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Campaign on Remote Sensing of Plastic Marine Litter

LOCATE: Prediction of plastic hot-spots in coastal regions using satellite derived plastic detection, cleaning data and numerical simulations in a coupled system

Executive Summary

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CONTRACT REPORT

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Acronyms

CMEMS Copernicus Marine Environment Monitoring Service

COAWST Coupled-Ocean-Atmosphere-Wave-Sediment Transport

DHI Danish Hydraulic Institute

ESA European Space Agency

N/A Not Applicable

ODE Ordinary Differential Equation

OSIP Open Space Innovation Platform

PARCELS Probably A Really Computationally Efficient Lagrangian Simulator

ROMS Regional Ocean Modeling System

SWAN Simulating Waves Nearshore

UPC Technical University of Catalonia (*Universitat Politécnica de Catalunya*)

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1 Introduction

Within the LOCATE project (Prediction of plastic hot-spots in coastal regions using satellite derived plastic detection, cleaning data and numerical simulations in a coupled system), the development of a predictive and monitoring tool was proposed to improve the regional management of floating litter in coastal areas. The tool has been built developing a marine litter dispersion numerical model coupled to hydrodynamic information, plastic data and evaluated with satellite derived information. The coupled model is envisaged to work in coastal regions and applied to the littoral region of the Barcelona city as a proof of concept with the aim to extend the concept to other regions.

This document summarizes the approach developed within the ESA's Discovery element-funded LOCATE project to detect and predict the plastic motion and accumulation in coastal areas.

2 The developed LOCATE system

The methodology used to predict and monitoring the marine litter distribution in the coastal waters of the city of Barcelona follows the combination of the following techniques:

- Numerical modelling
- Satellite derived information
- Observed plastic data

These techniques are resumed in Figure 1 and are explained in detail in the following sections.

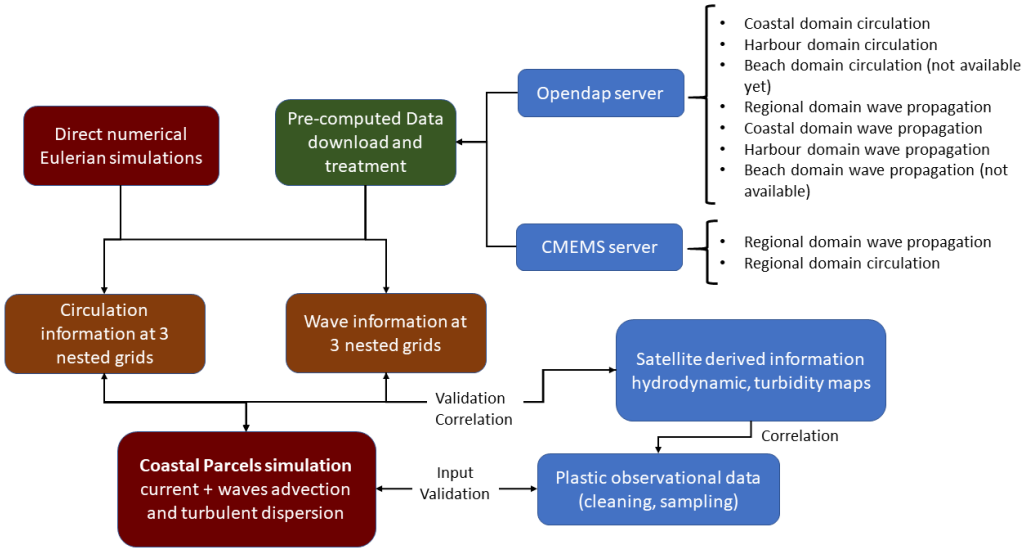

Figure 1. Working scheme of the coupled LOCATE plastic dispersion model

2.1 Numerical modelling

The marine litter coastal model (LOCATE model) is built upon the coupling of Eulerian hydrodynamic information and the Lagrangian simulation of marine litter particles using the hydrodynamic information. The coupling of the Eulerian hydrodynamic numerical model with the Lagrangian solver parcels means that two different sub-models need to be configured and optimized to obtain optimal plastic dispersion predictions (see Figure 1). The coastal numerical simulations require both high spatial coverages to simulate plastic exchange between regions and high spatial resolution close to the coastlines to solve coastal processes. This is obtained by the use of nested simulations.

Regional Eulerian hydrodynamic simulations are obtained from CMEMS products whereas the coastal hydrodynamic simulations use the open source Coupled Regional Modeling System (COAWST) system (https://woodshole.er.usgs.gov/project-pages/cccp/public/COAWST.htm). The Lagrangian solver uses the open source model Parcels (https://oceanparcels.org/).

2.1.1 Nested simulation domains

An important shortcoming in plastic dispersion predictions in coastal regions concerns the time and spatial resolution of the hydrodynamic input as well as the accurate representation of the coastal plastic transport processes. Most Lagrangian models of plastic particles do not resolve at small spatial scales needed to simulate coastal processes. On the other hand, plastic particles residence times in coastal environments can be large, travelling long distances. As a consequence, coastal numerical approaches focusing only at small scales with high spatial discretization but small spatial domain will experience plastic particles moving relatively fast (in energetic conditions) outside to the domain boundaries.

The approach of the LOCATE model to overcome this problem is to use nested domain grids with variable spatial resolution covering relatively large areas around the coastline with lower resolution nested to smaller grid subsections with larger resolution at the coastline. The nested grid domains where the hydrodynamic inputs are available are:

- **Regional domain** with a spatial grid size of 2500m. The hydrodynamic in this domain is obtained from Copernicus Marine Systems (CMEMS) IBI-MFC.

- **Coastal domain** with a spatial resolution of 350m. The model inputs are obtained from the COAWST model scheme which is nested to the regional domain (CMEMS, IBI-MFC) and forced by metocean forcing.

- **Harbour domain** with a typical resolution of 70m. The model inputs are obtained from the COAWST model scheme which is nested to the coastal domain and forced by metocean forcing.

2.1.2 Hydrodynamic numerical simulations

The hydrodynamic data that is currently available is derived from two different models:

- Wave propagation model
- Circulation model

Currently, plastic dispersion simulations assume that the driving force behind plastic movement is a linear combination of wave induced drift and mean currents. This approach is realistic in mid-low energetic conditions and in coastal regions relatively far from the coastline (100m form the coastline to the continental shelf).

The regional Eulerian hydrodynamic information (Regional grid) are obtained from CMEMS products directly downloading the required information (https://marine.copernicus.eu/). In particular the set of Atlantic-Iberian Biscay Irish (IBI) set of analysis and forecast products are used. The operational IBI system is produced daily, providing a 5-day forecast of high frequency (1 hour) hydrodynamic information.

The coastal and harbor hydrodynamics are obtained from coastal simulations performed at UPC using the ROMS numerical models. The operational coastal modelling system is developed by LIM-UPC in collaboration with *Puertos del Estado*. Therefore, regular hydrodynamic numerical simulations performed every day are available in the *Puertos del Estado* opendap web page: http://opendap.puertos.es/thredds/catalog.html.

2.1.3 Lagrangian particle simulations

The open source numerical model Parcels (Probably A Really Efficient Lagrangian Simulator) was adapted to work at a regional coastal scale using the hydrodynamic outputs previously described. Parcels is a Lagrangian model that allows user customization of the different python tools available in Parcels to produce the simulation of virtual plastic particles movement in space and time.

Parcels is a highly customizable model allowing the generation of different kernels and creating many different types of simulations. The LOCATE model incorporate the following floating particles related transport processes:

- Wave induced motion (Stokes drift)
- Coastal currents induced motion
- Dispersion
- Plastic particles beaching

The model developed here incorporates a beaching module in which the land-water boundary is detected and particles crossing the boundary are removed from the simulation and their position and time stored.

2.2 Satellite derived information

Information derived from various satellites was used in this project. For altimetry and hydrodynamic information, we used data from CryoSat2, Jason2&3, SARAL and Sentinel-3, whereas for bathymetry and water quality (turbidity) retrievals, imagery from Sentinel-2 was used. More specifically, the following satellite-derived information was used in the project:

- Hydrodynamics data from satellite altimeters (e.g., Sentinel-3). The following hydrodynamics variables have been obtained:
  - Significant wave height (SWH, Hs), average wave height (from trough to crest) of the highest third (33.33%) of the waves in a given sample period
  - Wind speed at the reference level 10 m above the sea leel
  - Surface elevation (sea level anomalies)
- Water quality (turbidity) derived from measurements of the Multispectral Instrument (MSI) onboard Sentinel-2.
- Domain bathymetry. Sentinel-2 data is used to calculate satellite derived bathymetry.

Satellite derived information has been already used to validate hydrodynamic velocities and wave heights.

3 LOCATE model results and Discussion

Numerical simulations have been performed for the 2017's year scenario using plastic inputs at the two major rivers in Barcelona (Llobregat river at the south edge and Besós river at the north side of Barcelona). The plastic input data has been obtained from visual data recorded at the two major rivers in Barcelona. Numerical simulations have been performed in the time spam covering from May to August 2017.

Numerical simulations show a complex particles motion pattern induced by the combined influence of waves, currents and the coastal orientation. Coastal orientation and the wave incidence influence in the probability of particles to return to the coastal or to remain in coastal waters. The wave energy tends to move the particles towards the coastline whereas the coastal currents tend to disperse the particles depending on current forcing variables (wind, waves, density gradients). A more detailed analysis is presented in the Full final report.

For the same period of time (May-August 2017), satellite information has been analysed to obtain turbidity. Turbidity information is presented as total suspended matter (in g/m^3). Turbidity information is compared to numerical results of particles concentration per Km^2 thorough the coastal region. Turbidity information and particles concentration for specific days are presented in Figure 2. Some correlation is found in some recirculating eddies whereas there are other discrepancies have been observed attributed to the presence of other rivers (Foix river) not considered in the numerical simulations but affecting the turbidity satellite images. The comparison between turbidity images and concentration distribution deserves a deeper future study.

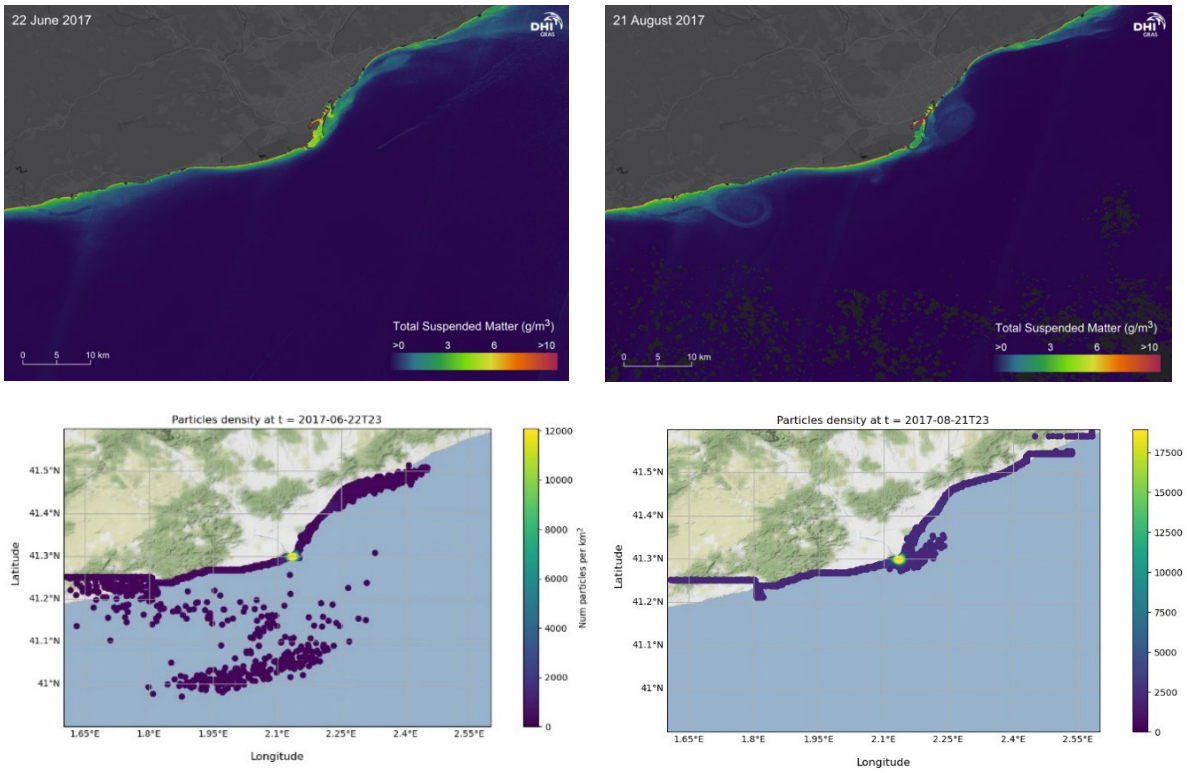

Figure 2. Satellite derived turbidity information in g/m3 of total suspended matter and corresponding particles concentration in items per Km².

4 Conclusion

A floating marine plastic dispersion model, developed in the framework of the ESA funded LOCATE project, has been presented. The LOCATE model focuses on the dispersion of floating marine debris mainly in coastal waters and in the continental shelf region close to the coastline, studying the plastic litter exchange from coastal to offshore regions.

The numerical model can reproduce the coastal processes transporting floating marine debris using nested grid domains. LOCATE model can simulate the particles motion induced by;:

- Currents generated by wind, tides and density gradient
- Waves
- Plastic beaching
- Diffusion

The LOCATE model is fully functional and it is hosted temporally in a private Git. After publication of the preliminary model results, LCOATE will be hosted in a public Git (Github) with free access to interested parties. LOCATE has been applied to several cases in the Catalan coast combining visual observation of plastics, satellite information and cleaning data. It is observed a complex transport patter influenced by the combined influence of waves, current and the coastline orientation. The

detailed influence of wave energy, wave incidence, current intensity, coastline orientation with respect to the wave incidence on particle beaching and particle export to open areas is being studied.

Future development and application of the model includes:

- Improve identification of plastic inputs and continuing to evaluate the potential link of turbidity and plastic accumulation
- Model application to observational data of microplastic accumulation in Barcelona beaches.
- Model application to simulate Marine Rescue events in coastal regions.
- Implementation of a fully coupled wave-current interaction model where wave-induced currents are accounted for.
- Improve the model robustness and the plastic input identifications to make the model operational in the Catalan coast.
- Extension of the LOCATE model scheme to other regions such as the Black Sea.
- Explore the simulation capabilities to episodic events of plastic accumulation such as “windrows”.