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Towards improving the representation of beaching in oil spill models: A case study

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ABSTRACT

Oil–shoreline interaction (or "beaching" as commonly referred to in literature) is an issue of major concern in oil spill modeling, due to the significant environmental, social and economic importance of coastal areas. The present work studies the improvement of the representation of beaching brought by the introduction of the Oil Holding Capacity approach to estimate oil concentration on coast, along with new approaches for coast type assignment to shoreline segments and the calculation of permanent oil attachment to the coast. The above were tested for the Lebanon oil spill of 2006, using a modified version of the open-source oil spill model MEDSLIK-II. The modified model results were found to be in good agreement with field observations for the specific case study, and their comparison with the original model results denote the significant improvement in the fate of beached oil brought by the proposed changes.

1. Introduction

A general image on the processes and respective drivers controlling the fate of oil spilled in the sea, can be drawn from Fig. 1. Focusing on coastal areas, oil behavior at the shoreline depends on a number of interrelated factors that can be summed up to three categories: (a) oil properties, (b) coast type and beach properties, and (c) coastal hydrodynamics.

Oil–shoreline interaction – or "beaching" (the term that prevails in literature) – is an essential part of oil spill impact assessment, as it regards the definition of the location and extent of oiled shorelines, the amount of oil that reaches and stays at the shore, as well as the temporal characteristics of the processes in action. These processes (that follow oil attachment to the coast) are far too complicated and – still – not deeply understood, due to the great amount of parameters and uncertainties involved in the physical problem. Wave and tide action on the foreshore, combined with the complex two-phase flow (water–oil) and ongoing oil weathering, seem to create an insurmountable obstacle for the detailed representation of the phenomenon. Accordingly, research attempts to describe it until now follow the approach of parametrizing the behavior of "beached" oil based on available field data, laboratory experiments and approximations adopted from groundwater hydraulics.

Gundlach and Hayes (1978) set the basis for coast type dependent parametrization of beaching, proposing a method for classifying shorelines according to their vulnerability. The classification, expressed by the "Vulnerability Index", was to reflect the sensitivity of each coast type to oil pollution. Based on the same notion, Torgrimson (1980) suggested the use of half-life values to describe the rate of oil re-entrainment after its attachment to the shoreline; the specific approach has become one of the most widely used in oil spill modeling (see details in Section 2.4). Equally widespread is the approach to use a limiting value for the total amount of oil than can be accumulated on shore, commonly referred to as Oil Holding Capacity (henceforth denoted by OHC).

OHC is defined as the maximum oil volume the beach can actually hold. A series of different methods to estimate OHC have been proposed over the years. Gundlach (1987) developed OHC and oil removal coefficients for different shoreline types, based on field data from the Amoco Cadiz, Ixtoc I and Urquiola spills. Owens and Teal (1990) proposed an organized set of activities for data collection after shoreline impact (see Section 2.3 for details), resulting in OHC estimates appropriate to be used as case-independent values in the absence of better data. Cheng et al. (2000) proposed an empirical formula for the calculation of OHC, based on field data from Gundlach (1987) and Reed et al. (1989), and the notion that the maximum loading expressed by OHC can be divided in a sur-

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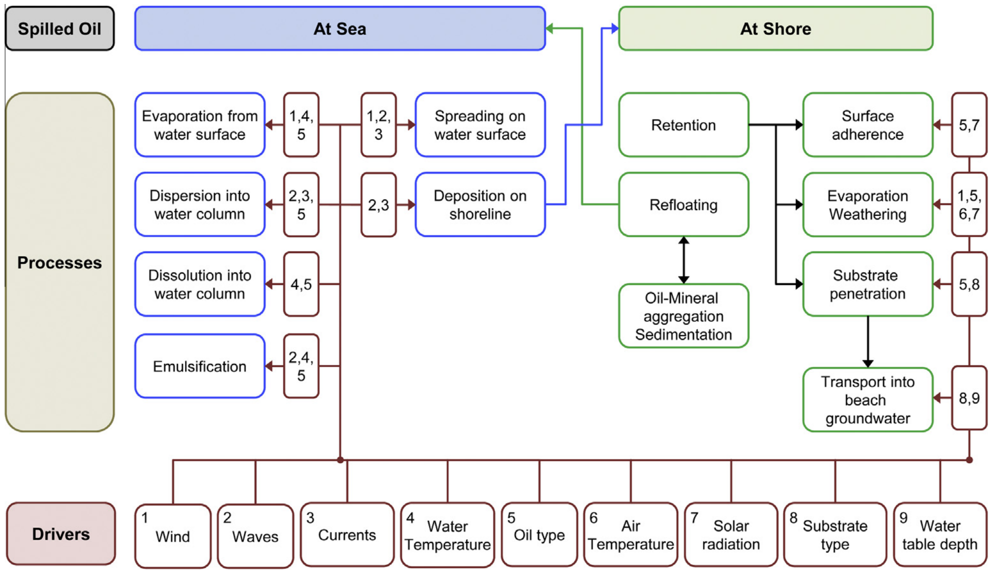

Fig. 1. Schematic representation of interrelated oil fate processes and drivers (figure redrawn and modified after Etkin et al., 2007).

face and a subsurface component. Humphrey et al. (1993) suggested the calculation of OHC based on fundamental hydraulic modeling, proposing a formula including geometric properties of the beach (length, width, depth) and its effective porosity to represent the volume fraction that "entraps" oil. Based on the aforementioned approach, Boufadel (2000) proposed a methodology to calculate OHC incorporating the response to tide of the water table in the beach. Useful insights in the described processes, or even direct estimates of OHC, can be extracted from extensive field trial data as well (e.g. the Svalbard Shoreline Field Trials; Sergy and Goodman, 2003).

The use of approaches described in the previous paragraph can be found in a series of models and respective case studies. Indicative reference can be made to the work of Shen et al. (1987), Cheng et al. (2000), Chao et al. (2001), Wang et al. (2005), Guo and Wang (2009), and Danchuk and Willson (2010).

A separate case is that of the coastal oil spill model COZOIL (Reed et al., 1989), which includes explicit representations of the active processes that affect the fate of an oil spill in the nearshore, foreshore and backshore. However, the model aims to simulate mainly nearshore spills, and its conceptual/structural differences from typical operational spill models (based on the Eulerian–Lagrangian approach) restrain its use to smaller-scale applications.

The present work studies the improvement of the representation of beaching brought by the introduction of coast type- specific Oil Holding Capacity estimates, along with a new algorithm for coast type assignment to shoreline segments and a new approach for the calculation of permanent oil attachment to the coast based on the half-life approximation. The above are tested for the Lebanon oil spill of 2006, using a modified version of the open-source oil spill model MEDSLIK-II (De Dominicis et al., 2013a). The modified model results are found to be in good agreement with field observations for the specific case study (OSOCC, 2006); their comparison with the original model results denote the significant improvement in the fate of beached oil brought by the proposed changes.

2. Materials and methods

2.1. MEDSLIK-II: A Lagrangian oil spill model

MEDSLIK-II (De Dominicis et al., 2013a) is an oil spill model for surface oil slicks in the marine environment. The processes of transport and weathering of oil are simulated using a Lagrangian model formalism coupled with an Eulerian circulation model. The system is identified by structural, oil slick and particle state variables. Structural state variables, i.e. the components of oil concentration (at coast – surface – dispersed – at the bottom), are obtained based on the definition of the other two sets of variables. Oil slick state variables are used for the representation of the transformation processes (evaporation, spreading and dispersion), which are considered to act on the bulk slick volume based on the fate algorithms of Mackay et al. (1980); these variables regard the definition of the surface and dispersed volumes of the slick. The Lagrangian particle formalism is then applied decomposing the bulk volume into N constituent particles, each of them characterized by a number of particle state variables (i.e. particle volume, particle status index identifying the classes correspondent to the four structural state variables, and particle position vector). Oil concentration is calculated afterwards by assembling the Lagrangian particles together, along with their associated properties. The processes of interest in the present work will be further discussed in Sections 2.2, 2.3 and 2.4; a detailed description of MEDSLIK-II in the framework of Lagrangian oil spill modeling can be found in De Dominicis et al. (2013a) and the model validation in De Dominicis et al. (2013b).

2.2. Coast type data and assignment to shoreline segments

A sound mathematical formulation of oil–shoreline interactions is by itself not enough to improve the representation of beaching in oil spill models, especially since the involved processes are largely affected by coast type, beach properties and their variation in the area of interest. Accordingly, the availability of field data and their correct assignment to the segments used to reconstruct the shoreline is essential for operational oil spill models. This intuitively deduced claim can be supported by any respective sensitivity analysis, as was done for MEDSLIK-II in this work before the final model applications.

Regarding coast type data, the improvement for the Lebanon oil spill that is studied in the present work (see Section 2.5) was based on the Oil Spill Operations and Coordination Centre Report (OSOCC, 2006). The report identified 30 points of known coast type (Fig. 2a); this dataset was extended with the addition of 163 additional points (Fig. 2b), identified on the basis of their proximity to