FEMDrift4Ocean

Training and Tutorial

Developed as part of the EDITO Model Lab Hackathon 2025

Coast2Ocean Team

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1. Introduction

FEMDrift4Ocean is a modelling framework that connects the SHYFEM hydrodynamic model with the OpenDrift model to simulate the transport and fate of floating material (e.g., marine litter, tracers, or particles) in complex coastal environments.

The framework also includes the Retention Clock, a simplified indicator that translates dynamic marine processes, such as currents, dispersion, and connectivity, into an interpretable matrix. This helps assess coastal system behaviour and supports decision-making for marine governance, pollution response, and coastal resilience.

This tutorial provides step-by-step guidance for users who wish to:

- Run SHYFEM–OpenDrift coupled simulations on the EDITO platform.
- Understand how to configure and launch particle dispersal experiments.
- Compute and visualize retention and connectivity indicators using the Retention Clock method.

This tutorial provides users with an example with which they will be able to reproduce the main workflow of FEMdrift4Ocean, modify input data for their own regions, and explore how coastal dynamics influence particle transport and accumulation patterns.

2. Getting Started on the EDITO Platform and Input Data

To run the workflow, users need an EDITO account:

1. Go to https://datalab.dive.edito.eu and log in with your credentials.
2. lunch the project service from Service catalog, Project: femdrift4ocean

You will find the project organized as shown below:

`opendrift-output/` → results from OpenDrift simulations

`shapefiles/` → input polygons for retention/clock analysis

`shyfem/` → SHYFEM hydrodynamic data and configuration

`retention-clock-annotated.ipynb` → notebook for retention clock and connectivity

`shyfem-opendrift-annotated.ipynb` → notebook for running OpenDrift using SHYFEM outputs

`retention-clock-test.ipynb` → notebook for retention clock – test

`shyfem-opendrift-test.ipynb` → notebook for running OpenDrift – test

3. Converting SHYFEM Internal Output

3.1. About SHYFEM

The finite element hydrodynamic model SHYFEM (System of HYdrodynamic Finite Element Modules; https://github.com/shyfemcm/shyfemcm) is a numerical program package designed to simulate circulation and transport processes ocean and coastal systems, such as lagoons, seas, estuaries, and lakes. It resolves hydrodynamic equations using finite elements and an effective semi-implicit time integration algorithm, which makes it particularly suitable for applications in areas with complex geometry and bathymetry.

Finite elements are especially well adapted to problems involving irregular coastlines and variable topography. Unlike finite difference methods, the finite element approach allows non-uniform spatial resolution, with smaller elements concentrated in regions of interest, providing high numerical flexibility. SHYFEM can operate in both two-dimensional (depth-integrated) and three-dimensional modes depending on the user's needs. In the 3D configuration, the model solves the primitive equations for momentum, continuity, and scalar transport on an unstructured triangular mesh in the horizontal and a flexible Z-layer discretization in the vertical. The model uses a semi-implicit time stepping scheme, which is unconditionally stable for gravity waves, bottom friction, and Coriolis terms, while advection is treated explicitly. For detailed descriptions of the numerical formulation and past applications, see: Umgiesser et al., 2004 and Ferrarin et al., 2017.

3.2. Why Convert SHYFEM Output

SHYFEM produces its hydrodynamic results in an internal binary format (.shy files), which cannot be directly read by external frameworks such as OpenDrift. Therefore, it is necessary to convert SHYFEM outputs into NetCDF format following CF- and UGRID- compliant conventions, so they can be used as forcing input for particle simulations.

The conversion process extracts the following key variables:

- Water surface height above reference datum (water_level)
- Eastward sea water velocity (u_velocity)
- Northward sea water velocity (v_velocity)
- Temperature and salinity (if available)
- Node coordinates and mesh connectivity

3.3. Shyfem Folder and example Test Case: Mar Menor

The shyfem folder on the EDITO platform includes all necessary components for conversion:

`mar-menor_test_case/` → Example SHYFEM test setup for the Mar Menor.

`shyfemcm_8.1.1/` → SHYFEM source code.

`shyfem2nc_od.sh` → Shell script for converting SHYFEM outputs.

A simple Mar Menor test case is provided to demonstrate the conversion workflow. This case allows users to test the SHYFEM-to-NetCDF process and verify the compatibility of the generated file (mm_hyd_43.nc) with OpenDrift. It is possible to run the test directly in the EDITO environment.

The SHYFEM model and utilities are included in the workflow and linked to the bin/ directory of the SHYFEM source (shyfemcm_8.1.1/). The model is compiled, and the hydrodynamic model can be run.

3.4 Running the Conversion Using the shyfem2nc_od.sh

The shyfem2nc_od.sh script converts SHYFEM internal output files (.shy) into CF-compliant NetCDF files that can be directly used by OpenDrift. A short guide is provided alongside the script for reference.

To run the script, navigate to the case study folder and execute:

```
./shyfem2nc_od.sh <basename>
```

Example (Mar Menor case in mar-menor_test_case/):

```
./shyfem2nc.sh mm_hyd_43
```

The conversion produces a CF-compliant NetCDF file such as, mm_hyd_43.nc. This file contains the hydrodynamic variables (e.g., water level and u/v velocities) ready for use in OpenDrift. You can verify the structure by using ncdump -h mm_hyd_43.nc.

4. Running the OpenDrift Simulation

The OpenDrift framework is used to simulate the movement and dispersion of particles (e.g., marine litter, tracers, or virtual drifters) using hydrodynamic outputs from SHYFEM as forcing input. The model integrates particle trajectories over time based on velocity fields and optionally considers processes such as wind drift, diffusion, or vertical movement. For more information, visit: https://opendrift.github.io/ (Dagestad et al., 2018).

In the shyfem-opendrift-annotated.ipynb example, we use the Mar Menor test case to demonstrate how SHYFEM data can be read into OpenDrift and used to simulate particle dispersal over a one-day period. The reader unstructured (shyfem) module allows OpenDrift to read SHYFEM's unstructured grid format.

Before running the OpenDrift simulation, it is important to define the polygon shapefile representing the areas where connectivity and retention will later be calculated using the Retention Clock method. These polygons define the zones where particles are initially released and where their residence or exchange will be assessed during the simulation.

In this example, the polygons and coastal landmask used for the Mar Menor test case can be found in the folder shapefiles. mar-menor-landmask.shp defines the coastline and lagoon boundaries (used as a physical landmask). MM_test_areas.shp contains several numbered polygons that represent different analysis regions for computing connectivity and retention later.

Figure 1 - 4 shows the result of the OpenDrift simulation for the Mar Menor case. presents the same simulation combined with the test-area polygons used for the Retention Clock analysis.

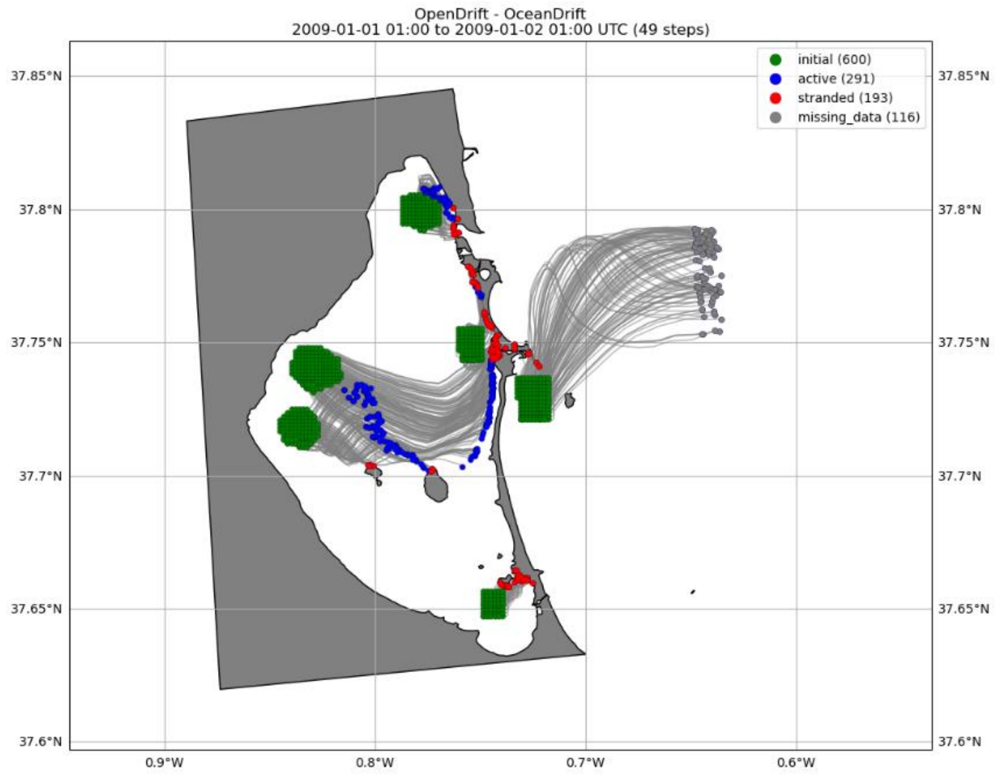

Figure 1. OpenDrift simulation of particle dispersal in the Mar Menor lagoon (test).

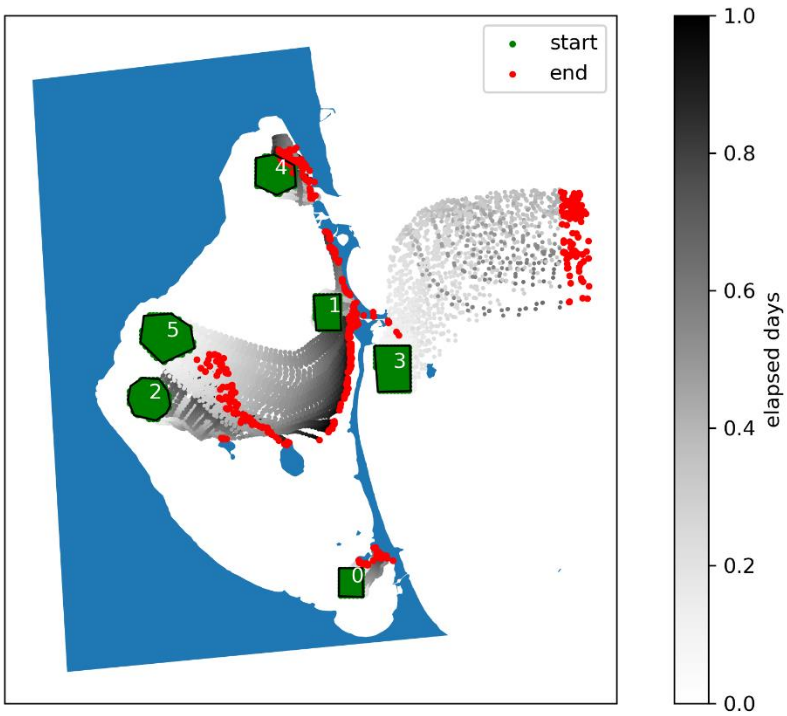

Figure 2. OpenDrift results overlaid with analysis polygons used for the Retention Clock (test).

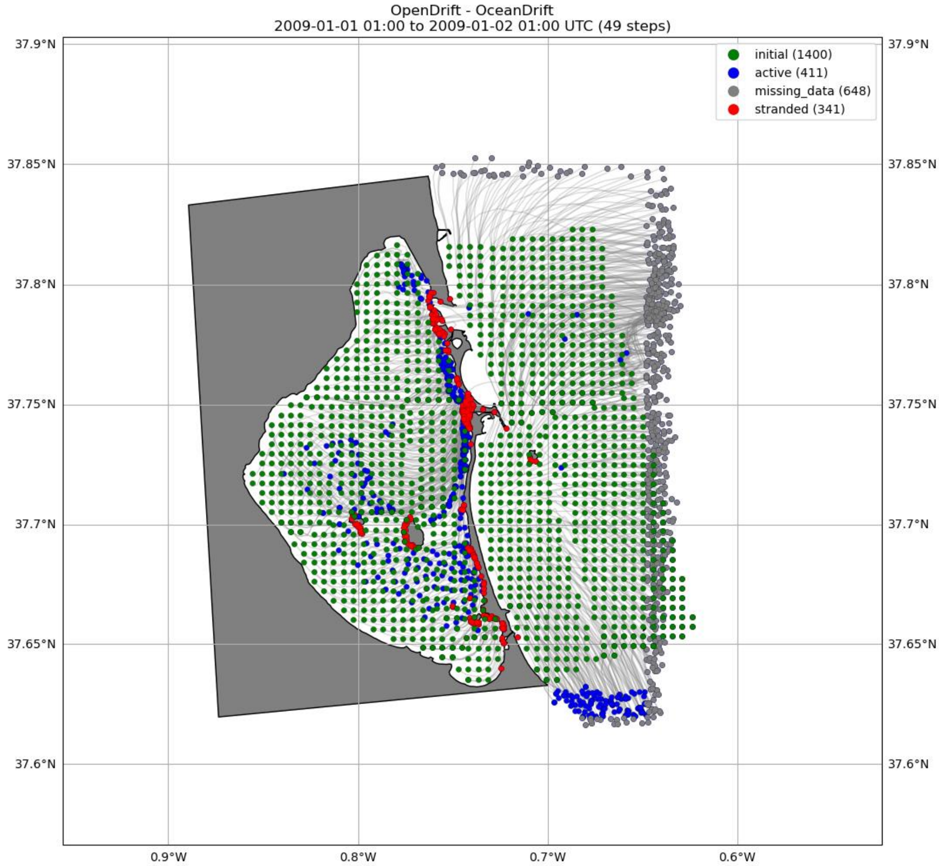

Figure 3. OpenDrift simulation of particle dispersal in the Mar Menor lagoon (annotated).

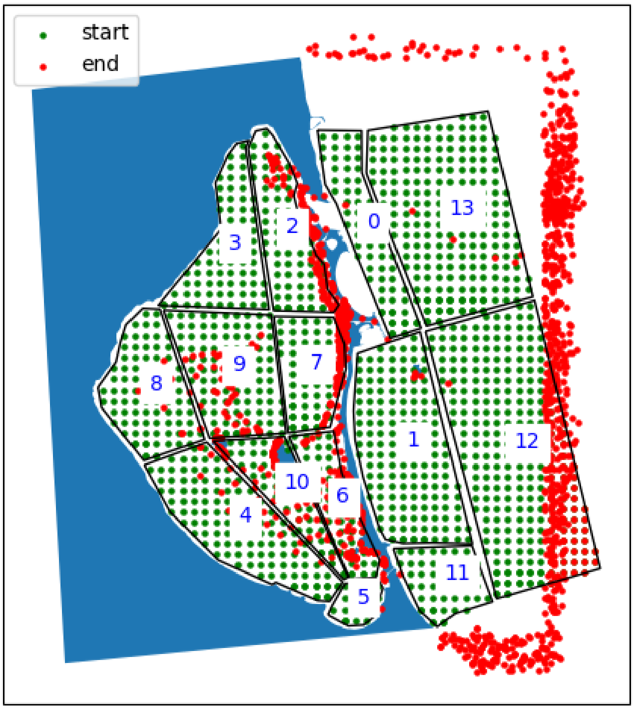

Figure 4. OpenDrift results overlaid with analysis polygons used for the Retention Clock (annotated).

5. Retention Clock Analysis

The retention clock method quantifies how long particles remain within defined regions and how they are exchanged among them. It extends a standard connectivity matrix by incorporating a temporal dimension, thereby capturing how connectivity evolves through time. This approach was originally proposed by Defne et al. (2016) to describe time-dependent hydrodynamic connectivity in marine systems.

The Python script included in this project reproduces the original MATLAB workflow presented in Defne et al. (2016). It reads particle trajectories generated by OpenDrift, loads polygon shapefiles defining the regions of interest, and performs three main steps:

1. Load and preprocess data – Read particle trajectories from the OpenDrift NetCDF output and the polygon shapefiles.
2. Compute particle-to-polygon connectivity – At each time step, determine which polygon each particle occupies, and count how many particles are located within each region. This produces a time-dependent connectivity matrix describing how particles move between polygons through time.
3. Generate Retention Clock Matrix (RCM) – Aggregate the time-resolved connectivity data into regular time intervals (e.g., 2-hours bins) and visualize them as polar plots. Each "clock" shows the evolution of connectivity between source and destination polygons over time.

All necessary input files (OpenDrift output and shapefiles) and the full notebook `retention-clock- annotated.ipynb` are available in the shared project space.

Figure 5 and 6 shows Retention Clock Matrix (RCM) for the Mar Menor test case. Each panel represents the time-dependent probability of particles released from a source polygon (rows) reaching a destination polygon (columns). Wedges correspond to successive time intervals (2 –hours in this examples), and color intensity indicates the fraction of particles transferred between regions. Dark diagonal wedges denote high self-retention, indicating that particles tend to remain within their source areas, whereas off-diagonal wedges highlight connectivity and exchange between different areas.

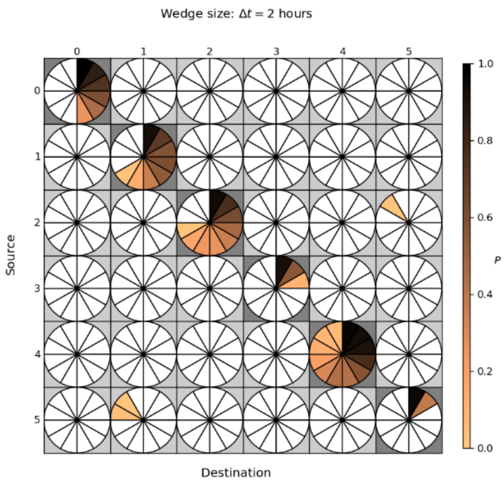

Figure 5. Retention Clock Matrix (RCM) for the Mar Menor test case (test).

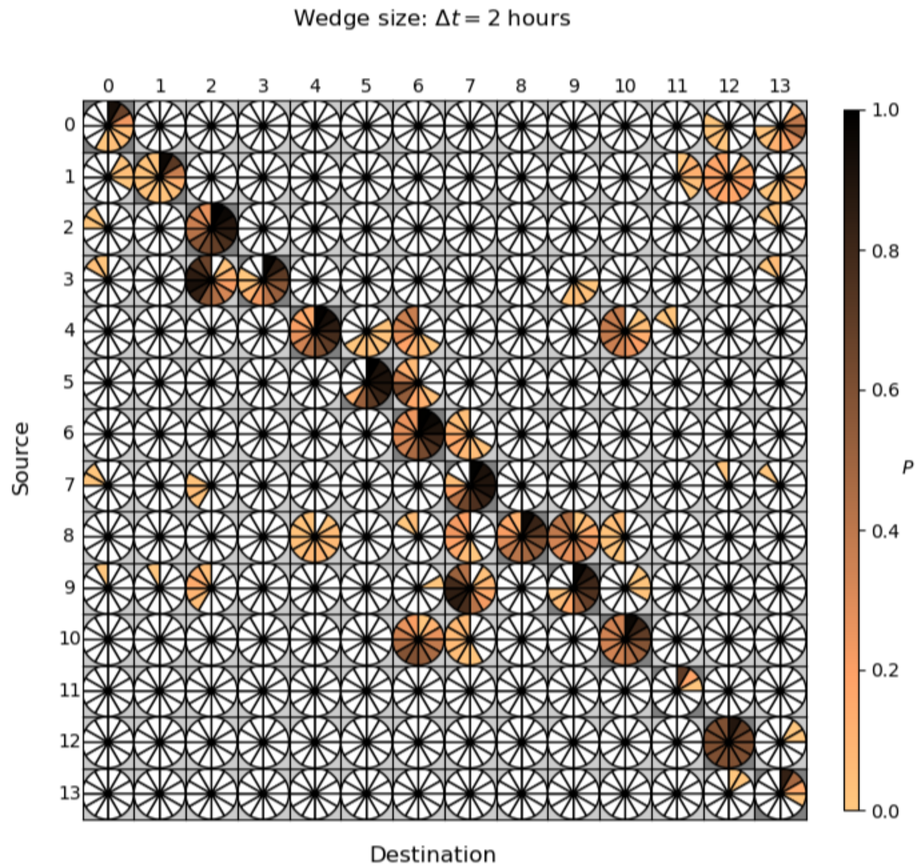

Figure 6. Retention Clock Matrix (RCM) for the Mar Menor test case (annotated).

References

Dagestad, K. F., Röhrs, J., Breivik, Ø., & Ådlandsvik, B. (2018). OpenDrift v1. 0: a generic framework for trajectory modelling. *Geoscientific Model Development*, *11*(4), 1405-1420.

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Ferrarin, C., Maicu, F., & Umgiesser, G. (2017). The effect of lagoons on Adriatic Sea tidal dynamics. *Ocean Modelling*, *119*, 57-71.

Umgiesser, G., Canu, D. M., Cucco, A., & Solidoro, C. (2004). A finite element model for the Venice Lagoon. Development, set up, calibration and validation. *Journal of Marine Systems*, *51*(1-4), 123-145.