AtlantOS

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1. Introduction

1.1 There is an elephant in the room

According to recent estimates, over 600,000 ton of oil are spilled in the ocean every year and, surprisingly, we still ignore the impacts those spills could have in the coastal environment (US National Research Council, 2009). About 50% of the volume of oil spilled in the sea is not due to large maritime accidents (e.g. vessel explosions, foundering) but, instead, small spills generated by vessel operations (e.g. tank washing, engine leakages). It is therefore clear that both accidental and operational spills do represent a potential threat to our coasts and depicting a global oil spill hazard scenario is the first step towards an effective oil spill risk management at such scales.

1.2 Global Mapping of the Oil Hazard Across the World Ocean Coasts (GLAMOR)

The GLAMOR initiative has been proposed under the European project AtlantOS (https://www.atlantos-h2020.eu/). It aims at mapping the coastal oil spill hazard associated with the maritime traffic in the whole Atlantic Ocean, demonstrating that coordinated international efforts to observe and model the ocean can help society in solving societal impact large scale problems.

GLAMOR is the result of the research we has been carried out at the University of Bologna in coastal oil spill risk mapping. Back in 2015, after identifying a critical lack of standards in oil spill risk mapping (i.e. vocabulary, methodologies, concept of risk/hazard) and the negative impacts on the risk management, we proposed a theoretical oil spill risk assessment framework (Sepp-Neves et al., 2015). The new framework, so-called IT-OSRA, was based on a widely-accepted standard on risk management (ISO 31000:2009) and it relies on ensemble oil spill simulations to estimate the oil spill hazard and its uncertainties. For further information on IT-OSRA, the reader is referred to the original paper (Sepp-Neves et al., 2015).

In a second moment, it was identified that the methods used to analyze the IT-OSRA ensemble experiment results were not robust enough to undertake a global oil spill hazard mapping initiative (see Sepp-Neves et al., 2016). Following the positive examples given by other risk fields such as earthquakes (Gutemberg and Richter, 1944), floods and landslides (see Malamud, 2007), it was chosen to rely on the statistical distribution of our dataset for the hazard estimation.

The reader will find in section 2 an as-detailed-as-possible description of the methodology employed to map the oil spill hazard linked to maritime traffic in the Atlantic Ocean. On section 3 we present the analysis of the results in terms of probability distributions. In section 4 we briefly demonstrate how to use web-portal to give objective answers to the main questions posed when dealing with the oil spill hazard.

2. The GLAMOR methodology

As suggested in the available literature, oil spill impacts on the shore will depend on both the frequency in which pollution events occur and their magnitude (i.e. the concentration of oil found on the shore) so that to map the hazards we need to consider a probabilistic distribution of events of a certain magnitude and the corresponding number of events.

GLAMOR use an ensemble numerical oil spill modelling approach where the likely trajectory of the oil will be simulated for different met-ocean realistic conditions for one test-case year, 2013[1]. The ensemble members proposed for the GLAMOR experiment were designed to address uncertainties in variables able to modulate the frequency and magnitude of beaching events (i.e. arrival of oil at the coast):

- Where the spill will happen;
- When will the spill happen (or the meteo-oceanographic conditions during the spill event);
- How will the spill be (or the spill characteristics, namely volume and density of oil spilled, and duration of the spill);
- And, since we are dealing with numerical oil spill modeling, the what is the best oil spill model setup.

are considered to build a probability distribution for different coastal stretches, in particular the coastlines of nations bordering the Atlantic Ocean.

In order to address uncertainties on the position of the spill, 10-day-long simulations were carried out for 9689 possible Release Points (from now on referred to as RPs as well) covering a 100km-wide offshore area, with a spatial resolution of ¼ degree, where most of the maritime traffic is confined (see Figure 1). The procedure was repeated for each RP every 10 days for the 2013 currents and winds from CMEMS and ECMWF global analyses, addressing uncertainties on the met-ocean conditions during the spill. Finally, different oil spill model setups were used to run the same batch of simulations leading us to approximately 350,000 oil spill scenarios across the Atlantic per model setup[2].

2.1 Oil spill models and met-ocean inputs

The available literature shows that different oil spill models may differ in their predictions and adopting a multi-model approach can lead to improved forecasts (Liu et al., 2011; Zodiatis et al., 2016). Two Lagrangian oil spill models were used in GLAMOR, MEDSLIK-II and MOHID, and the reader is referred to the papers published by De Dominicis et al., 2013 and Janeiro et al., 2008, respectively, for further information on the models' physics. In short, all the simulations ran with MEDSLIK-II were also carried out with MOHID and included in GLAMOR as ensemble members.

Both oil spill models use 3D ocean temperature and current fields and surface winds to predict the trajectory of the spills. Daily ocean fields were obtained from the Marine Copernicus website (http://marine.copernicus.eu) with global coverage and ¼ degree spatial resolution (CMEMS GLOBAL) and 6h resolution winds from ECMWF ERA-Interim reanalysis with an 80km spatial resolution. The bathymetry used in GLAMOR was furnished by GEBCO with a 30'' resolution and coastlines were downloaded from NOAA GSHHS website.

[1] The authors are fully aware that the current number of years covered is insufficient to regard all the possible met-ocean conditions. GLAMOR is an on-going project and further years will be included and the quality of our outputs updated periodically.

[2] The description of our experiment corresponds to what will be achieved by the end of the project.

Figure 1 Release Points off the African coast and islands.

3. Analysis of the model ensemble simulations

It is not a trivial task to extract useful information from hundreds of thousands of oil spill scenarios. Our first step was to propose a list of questions we MUST answer to give support to decision and policy makers:

- In case of a spill at a given release point, what is the most likely fate of the oil?
- Which areas of the Atlantic maritime corridors (or any subarea) represent more threat to the coastal environment?
- Which coastal areas are exposed to higher hazard levels and which are less exposed?

To properly answer these questions, we should try to give probabilistic answers that reflect the uncertainty of our results.

Oil spill models are able to predict the temporal evolution of several spill variables. GLAMOR is focused on the coastal oil spill hazard and, consequently, we limited our analysis to two variables: the concentration of oil found at the coasts (in tons of oil per km of coastline) and the concentration of oil at the sea surface (tons/km2) (see Figure 2).

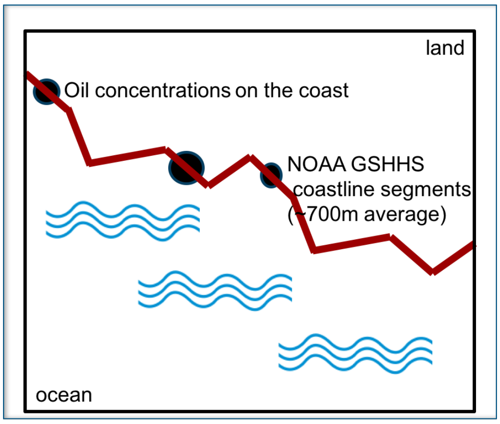


Figure 2 Scheme representing the data used to estimate the oil spill hazard in GLAMOR. Black dots represent different oil concentrations (in tons/km) found at the coastline segments (obtained from NOAA GSHHS repository).

As a first exercise, all the non-zero beached oil concentrations estimated by each of our ensemble members (after 240h of simulation) were put together into a histogram (Figure 3). The message was clear: 1) most of the beaching events occurred during our experiment involved small concentrations of oil, 2) the range of concentrations found on the coast covered several orders of magnitude and 3) the number of high concentration events, although relatively small, involves high volumes of oil and cannot be neglected.

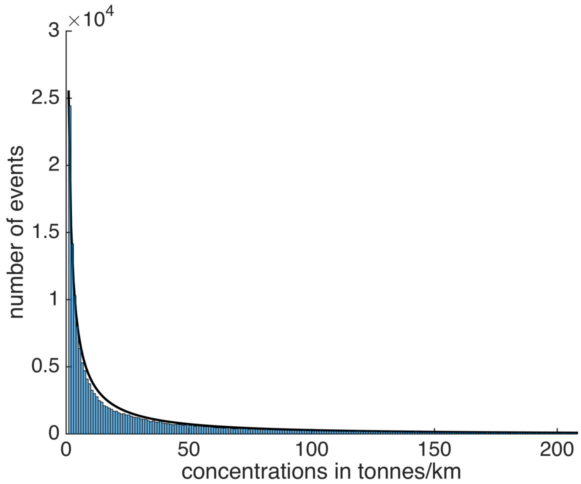


Figure 3 Example of a beached oil concentration histogram obtained after approx. 25,000 simulations in a pilot area (Southern Portuguese coast). Solid black line corresponds to the Weibull fit.

After getting acquainted with our results, we proceeded to identifying the most suitable statistical distribution to describe our dataset. The characteristics of our data suggest an exponential-like distribution, more precisely a Weibull distribution defined by:

$$W(x) = \frac{b}{a}\left(\frac{x}{a}\right)^{b} e^{-\left(\frac{x}{a}\right)^{b}} \quad (1)$$

where a and b are the shape and scale parameters, respectively, and x, in our case, the concentration of oil at the coast.

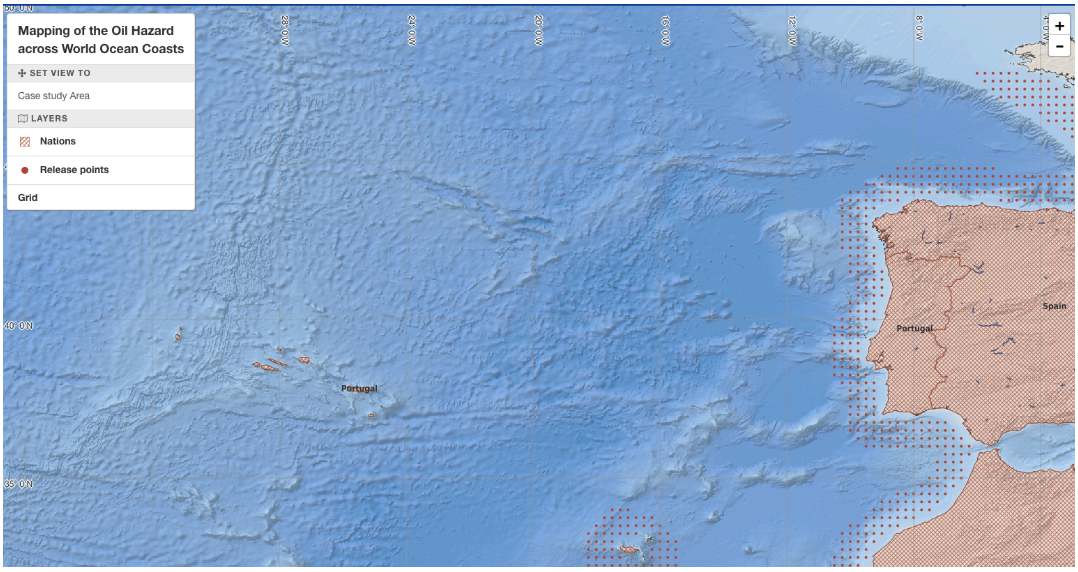
4. GLAMOR questions and answers

In the following paragraphs, we will show how GLAMOR can be used to support the oil spill risk management at an Atlantic Ocean scale. Three are the questions that can be answered with GLAMOR:

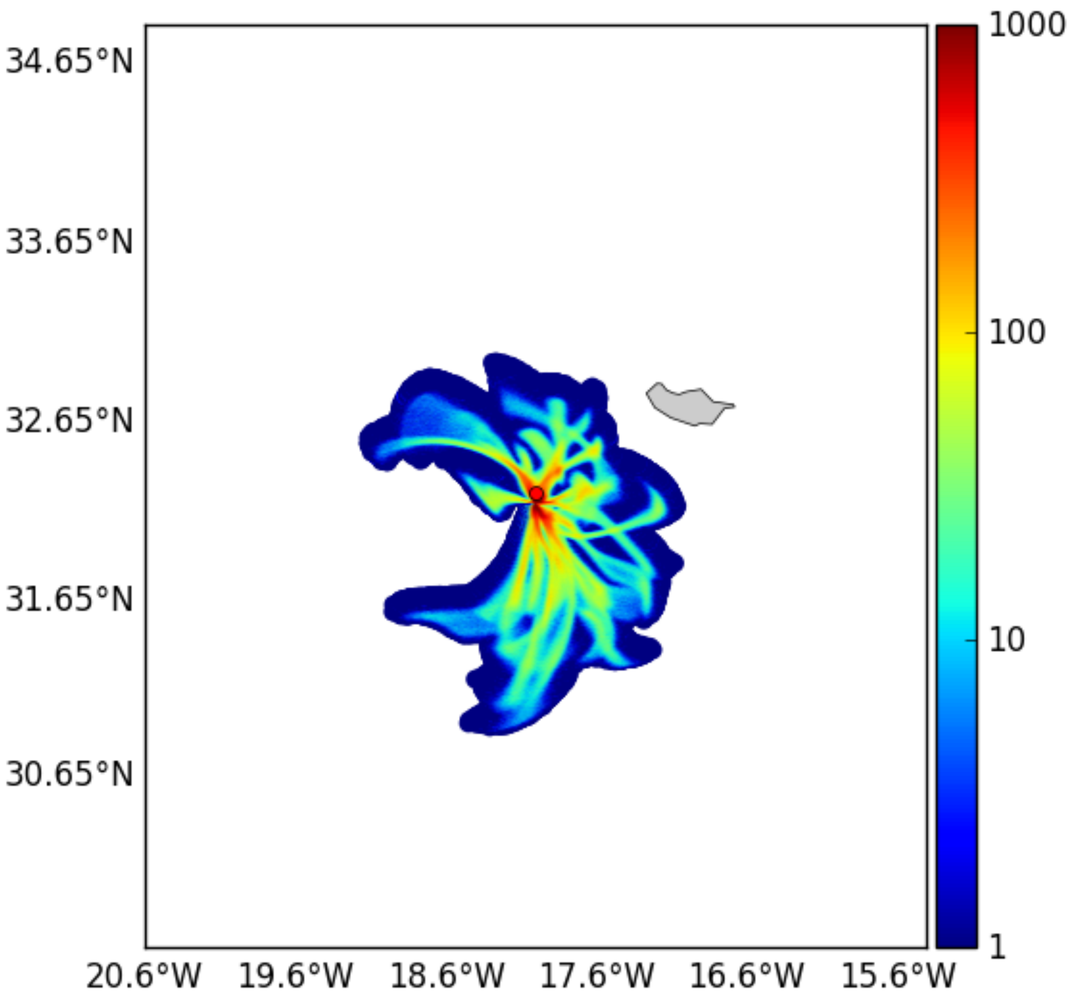
4.1 What is the most likely fate of the oil?

As a first approach, 36 spill scenarios (one year of simulations using a single oil spill model setup) are simulated for each release point in GLAMOR with different trajectories and impacted areas. The most likely fate of a spill considering a certain release point will depend on the meteo-oceanographic conditions that will modulate the oil weathering and transport. In this sense, we chose to answer the proposed question through maps of cumulative oil concentration at the sea surface.

The user, by opening the GLAMOR web-portal and clicking on "Service Portfolio" -> "Access to products" will be directed to the oil spill hazard GIS. In Figure 4a we have a general look of the release points off the Iberian Peninsula extracted from the GLAMOR website. By clicking on any of the release points, the user will get a map of the spill most likely fate based on the cumulative oil concentration at the surface (Figure 4b). Areas with higher cumulative concentration are either affected by frequent but small magnitude pollution events or a few rare and large events.



(a)



(b)

Figure 4 (a) Sample from GLAMOR showing release points of the Iberian Peninsula. In (b) we see a map of cumulative concentrations of all spills originated at the RP marked in red. Concentrations in tons/km2

4.2 Which areas of the Atlantic maritime corridors (or any subarea) represent more threat to the coastal environment?

To be implemented by the end of the experiment.

4.3 Which coastal areas are exposed to higher hazard levels?

As a first approach, the ensemble average beached oil concentration was used as a proxy of the oil spill hazard in a given area. So far, the hazard index has been computed at the national level with three exceptions, USA, Brazil and Argentina, where the indexes were assigned to coastal states due to the large extent of their territories. The ensemble standard deviation was used as a measurement of the uncertainty in the hazard estimates. The average (2) and standard deviation (3) were calculated from the Weibull distribution fit to the frequency histogram (Figure 5). For such a distribution it is:

$$\mu = a\Gamma(1 + {}^{1}/_{b}) \quad (2)$$

$$\theta = \sqrt{a^2\left[\Gamma\left(1 + \frac{2}{b}\right) - \left(\Gamma\left(1 + \frac{1}{b}\right)\right)^2\right]} \quad (3)$$

where a and b are the shape and scale parameters, respectively, and Γ the Gamma function.

The hazard is then presented as the histogram of the simulated beached oil concentrations in the area, the fit with a Weibull distribution, the average concentration (i.e. oil spill hazard) and standard deviation (i.e. uncertainties) (Figure 5) deduced from the fit of the distribution.

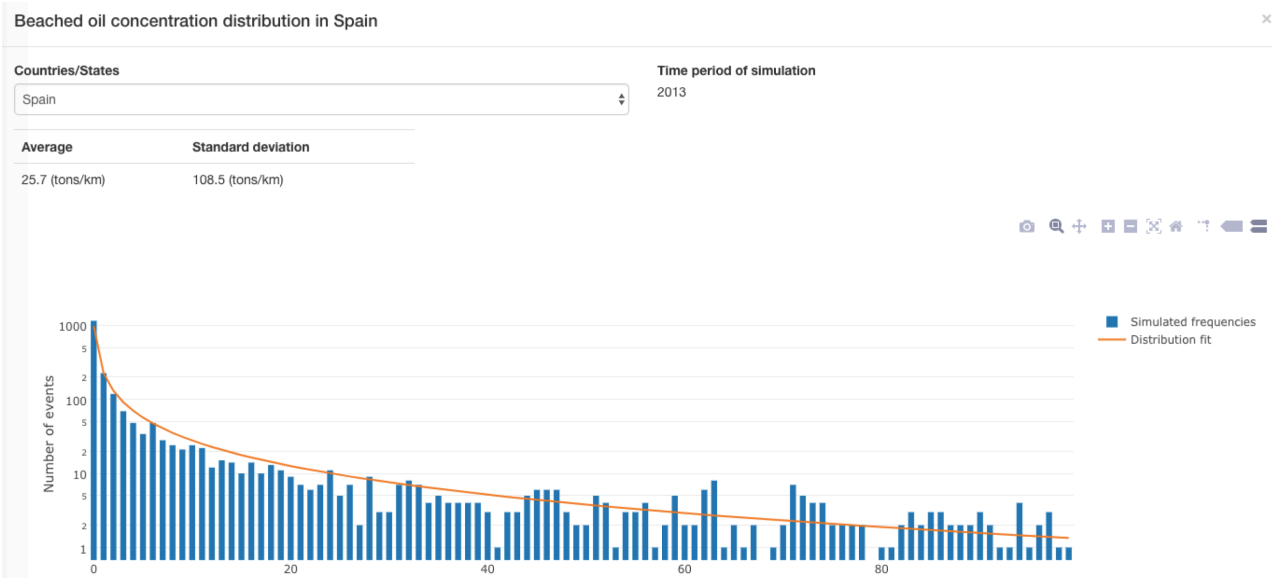


Figure 5 Snapshot from GLAMOR-web showing oil concentrations histogram for the Spanish territory with the fit, sample average and standard deviation (upper left)

5. The GLAMOR Web Portal

All the results provided by GLAMOR can be obtained through an open and free web-based oil spill hazard GIS (https://glamor.sincem.unibo.it) and the website was conceived to be intuitive and give a smooth experience to the end user.
The GLAMOR end users will find extra material in the website aimed to support a smooth and profitable use of the available products. The website is structured as presented in Figure 6 and its contents are summarized in the coming subsections.

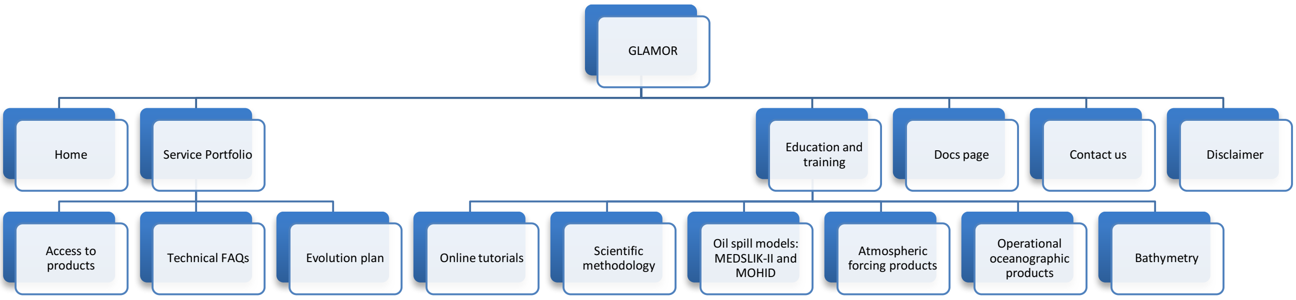


Figure 6 GLAMOR website structure

5.1 Home

This is the coastal oil spill hazard mapping Bulletin containing the coastal oil spill concentration distributions from an ensemble of oil spill simulations with release points chosen to be along a 100-km band near the whole Atlantic coastline. Two oil spill models were used (MEDSLIK – II and MOHID) coupled with Copernicus Marine Environment Service current analyses and ECMWF reanalysis wind and air temperature fields. For the first time the probable distribution of oil due to such releases is given for many coastal segments, together with uncertainty estimation.

5.2 Service portfolio

Access to products

Presentation of the web-GIS. See Section 1 of this report for further information.

Technical FAQs

Still need to contact us?
Send us your comments.

What does RP mean?

RP stands for "Release Point". In the IT-OSRA method we address the widest range of spill scenarios occurred off the coastline of interest and the simulated spills are originated at the pre-set RPs. In order to get more information on how the RPs were defined (especially the distance between two neighbouring RPs), check Sepp Neves et al., 2017.

What is the unit of measure of the Oil Spill Hazard maps?

In GLAMOR, we opted for employing the average concentration (in tons of oil per km of coast) found on the coast as a proxy of the oil spill hazard. The average (and standard deviation) is computed assuming a Weibull distribution using the outputs of the available simulations.

How were the ensemble members defined?
The ensemble members configuration was based on the available literature, trying to cover the uncertainties typically observed in oil spill events (see Sepp Neves et al., 2015 and 2016).

Can I use the GLAMOR results to have a reliable estimate of the hazard at my beach?
No. GLAMOR was thought and executed focused on giving a general picture of the oil spill hazard in the Atlantic basin. We should always bear in mind that the ocean fields used have a 1/12-degree resolution and do not fully reproduce the circulation close to the shore.

Evolution plan
GLAMOR is a dynamic webpage. Ensemble oil spill experiments are resource demanding and our website will be therefore built in steps.
The GIS system/webpage will be updated every six months adding more ensemble members and covering a longer time spam, improving our capability to address the uncertainties inherent to the oil spill hazard in the Atlantic coastlines.

5.3 Education & Training

Online tutorials

Scientific methodology
Oil spill hazard mapping from simulations builds the oil spill distribution along the coasts sampling the current fields every 5 days and using oil sources of pollution generated in a 25 km grid all along the coastlines.

The oil spill hazard mapping method applied in GLAMOR is based on the work developed by Sepp Neves et al., (2015) and later improved by Sepp Neves et al., 2016. The methodology is aligned with modern and standardized concepts of risk (ISO 31000 – Risk management principles) critically adapted to the oil spill case. The user can find the theoretical basis of our method in Sepp Neves et al., 2015.

The reasoning behind the ensemble members' configuration is presented in Sepp Neves et al., (2016), where the user will also find the results obtained with a small-scale case study carried out off the Portuguese coast. Missing points detected during the case study were solved and a robust oil spill hazard quantification method has been proposed employing an objective criterion to evaluate the suitability of the experiment setup.

The AtlantOS experiment setup[3]

Here the details for the model setup for the oil spill hazard bulletin

—Release Point grid: 1/4deg

—Spatial coverage of RP grid: coastal band (30 – 130 km offshore) covering ice-free areas in the Atlantic

—Number of parcels released in the simulations: 25,000 representing 10,000 tons (accidental scenarios)

— Oil API: 38

[3] The setup corresponds to the first ensemble member representing a frequently observed accidental oil spill. Further tests are being carried out to design an optimal list of complementary ensemble members and for operational spill scenarios.

— Current fields: CMEMS Global ocean daily analyses (1/12deg)

— Wind fields: ECMWF ERA-Interim Reanalysis

— Wave fields: Stokes drift disregarded

— Temporal coverage: only 2013 for now

— Number of simulations to be performed: ~600,000 x 2

Oil spill models: MEDSLIK-II & MOHID

MEDSLIK-II

GLAMOR uses MEDSLIK-II, an open and free oil spill model able to reproduce the transport and weathering processes taking place in spill events (http://medslikii.bo.ingv.it/). A paper on the model equations and structure is found in De Dominicis 2013a. Very useful information on the model calibration using real spill cases can be found in De Dominicis 2013b.

MOHID Oil Spill module

The MOHID water modelling system is a modular system including modules for several processes of the marine environment (physical, chemical and biological), which can communicate in real time during a simulation.
MOHID Oil Spill module is used in GLAMOUR as an ensemble member in the oil spill simulations. More details on the Oil module and its implementations can be found in Janeiro et al., (2008) and Janeiro et al., (2017).

Atmospheric forcing products

The atmospheric reanalysis ERA-Interim from the ECMWF was chosen as our wind input to guarantee consistent wind fields for the whole Atlantic and throughout the simulated period. Currently, ERA-Interim 10m winds are available with 0.5deg spatial resolution with a 6h interval.

Operational oceanographic products

Oil spill transport is modeled using the daily CMEMS global ocean products, freely available here. GLAMOR uses the CMEMS **daily analysis** current fields at 1/12-degree resolution. The top 150 m currents are used by the oil spill models to drive the Lagrangian movement of oil parcels from the initial release points.

Bathymetry

The bathymetry used in our experiment is based on the open and free GEBCO database. The bathymetry field, originally available with a 30' spatial resolution, was interpolated to the current field grid with a final resolution of 1/12-degree.

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