ADVANCING TOWARDS LITTER - FREE ATLANTIC COASTAL COMMUNITIES BY PREVENTING AND REDUCING MACRO AND MICRO LITTER

MOHID beaching parametrization upgrade

WORK PACKAGE 3. ACTIVITY 2, TASK 1

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Work package	WP3 - MODELLING APPROACHES FROM MICRO AND MACRO LITTER: FROM MODELLING OUTPUTS TO SOURCES AND HOTSPOTS
Activity and task	ACTIVITY 2 - IMPROVED MODELLING OF MACRO AND MICROPLASTICS, TASK 1 - DEVELOPMENT AND IMPLEMENTATION OF AN IMPROVED MARINE LITTER BEACHING PARAMETRIZATION IN MOHID LAGRANGIAN
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Version	V3
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1. Introduction

This report aims to describe the work done in the framework of Free LitterAT project, Work package (WP3) “Modelling approaches from micro and macro litter: from modelling outputs to sources and hotspots”, Activity 2, “Improved modelling of macro and microplastics”, Task 1 “Development and implementation of an improved marine litter beaching parametrization in MOHID Lagrangian model”. This report makes a brief description of the approach followed in the “Previous version” of the MOHID model for the beaching process. Next, a “Conceptual model” of the new approach is presented, the “Algorithm” implemented in the model source code. Finally, the “Results” using the new beaching/unbeaching approach for a schematic case are presented.

2. Previous version

The previous MOHID particle tracking model version has been implemented in several locations around the world to simulate the trajectories of litter, including both macro and microplastics:

- Brazil/Santos estuary (Almeida et al., 2023)
- Spain/Galicia Arousa (Cloux et al., 2022)
- Portugal/Algarve coast (Rosas et al., 2021)
- Uruguay/Atlantic coast (Rodriguez et al., 2020)
- Indonesia/Jakarta (Rachman, 2020)
- France & Spain/Bay of Biscay (Declerck et al., 2019)
- Uruguay/Punta del Este (Lozoya et al., 2016)
- Portugal/Nazare Canyon (Ballent et al., 2013)

One of the primary objectives of these studies was to identify coastal areas with litter accumulation. In this type of modelling study, it is essential to accurately compute the litter trajectories and, if applicable, the beaching process. The beaching process is particularly relevant on sandy coasts. In the case of MOHID, users can define a constant beaching probability over time for specific areas based on minimum depth (Cloux et al., 2022) and/or using polygons that define buffer zones along the coastline (Rosas et al., 2021).

The previous version was also used to support spill emergency operations. For example, on December 8, 2023, a container ship lost six containers off the coast of Portugal. One of them carried bags of polyethylene (PE) pellets: small plastic balls measuring about 5 millimetres each, used in the manufacturing of plastic products. In the context of a longstanding partnership, Hidromod assisted the Galician authorities (Plan Camgal-Intecmar) in predicting the fate of the spill. Drift simulation results based on the previous version of MOHID are presented in Figure 1. Simulation started on December 8th and the maps show the position of the particles on December 11th and 13th. The December 13 results compare well with the visual observations (red spot).

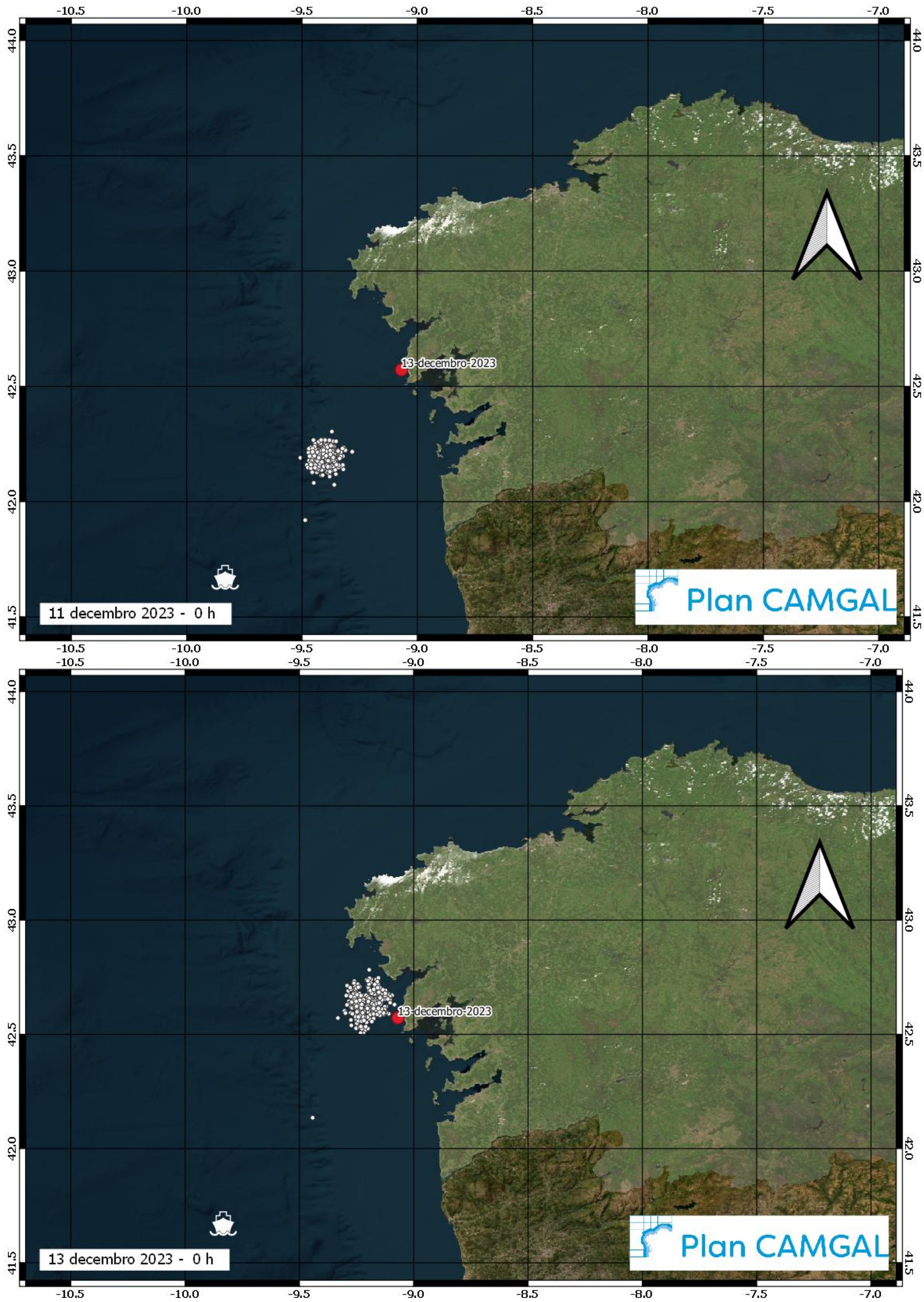

Figure 1 – Drift simulation results for December 11th (upper panel) and 13th (lower panel). Simulation started on December 8th (day of the accident). Location of the accident is represented by a ship icon.

3. Conceptual model

The beaching probability approach followed in the previous version of MOHID is also adopted by Kaandorp et al. (2022). However, in this case, the probability is computed as a function of the particle's residence time in the beaching zone and a beaching time scale. As an alternative, Huichao et al. (2023) propose a semi-analytic method that calculates the beaching probability based on beach slope, wave height, and period.
Allison et al. (2022) studied the Scottish coast and considered all particles crossing the land boundary to be beached. However, they associated an "unbeaching" probability function with the model's time step and the average residence time of a particle on the beach.

From the spatial/time scales point of view it was possible to identify, based on the available literature, two main approaches to simulate the beaching/unbeaching process. The first type is focused on simulating the litter trajectory at the coastal scale. The beaching\unbeaching parametrization is based on seasonal scale observations done along the coast. The metocean forecasts used tend to have a spatial resolution of the order of kms. The work of Kaandorp et al. (2022) for the Dutch coast and Allison et al. (2022) for the Scottish coast are good examples of this approach.

When the effect of waves over the beaching/unbeaching process is considered, an approach focused on the wave scales (order of meters and seconds) is followed. For example, Huichao et al. (2023) proposes a beaching parametrisation function of wave characteristics and beach slope. In this work the trajectories of the litter on a sloping beach are simulated by the Smoothed Particle Hydrodynamics (SPH) method, which is pre-verified through laboratory experiments. It is found that the beaching process of the litter can be divided into three steps: drifting in front of surf zones, surfing and leaping with plunging waves, and advancing via wave runup. The density of the litter combined with wave steepness determines whether the litter can enter the surf zone where it has a large chance to beach. Finally, Huichao et al. (2023) proposes a semi-analytical model with improved Morison's equations considering the second-order Lagrangian transport on a sloping beach. This semi-analytical model is much faster and is comparable in computational accuracy to the high-resolution SPH model. It has the potential to be incorporated into the existing marine models and replace the stochastic process assumed for the litter tracking in the nearshore, to achieve more accurate assessment on the stranded litter.

To implement this last approach in forecast mode it is necessary to generate very high resolution forecast able to solve in detail the wave steepness. This would be possible if in the beaching areas of interest, a Boussinesq type model was run in forecast mode (e.g. FunWave) focused on high-resolution simulations of nonlinear wave dynamics, particularly in shallow water and surf zones, capturing complex wave transformations and interactions. This model is much less time consuming than CFD and SPH models, but

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even so is much more computationally expensive than a wave spectral model (e.g. SWAN). Usually, the coastal forecast systems like the one managed by MeteoGalicia only run wave spectral models to forecast wind waves conditions. This type of model is designed to simulate the evolution of wind-generated waves in coastal regions. It is used primarily for predicting wave heights, periods, and directions in nearshore areas, including the effects of shallow water and complex coastal geometries with a resolution of the order of tens of meters.

In FreelitterAT, it has been decided to follow an alternative approach to the two presented above. In the MOHID upgrade an approach focused on hydrodynamic models (waves and currents) with horizontal resolutions of the order of tens of meters was adopted. These models can provide very accurate currents, sea level and wave forecasts outside of the surf zone. The beaching/unbeaching can happen when the water column is below/above a threshold defined by the user (Figure 2). The MOHID user can define different beaching areas with different water column thresholds.

The beaching/unbeaching can take place as a function of probability. The beaching/unbeaching probability (P) is computed following the following standard formula:

$$P = 1 - e^{-\frac{\Delta t}{T}}$$

Δt – particle tracking model time step
T – Empirical time scale defined by the user. For each beaching area the user needs to define a beaching and unbeaching time scale.

If the litter is beached, a “beached level” is defined based on the forecasted sea level (astronomic + meteorological tide). In beaching areas where the wave run-up effect can be relevant (e.g. sandy coast) the beached level can be increased by adding the run-up effect (option defined by the user for each beaching area). The wave run-up is computed using the formula proposed by Stockdon et al. (2006). In this formula the wave run-up is a function of the significant wave height, peak wave period and beach slope.

Upgrade MOHID beaching parametrization

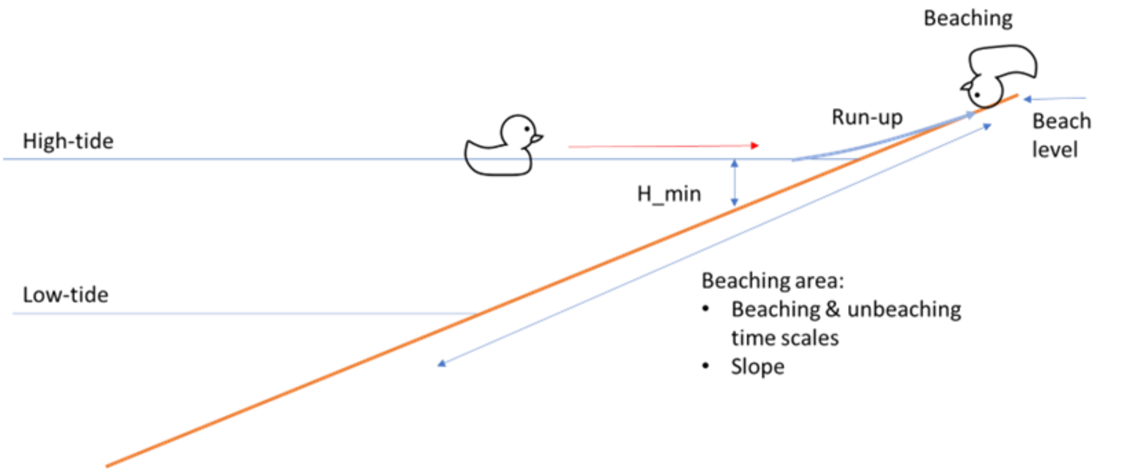

Figure 2 – Diagram illustrating the conceptual model follow in the upgrade of MOHID beaching/unbeaching process.

4. Algorithm

In Figure 3 a diagram illustrating the new beaching/unbeaching algorithm of MOHID Lagrangian model is presented.

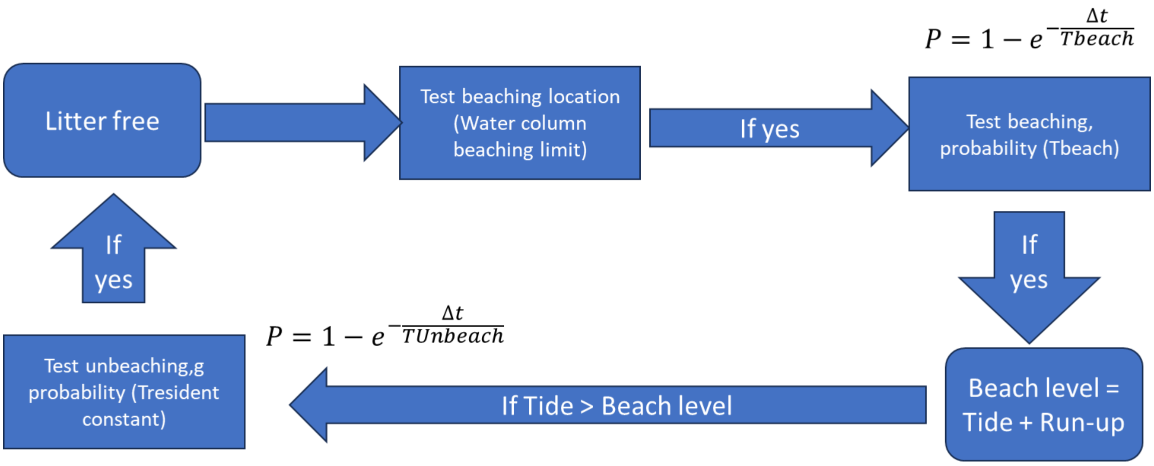

Figure 3 – Diagram illustrating the new beaching/unbeaching algorithm of MOHID Lagrangian model.

The user of MOHID configures the input file Lagrangian_x.dat to define the characteristics of each beaching area (Figure 4).

Lagrangian_1.dat

```

<BeginLitter>
<<BeginBeachArea>>
NAME                              : Beaching area 1
DESCRIPTION                       : Area 1 where litter can beach
FILENAME                          : ../../GeneralData/polygons/Beaching/Schematic.xy

FREE_LITTER_PROJECT               : 1
WATER_COLUMN_THRESHOLD            : 0.1
BEACH_TIME_SCALE                  : 3600

UNBEACH                           : 1
UNBEACH_TIME_SCALE                : 43200
RUN_UP_EFFECT                     : 1
BEACH_SLOPE                       : 0.005
RUN_UP_EFFECT_UNBEACH             : 1
<<EndBeachArea>>
<EndLitter>
```

Figure 4 – Example on how a beaching area is configure in the new MOHID version.

The new version of MOHID is available in the MOHID Git Hub project https://github.com/Mohid-Water-Modelling-System/Mohid. The new version was upload on June 11th, 2024, for other project partners to run tests (Figure 5).

Upgrade MOHID beaching parametrization

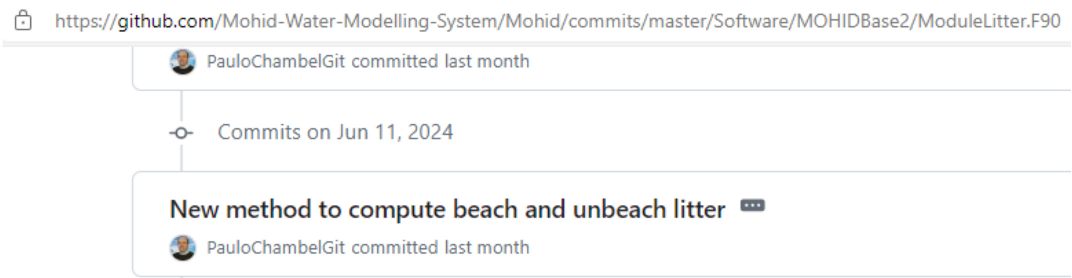

Figure 5 – Commit done on Jun 11, 2024.

5. Results

The upgrades described earlier were tested for a schematic straight-line scenario with a constant slope (0.005). In the model scenarios, the effect of wind velocity (zonal = 2 m/s, meridional =1 m/s), wind drag coefficient of 1.5%, astronomic tide (M2 = 2 m) and wave (Hs = 2 m, Peak period = 10 s) were considered (Figure 6). A 2D model discretization was assumed (Δx≈ 100 m).

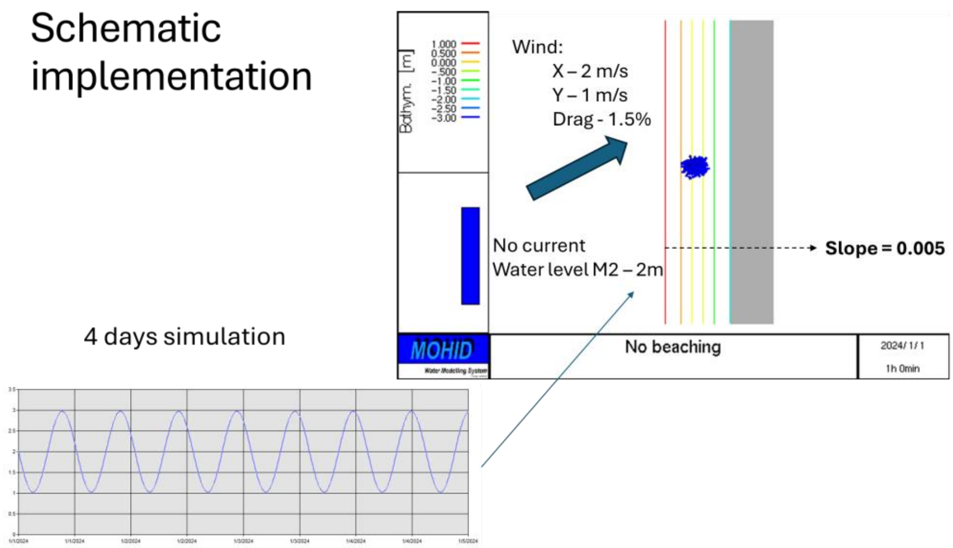

Figure 6 – Diagram explaining the schematic implementation.

The following scenarios were tested:

- Effect of different beaching time scales (no unbeach, no wave run-up) - Figure 7;
- Effect of different unbeaching time scales (beach time scale = 1h, no wave run-up) - Figure 8;
- Effect of wave run-up (beach time scale = 1h, unbeach time scale = 12h) - Figure 9;

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Upgrade MOHID beaching parametrization

- Effect of tide height change in time (beach time scale = 1h, unbeach time scale = 12h, wave run-up = Hs 2m, Peak period 10 s) - Figure 10.

Figure 7 clearly illustrates that the longer the beach time scale, the lower the probability of litter remaining on the beach. Results presented in Figure 8 indicate that if the unbeaching process is considered, and its time scale is equal to the beaching time scale, both processes tend to cancel each other out. For the model to exhibit a beaching trend under stationary metocean conditions, the unbeaching time scale must be longer than the beaching time scale.

Figure 9 further demonstrates that if the run-up process is factored into the litter beaching and unbeaching dynamics, under stationary metocean conditions, the effects of wave action tend to be also cancelled.

Finally, Figure 10 depicts the impact of tidal height variability (spring-neap cycle). Compared to a metocean scenario with constant tidal height, a scenario where litter begins to beach during spring tides will result in a more localized beaching area during neap tides.

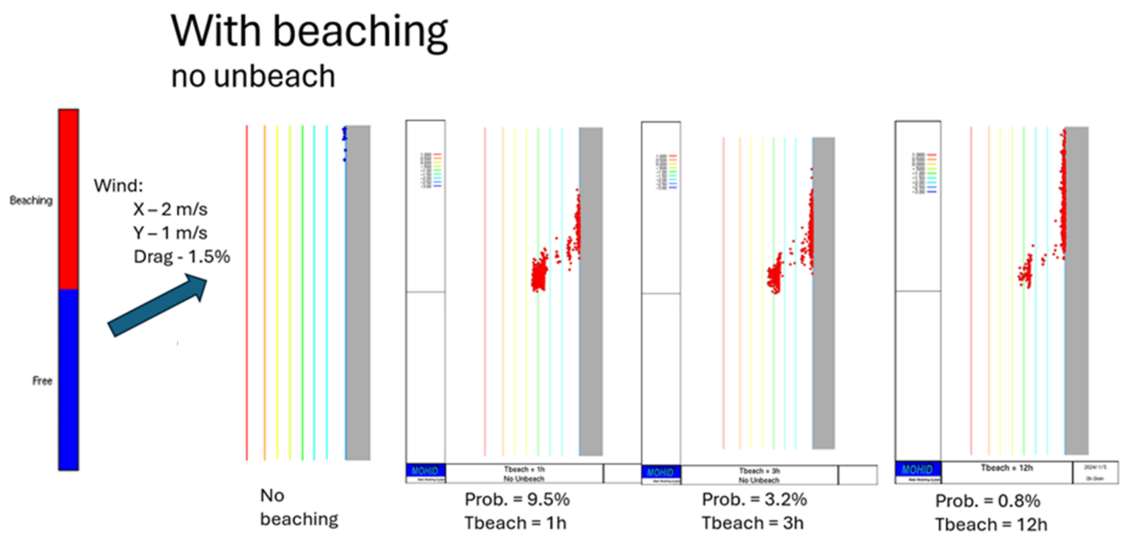

Figure 7 – Scenarios where different Beach Time Scales are tested. The unbeach is OFF.

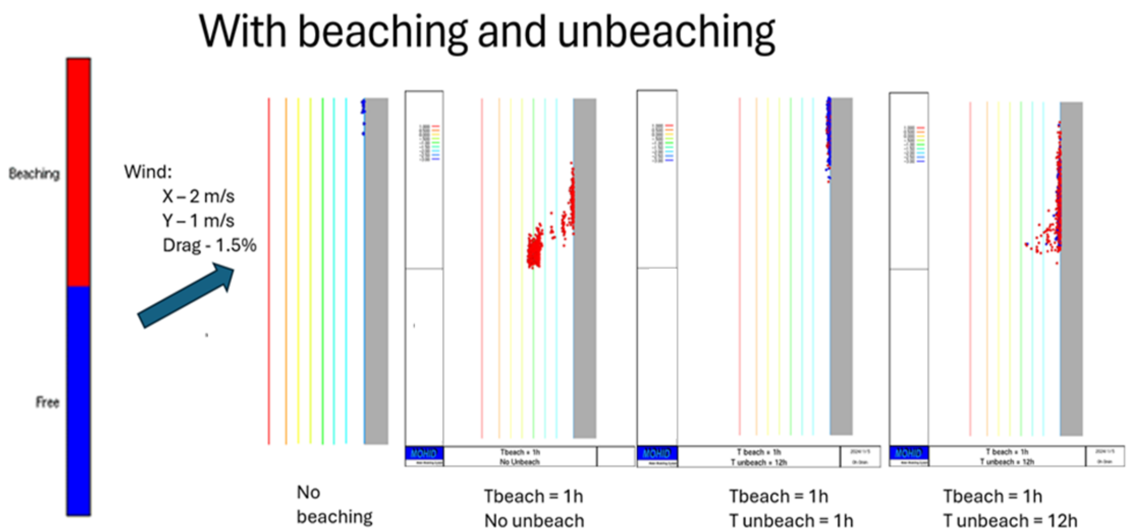

Figure 8 – Scenarios where different Unbeach Time Scales are tested. The beach Time Scale is assumed always equal to 1h.

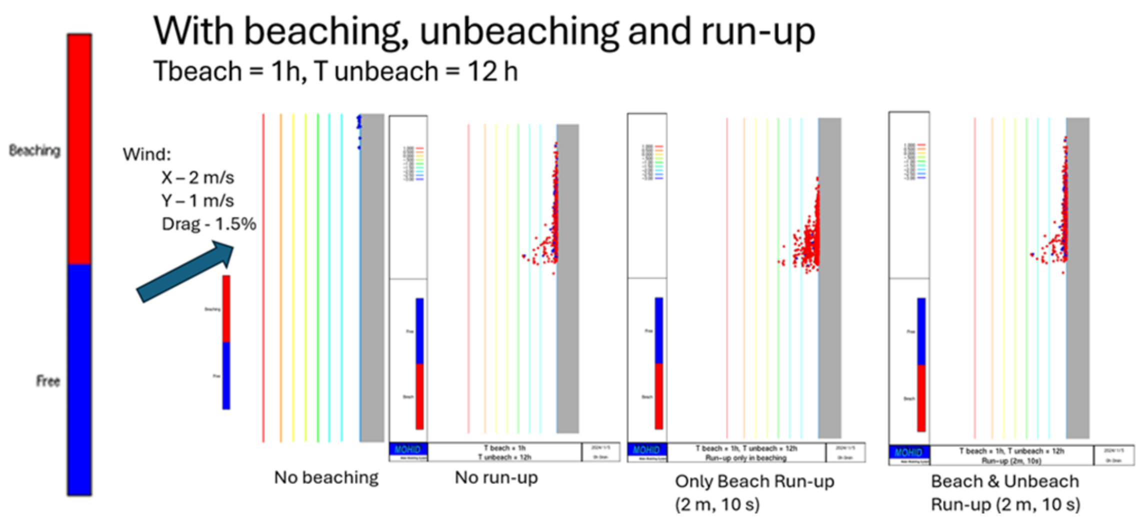

Figure 9 – Scenarios where the effect of run-up is tested (Hs= 2m, peak period = 10 s).

Upgrade MOHID beaching parametrization

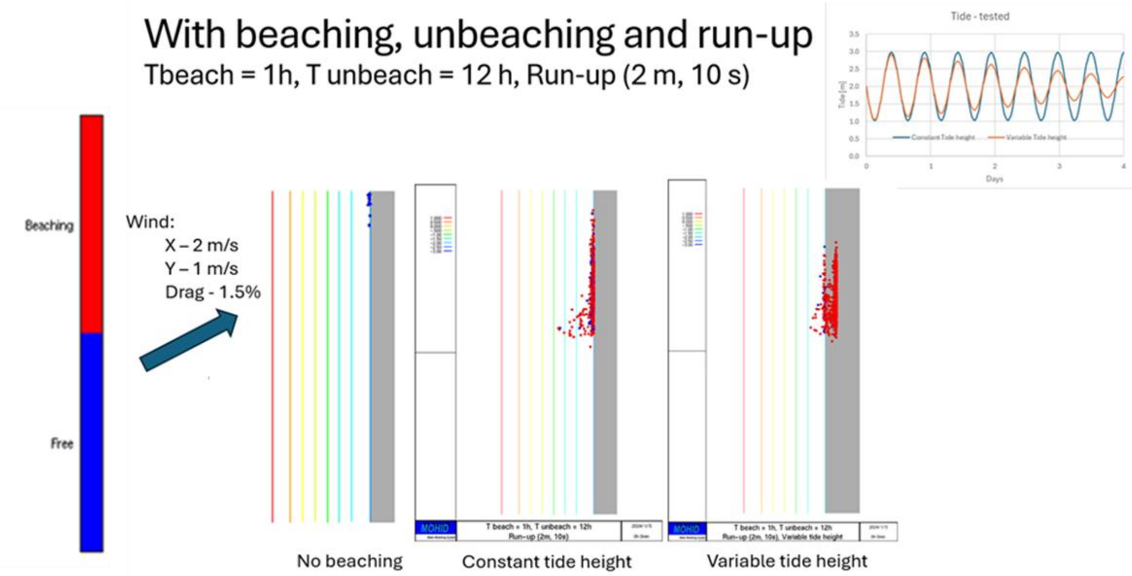

Figure 10 - Scenarios where variable tide heights are tested along 4 tide periods. The Unbeach Time Scale = 12 h, beach Time Scale = 1h and run-up (Hs=2 m, Peak period = 10 s) are assumed.

6. Conclusion

A new method for calculating beaching, based on the shoreline type, swell and tidal height has been implemented in the MOHID model. This new method is expected to replicate the distribution of marine litter on the coast more realistically. However, it is necessary to validate this implementation in more realistic scenarios, trying to support it with data and field sampling.

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