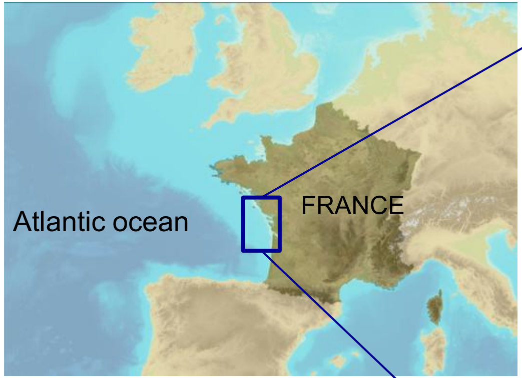
Example of a coastal flooding warning and position of Ré Island (in the black rectangle)

Illustration of the rocky shore at Ars en Ré

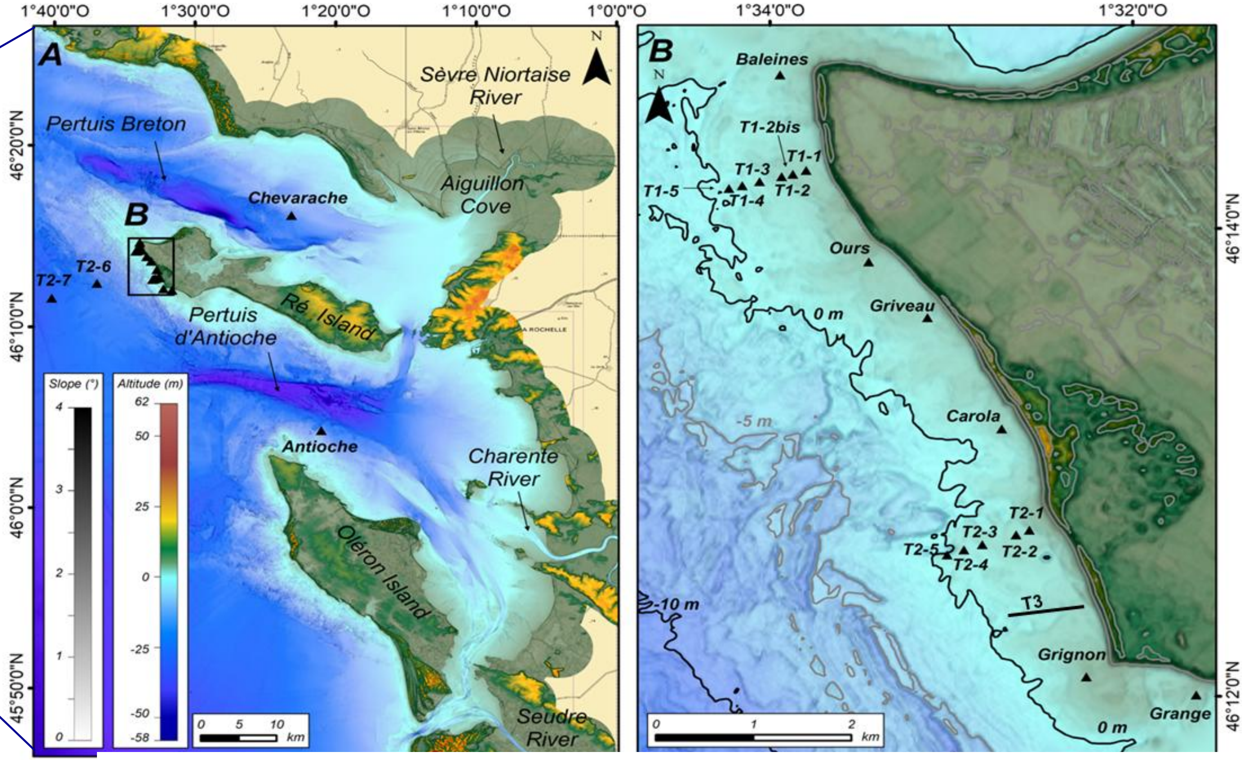
Oceanographic campaign on Ré Island : RiCoRé

Michaud et al., to be submitted to GMD

SHOM L'océan en référence

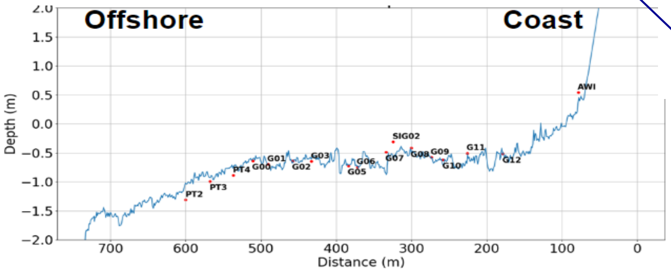


Location of the studied zone



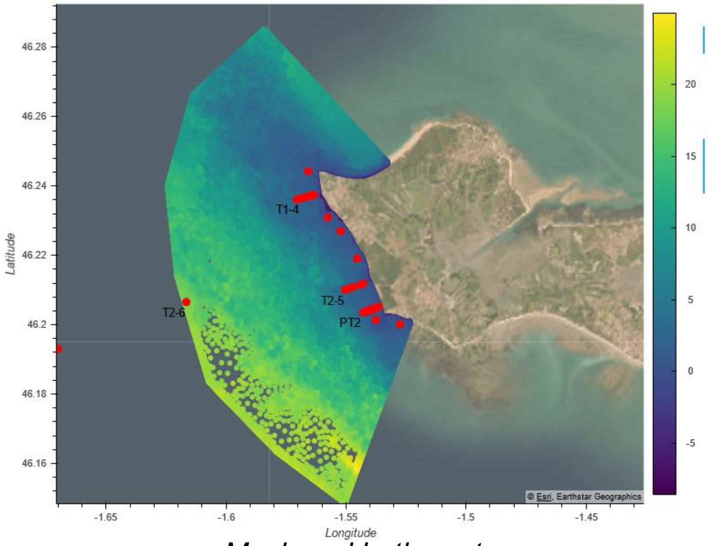
Morpho-bathymetry and mooring positions (black triangles) near Ars-en-Ré and its surroundings. A: coastal Topo-Bathymetric Digital Terrain Model covering a part of the Pertuis-Charentes at a resolution of 0.0002° (~20 m); B: coastal TBDTM of the surroundings of Ars-en-Ré at a resolution of 0.00005° (~ 5 m)

Cross-shore topography at T3



WW3 RICOREUG configuration

- Unstructured grid with resolution ranging from 30m to 5m nearshore
- Forcings
  - Arome (Meteo-France) wind
  - Water level from T2-7 AWAC instrument
  - Datawell spectra from T2-6 is imposed at the offshore boundary



Mesh and bathymetry

Calibration period

Significant wave height (Hm0) (top) and mean period (Tm01) (middle) at T2-6 measured (in blue) and simulated by NORGASUG(WW3 in orange), Wind speed (blue) and direction (red) measured at Saint-Clement-des-Baleines (bottom) during LEG1 and LEG2

Friction on complex bottoms

Implementation in WW3 of a new bottom friction source term (**BT5 switch**):

$$\frac{\partial N}{\partial t} + \nabla_x \cdot \dot{\vec{x}} N + \frac{\partial}{\partial k}\dot{k}N + \frac{\partial}{\partial \theta}\dot{\theta}N = \frac{S_{tot}}{\sigma}$$

$$S_{bf} = -\frac{1}{\sqrt{2}} f_w \, u_{b,r} \frac{\sigma^3}{g \sinh(kd)^2} N(k,\theta)$$

Madsen et al., 1989,
Lowe et al., 2005,
Sous et al., 2023

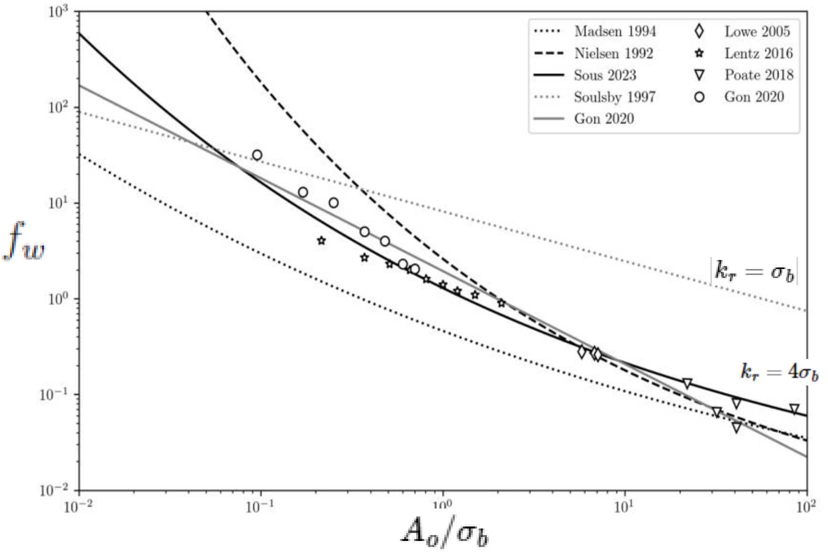
Wave friction coefficient (f_w)

Representative maximum near-bottom velocity ($u_{b,r}$)

$$f_{w,j} = exp(a_1 (\frac{A_o}{k_r})^{a_2} + a_3)$$

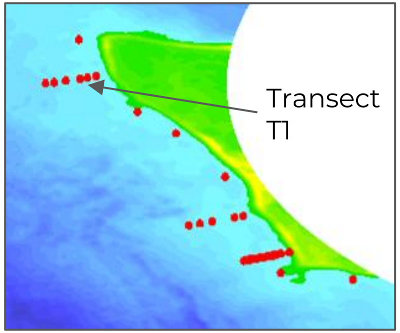
Hydraulic roughness (k_r)

With (a_1, a_2, a_3) = (5,-0.15,-5.9)

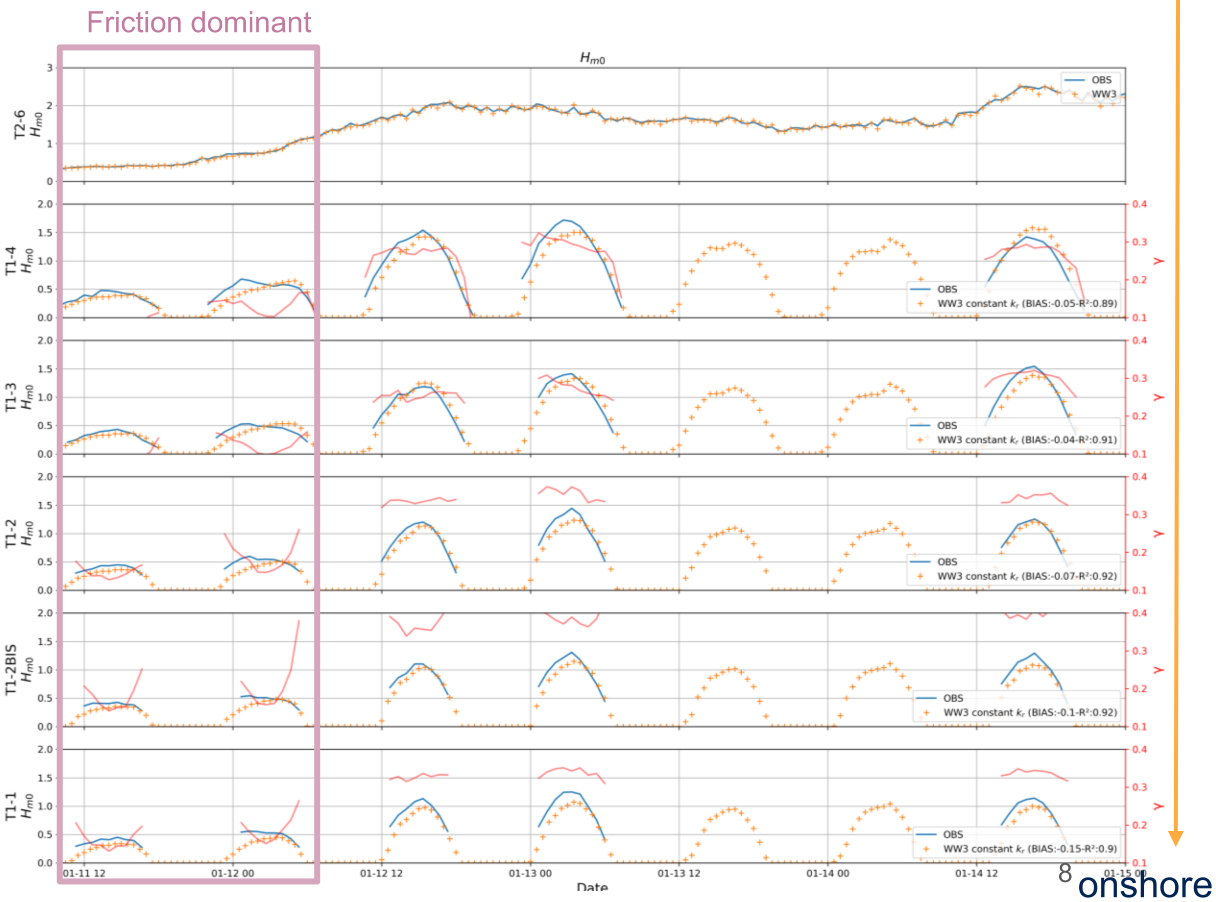


f_w in function of the ratio A_o/σ_b for different parameterizations. The points represent data from in situ measurement campaigns.

Calibration of k_r in RICOREUG



Note: T1-x stations numbered T1-1 to T1-4 from beach to open sea.



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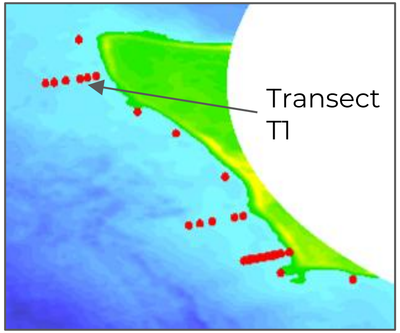

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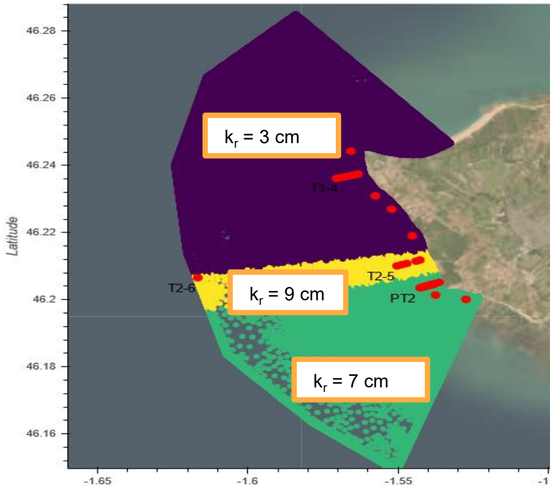
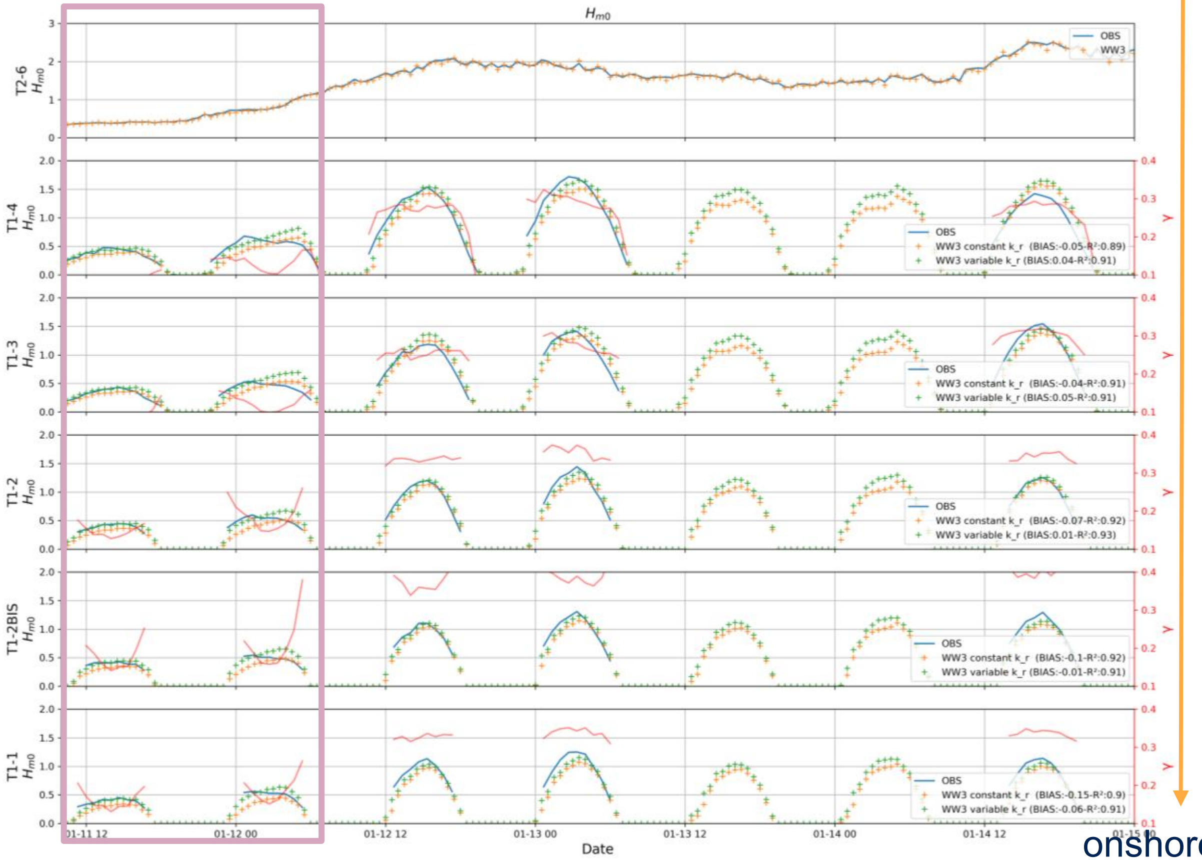


Friction dominant

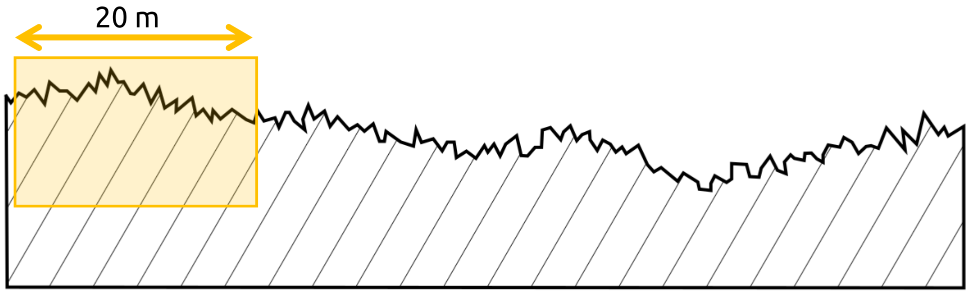
offshore

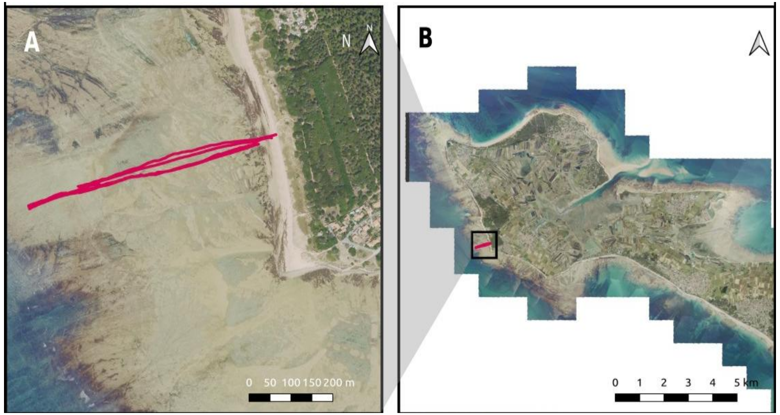


onshore

k_r vs microtopographic data

Separation between bathymetry/roughness features





A: GNSS surveys on Transect 3 on aerial pictures . B: Lidar-extracted digital elevation model.

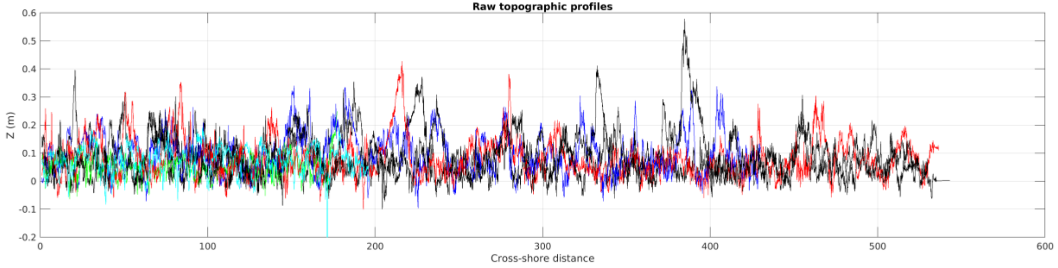
Bed signal

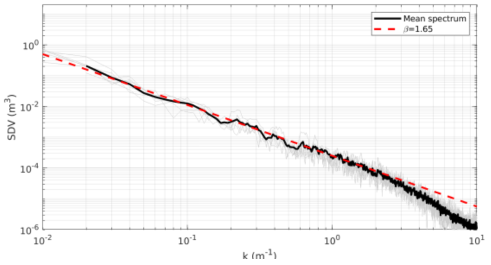
Roughness

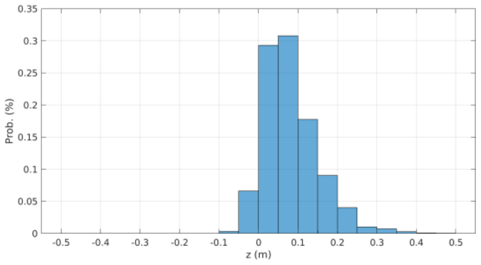
Bathymetry

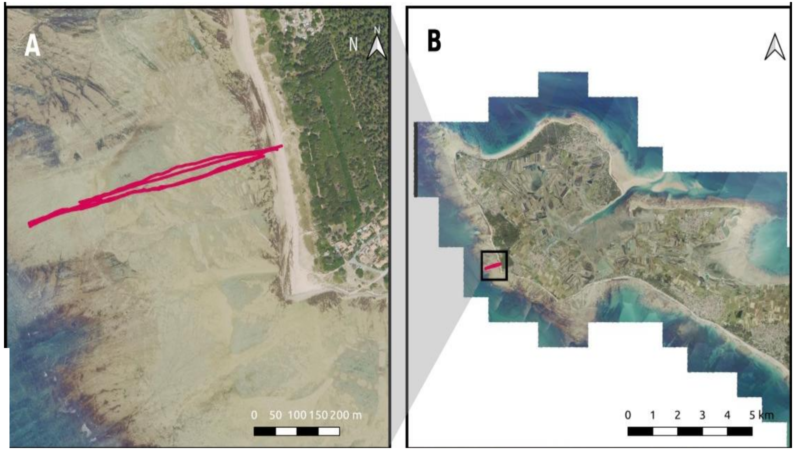
Extracted from M. Geindre (CoastalDynamics 2025 Aveiro)

k_r vs microtopographic data









Micro- topo data :

$$\sigma_b = 6.4\ cm$$

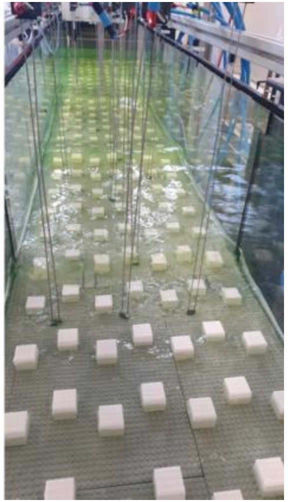
Hydrodynamics:

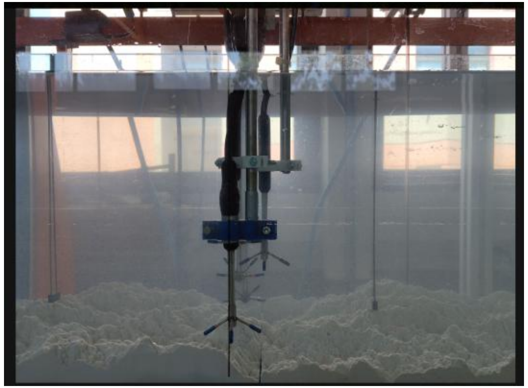
$$k_r = 7\ cm$$

$k_r \cong \sigma_b$?

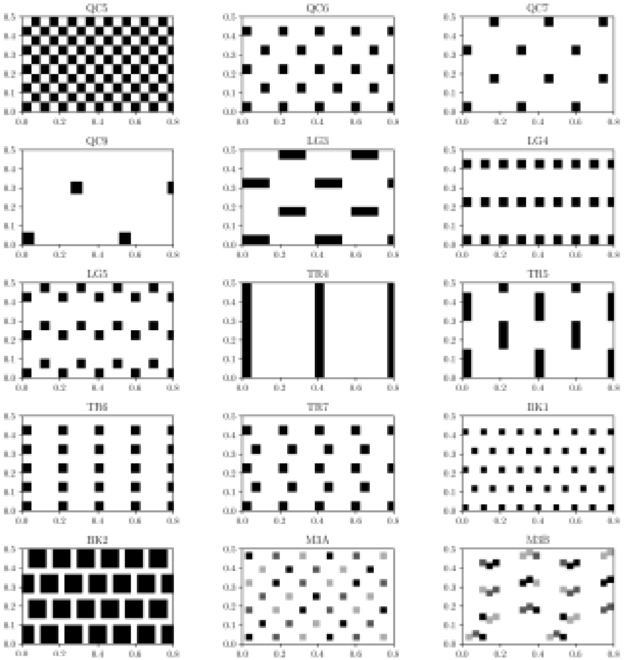
But is σ_b the only metric that needs to be considered?

Find new metrics to estimate the hydraulic roughness k_r





Rough seabed surfzone experiments in the CASH flume (SEATECH/MIO, Toulon) : LEGOLAS & COCODYROCK experiments



Rough seabeds tested in LEGOLAS

$$k_{r,m} = 4\sigma_{\aleph}\left(1 + \beta_s + \beta_d + \beta_e\right)$$

With

$$\begin{cases} \beta_s = -0.3\left(\tanh\left(Sk_{\aleph} - 0.8\right) - 1\right) \\ \beta_d = \Delta_{\aleph} \\ \beta_e = 1.1 ES_{\aleph,x} \end{cases}$$

Dealbera et al., 2024, 2025,
PhD thesis of E. Guelard Ancilotti & M. Geindre

Adaptative wave breaking parameterization

- Implementation of a new parameterization of the **breaking coefficient**—which controls the saturation of breaking waves

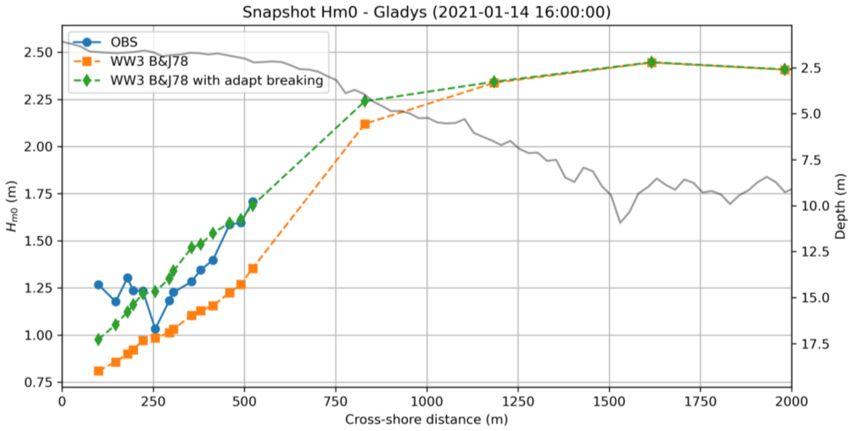
$$S_{db} = -0.25\ \alpha\ Q_b\ f_m \frac{H_{max}^2}{E} N(k,\theta) \longrightarrow S_{db} = -0.25\ \alpha\ \beta\ Q_b\ f_m \frac{H_{max}^2}{E} N(k,\theta)$$

Battjes & Janssen, 1978

With $\beta = 40 slope_{beach}$

Le Méhauté, 1962
Pezerat et al., 2021

uniformly saturated breaking



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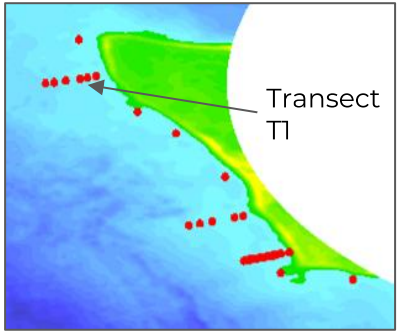

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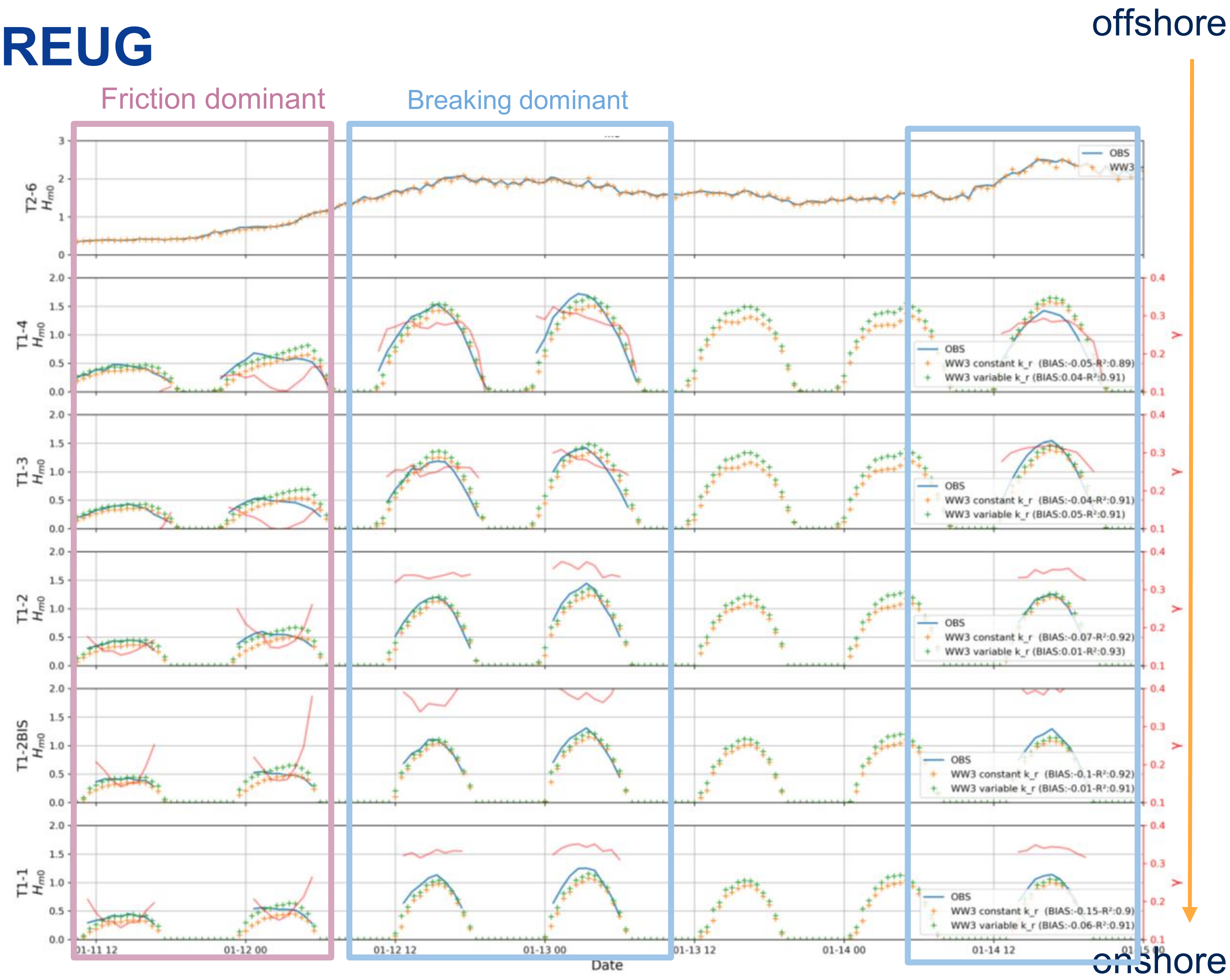


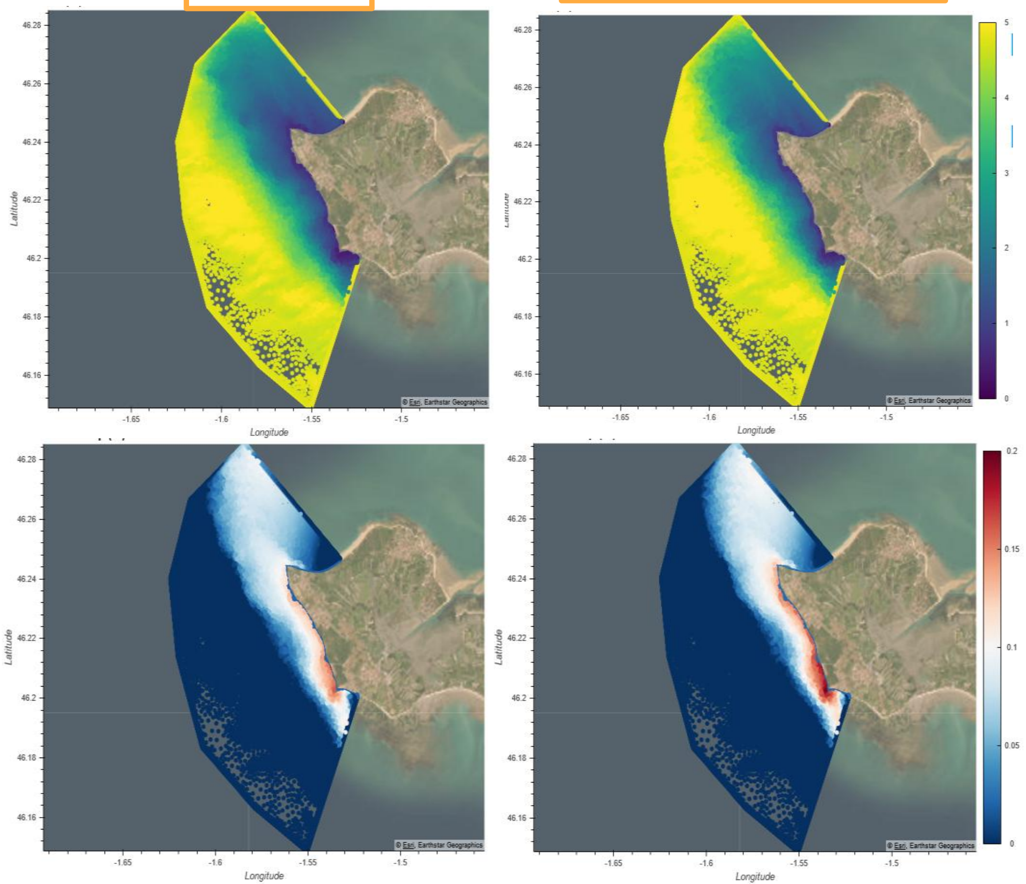
Impact of adaptative breaking param on the wave setup for Bella storm

Without

With adaptative breaking

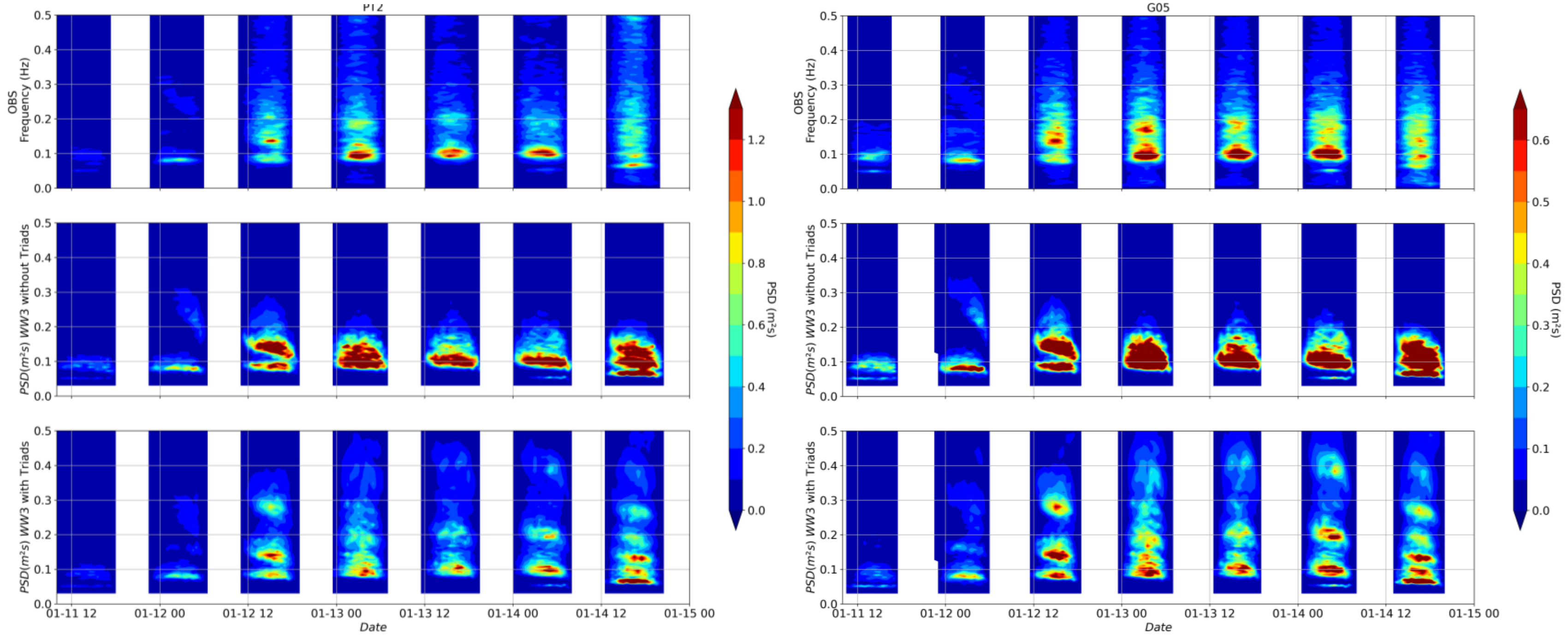
Hs

Wave setup



Impacts of triads

Hovmöller diagramm of E(f) for observations (top), simulation without (middle) and with triads (bottom), on transect 3 offshore (PT2, left) and onshore (G05, right)

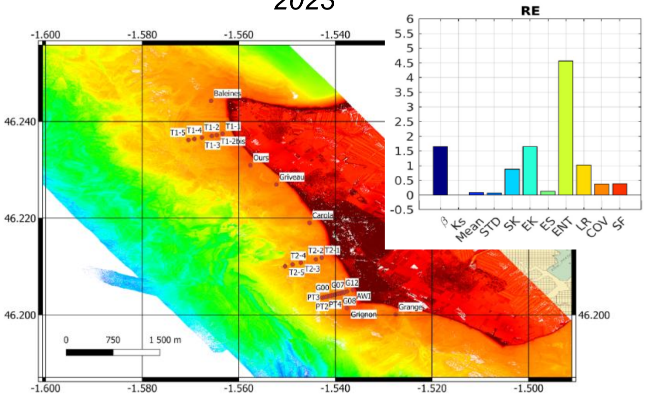


Conclusions and prospects on dissipation on complex bottom

- Implementation of new parameterizations in WAVEWATCH III ® to represent wave dynamics on the Ars-en-Ré rocky shore
- Validation with in situ data during the calibration period
- Evaluation of the contributions of the different processes during storms in progress


Socoa cliffs, Ezponda sea campaign 2021, and Mayotte Reef, Futurisks sea campaign 2023

- Study of micro-topographic data to link bottom metrics to bottom dissipation laws and develop laws applicable to all types of complex bottoms
- Extension to other sites with complex roughness and different types of slope
- Comparison with phase resolved model (prefered Canopy drag approach)

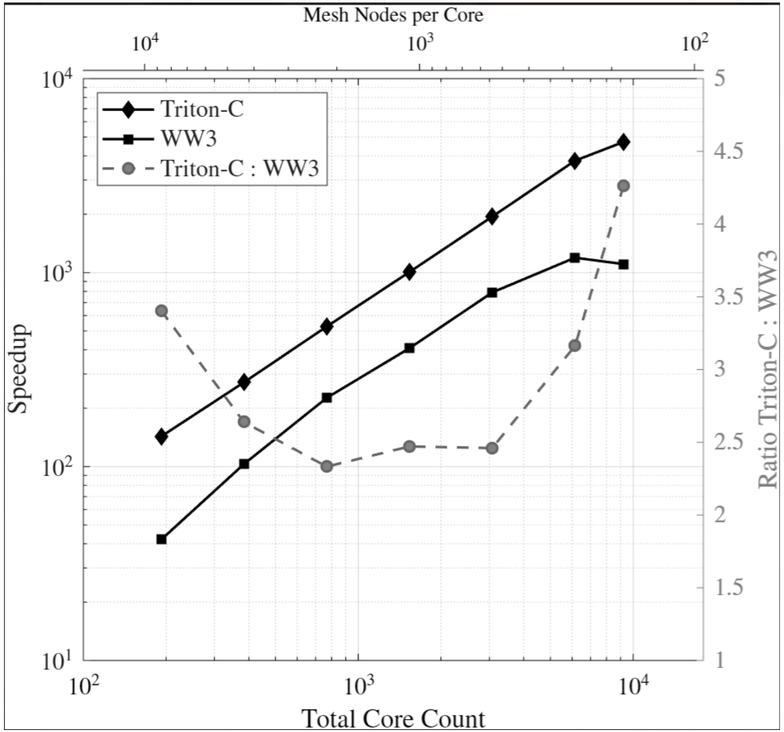


Lidar acquisition and topographical metrics on Transect 3

Sous et al., 2024

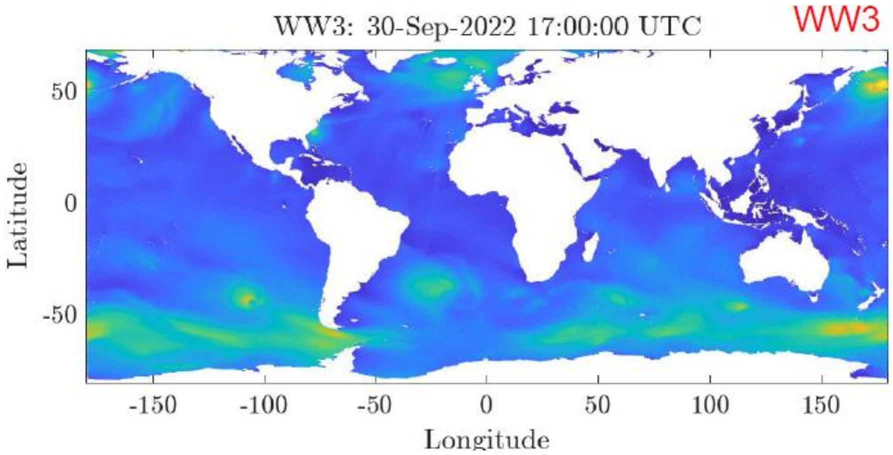
Perspectives : A new version of ww3 in C++ called Triton

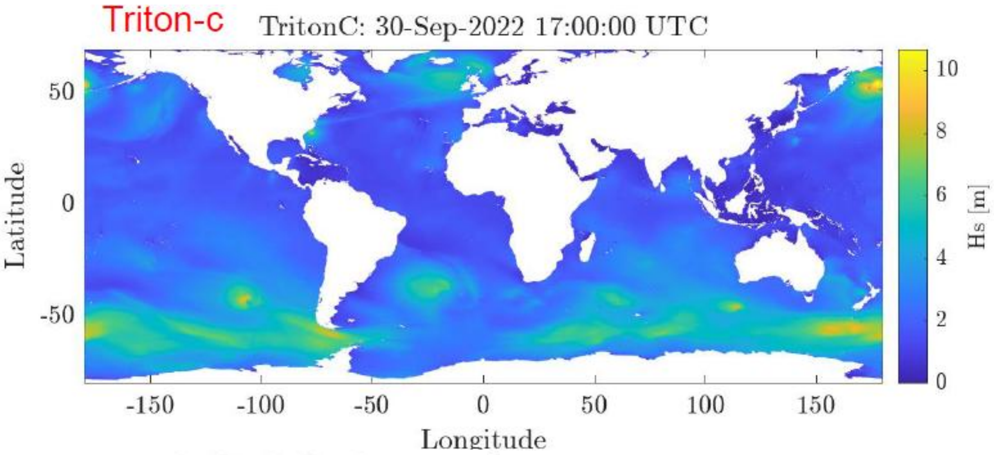
C++20 Development – Latest language features for performance &flexibility
Qt Creator Build – Live compilation, real-time & compile-timetesting
Latest Source Terms – Community-standard, up-to-date physics
Parallelization – OpenMP/MPI, with roadmap to hybrid & GPU support
Advanced Vectorization – Mixed SOA-AOS structures, AVX2/AVX-512 optimized
HPC-Ready – Designed for modern multi-core CPUs, cache, memory & GPU clusters

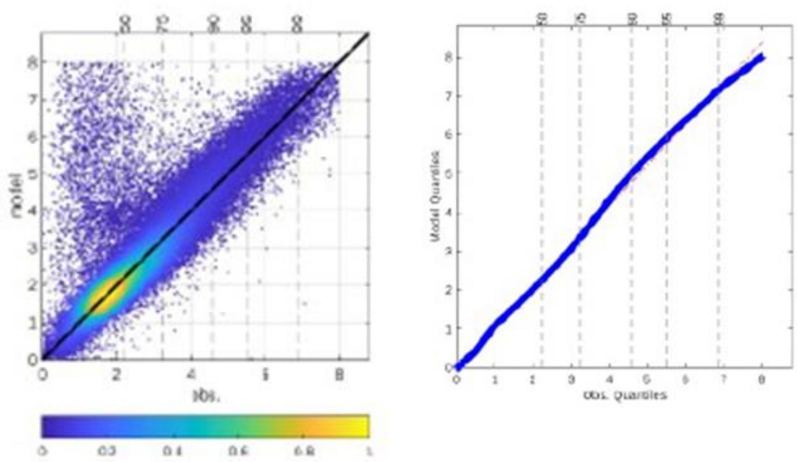


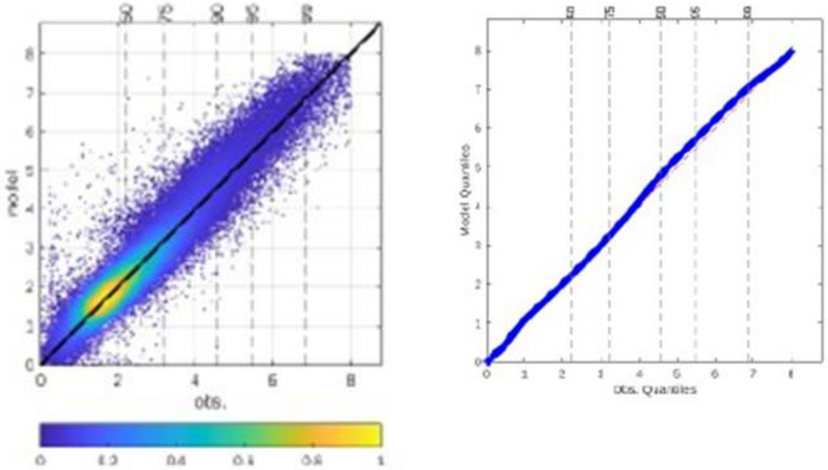
One-Click Project & Build Management – Direct CMake, qmake & Qbs support, no manual Makefiles
Smart Code Editing & Refactoring – Context-aware completion, syntax checks, rename/extract tools
Visual UI Designer – Drag-and-drop interface design
Integrated Debugging – Debug directly within IDE
Live Compilation – Feedback during typing
GitHub Integration – Auto-detect repos, clone/push/pull, branch & PR workflows in-IDE
Cross-Platform Toolchains & Kits – Build and run on multiple platforms
Compile-time validation: static_assert, constexpr, C++20 Concepts → catch errors at compile time, zero runtime cost
Automated regression tests: benchmark memory, performance, parallel coherence, numerical accuracy, and physical correctness
Threshold alerts: configurable baselines; CI fails on regressions (>1% slowdown, >1 MB memory, output drift)
Seamless CI integration: compile-time checks + regression suite in pipeline for immediate feedback

Some first comparisons WW3/Triton



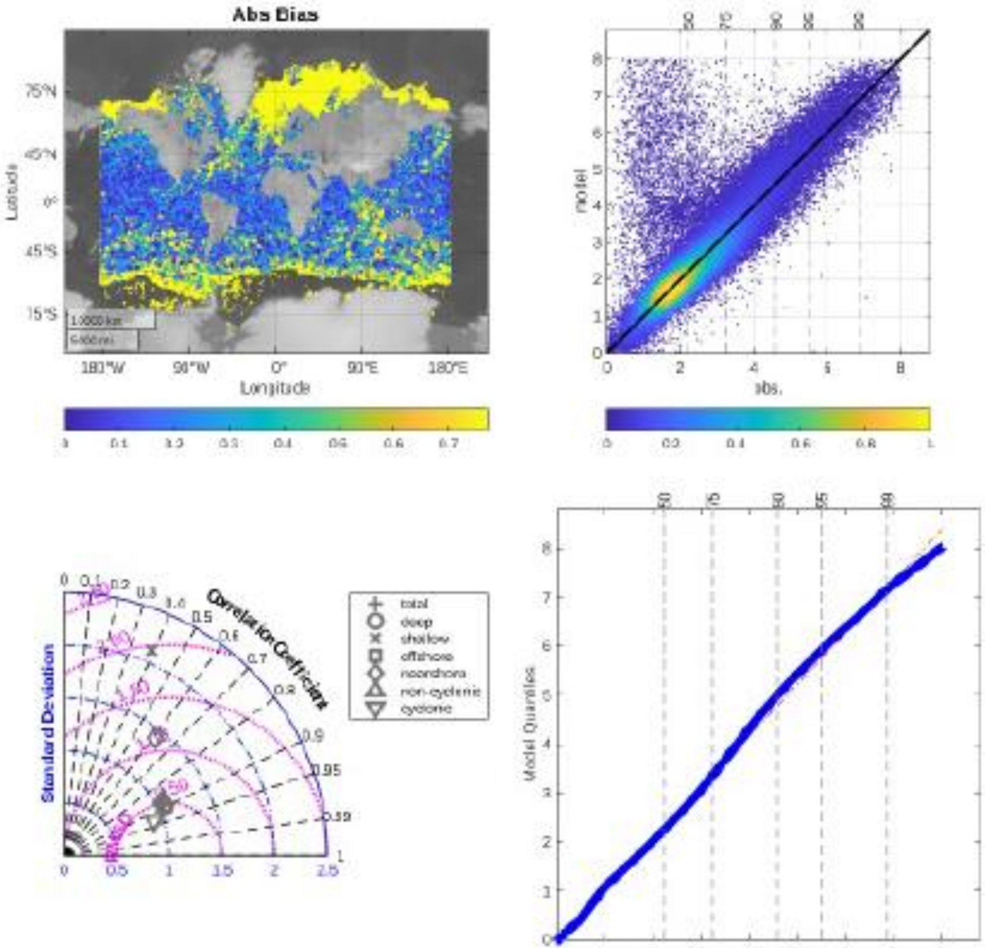




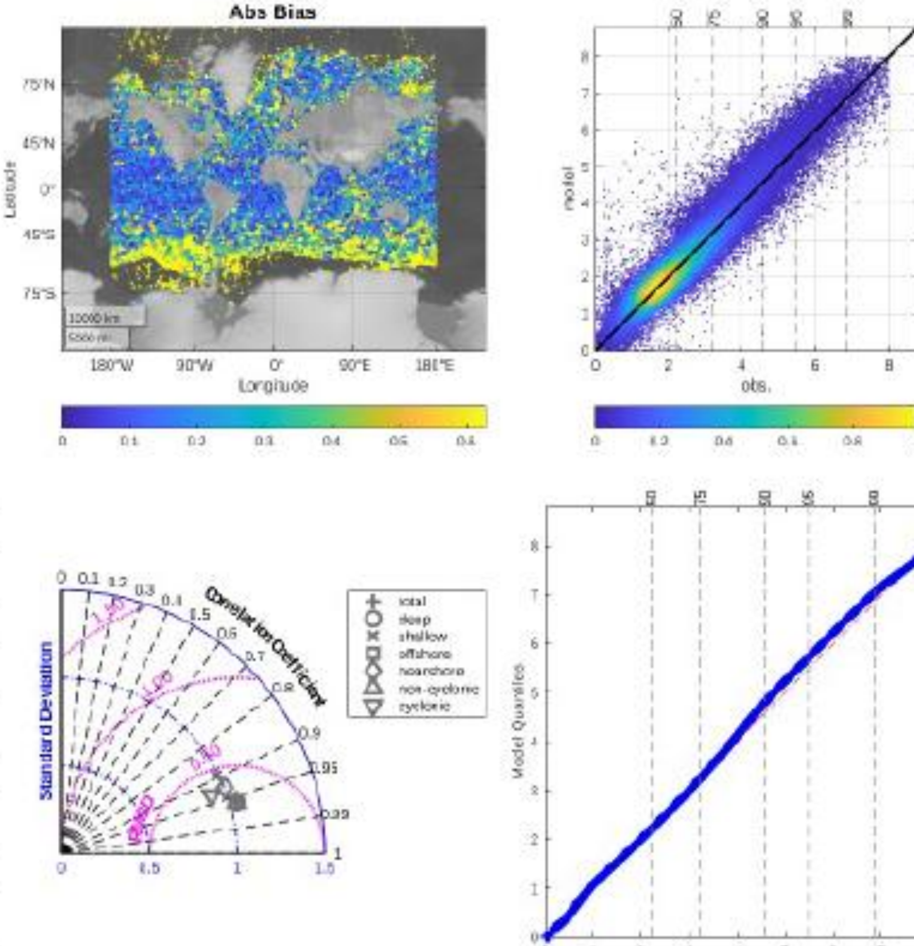


Any questions ?

A huge thanks to all the people involved in the field, analysis or simulations. The Ars-en Ré data has been retrieved during the RICORE 2020 experiments, supported by SHOM (HOMONIM project and PEA PROTEVS) and the GLADYS-UM group. This work received government funding managed by the ANR under France 2030, reference ANR-22-POCE-0002.


Abs Bias
Latitude
Longitude
model
obs.
Standard Deviation
Correlation Coefficient
total
deep
shallow
offshore
nearshore
non-cyclonic
cyclonic
Model Quantiles
Obs. Quantiles

WW3


Abs Bias
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total
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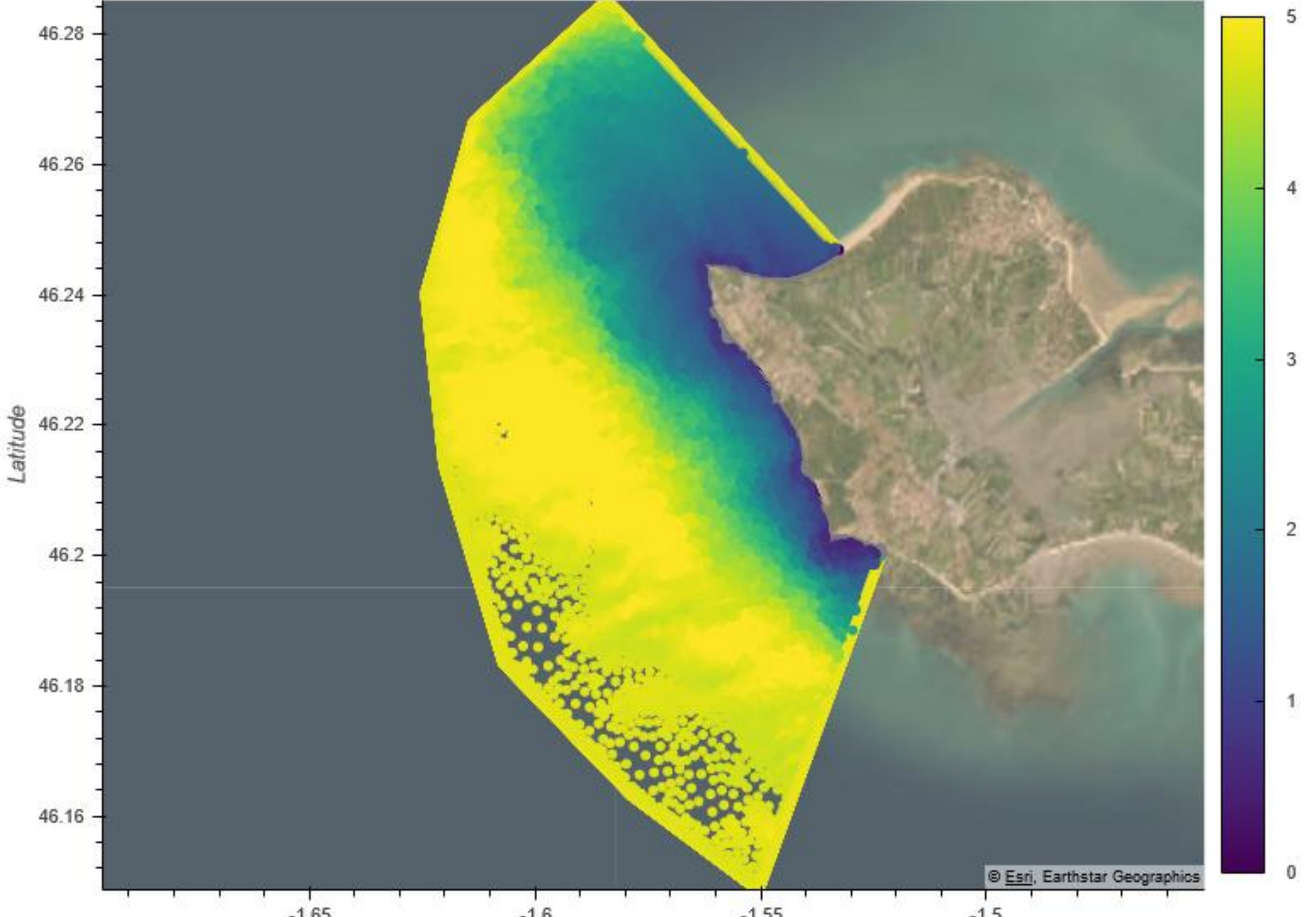
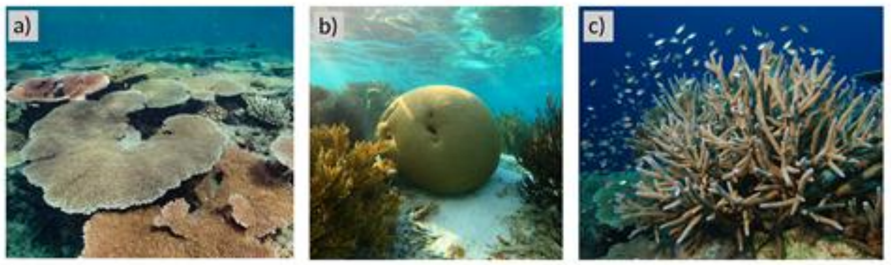
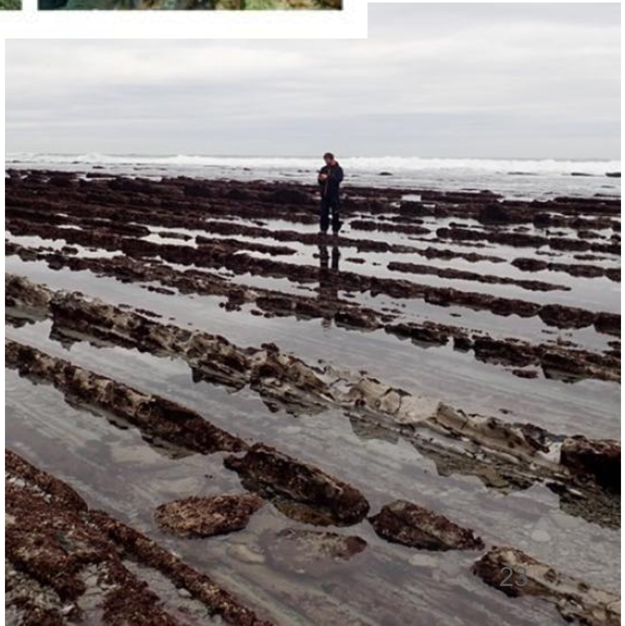
Triton-c


46.28
46.26
46.24
46.22
46.2
46.18
46.16
Latitude
-1.65
-1.6
-1.55
-1.5
5
4
3
2
1
0
© Esri, Earthstar Geographics

Conclusions and prospects on dissipation on complex bottom



What is the link between k_r and topography ?



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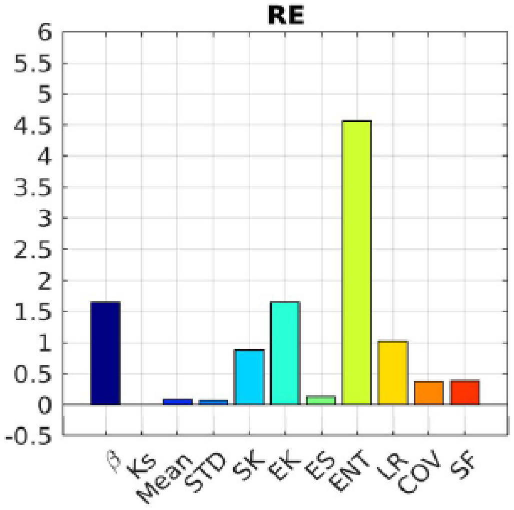
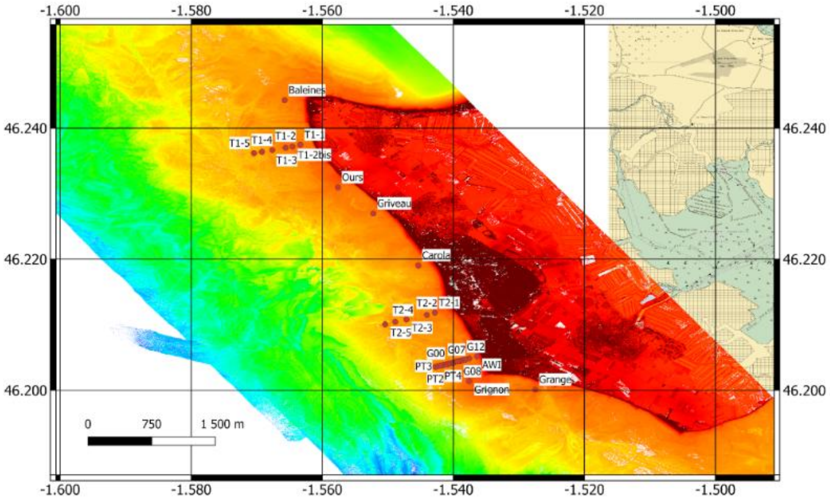


Statistical metrics obtained on transect 3



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$$\beta_d = \Delta_{\aleph}$$

$$\beta_e = 1.1\,ES_{\aleph,x}$$

Sous et al., 2024

Last nearshore improvements

Adaptative wave breaking parameterization

$$S_{db} = -0.25\ \alpha\ Q_b\ f_m \frac{H_{max}^2}{E} N(k,\theta) \longrightarrow S_{db} = -0.25\ \alpha\ \beta\ Q_b\ f_m \frac{H_{max}^2}{E} N(k,\theta)$$

Battjes & Janssen, 1978

With $\beta = 40 slope_{beach}$ **Pezerat et al., 2021**

SPB triad parameterization

- LTA (Lumped Triad Approximation) method already implemented **Eldeberky, 1996**
- SPB (Stochastic Parametrized Boussinesq) method is tested **Becq-Girard et al., 1999**

Latest developments in WW3

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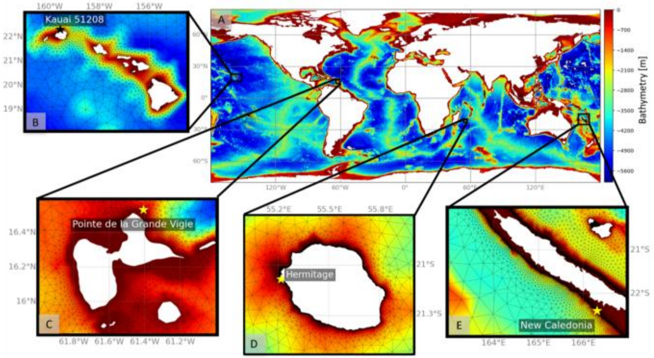
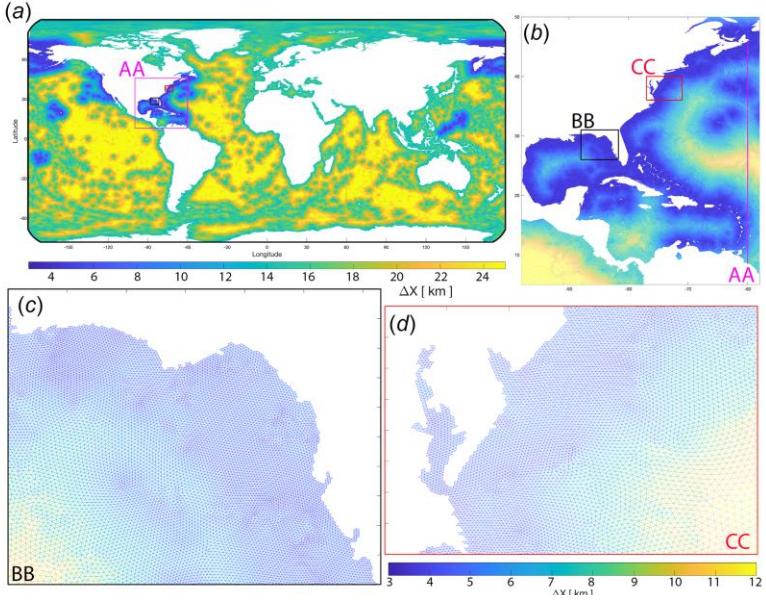


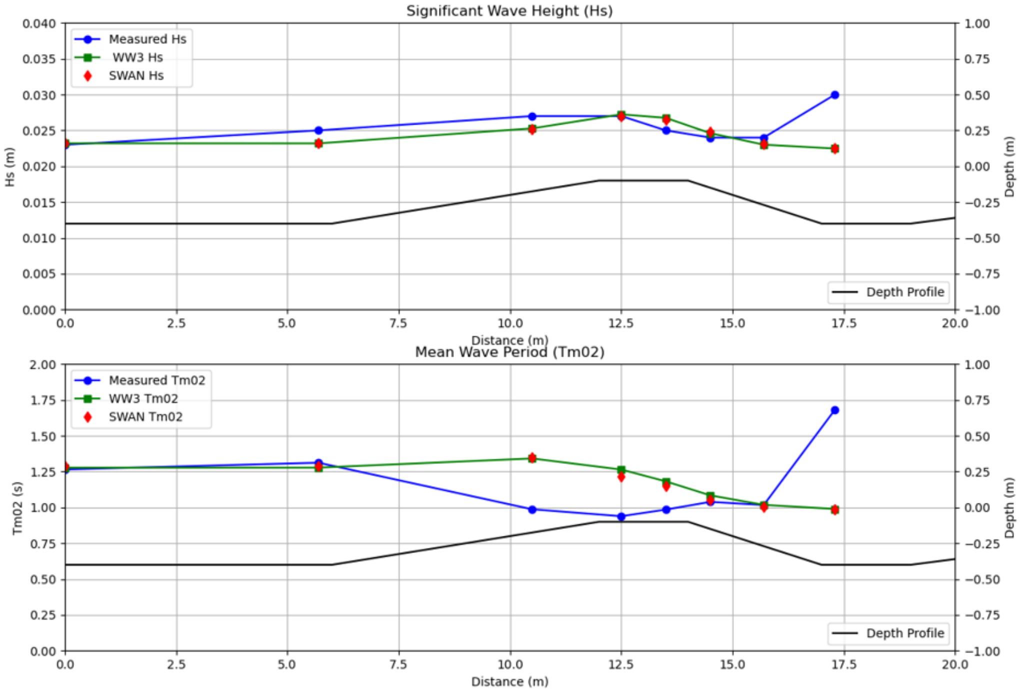
Gaffet et al., 2025 GMD



Abdolali et al Ocean Modelling in press

Triad parameterizations

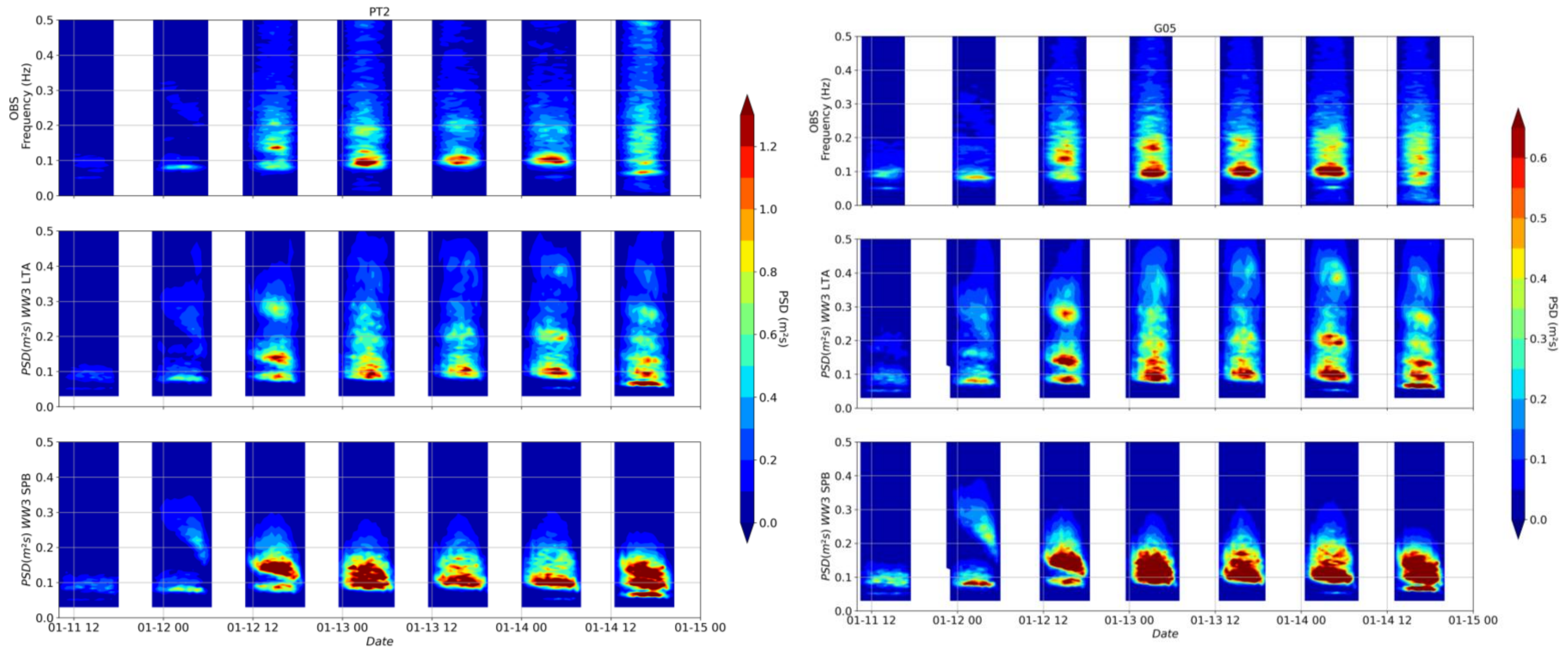
- LTA (Lumped Triad Approximation) method already implemented — **Eldeberky, 1996**
- SPB (Stochastic Parametrized Boussinesq) method is tested — **Becq-Girard et al., 1999**



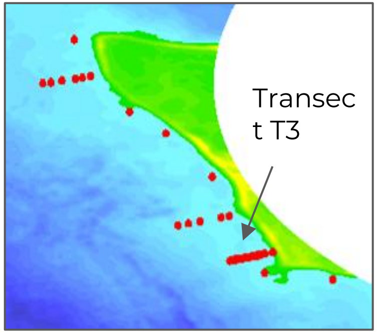
Booij & Dingemans, ?

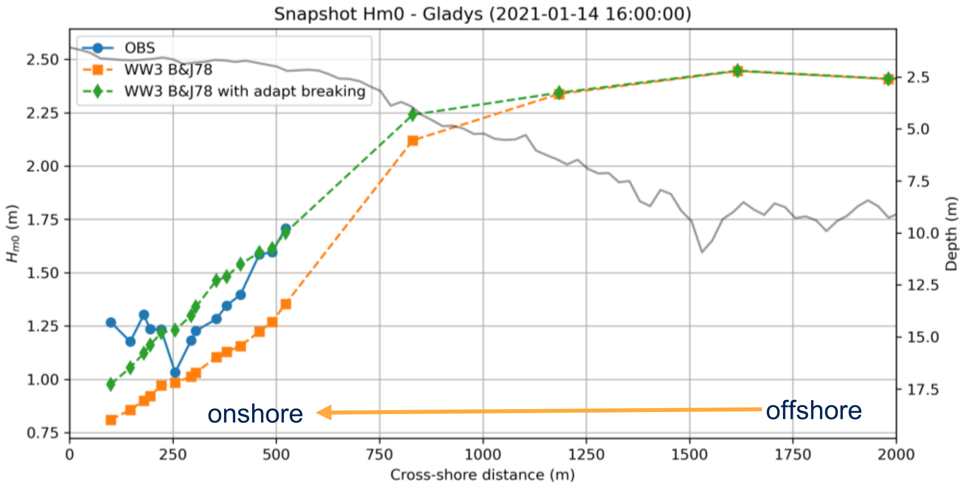
Impacts of triad parameterizations on the spectra

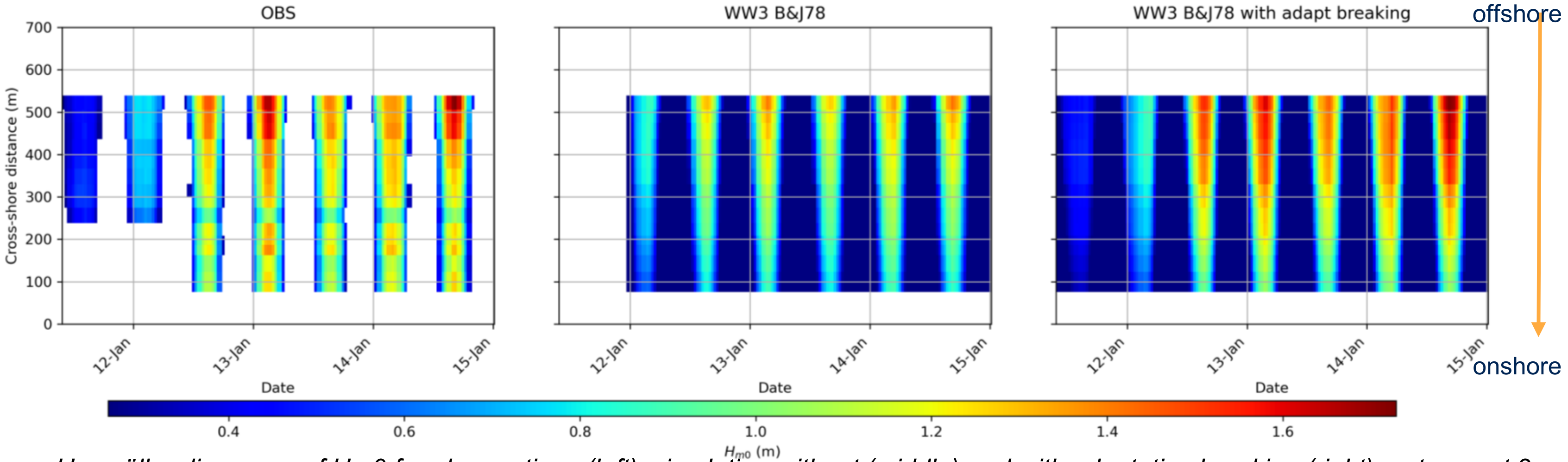
Hovmöller diagramm of E(f) for observations (top), simulation with LTA (middle) and SPB triads (bottom), on transect 3 offshore (PT2, left) and onshore (G05, right)



Impact of adaptative breaking







Hovmöller diagramm of Hm0 for observations (left), simulation without (middle) and with adaptative breaking (right) on transect 3

Contribution of the different processes