Marine Pollution Bulletin 58 (2009) 967–975

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Model-based long-term reconstruction of weather-driven variations in chronic oil pollution along the German North Sea coast

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ARTICLE INFO

Keywords:
Hydrodynamic modeling
Coastal oil pollution
Lagrangian trajectories
North Sea
Beached bird surveys

ABSTRACT

Lagrangian passive tracer transport simulations covering the 46-year period 1958–2003 were utilized to compare the exposures of different parts of the German North Sea coast to ship-related chronic oil pollution. Assuming the spatial distribution of oil releases to be proportional to estimated ship traffic density, detailed drift reconstructions allowed for the reconstruction of wind-induced inter-annual variations in coastal pollution. For the winter months, a statistical relationship between simulated advective transports and prevailing sea surface pressure fields was established via Canonical Correlation Analysis. Wind effects were found to be more important for the northern (Schleswig-Holstein) than for the southern (Lower Saxony) part of the German North Sea coast. For Schleswig-Holstein, simulations showed consensus with beached bird survey data from this region. Proper identification of weather-driven inter-annual and spatial variations in monitoring data helps to avert misjudgments with regard to trends in the general level of chronic oil pollution.

1. Introduction

Chronic oil pollution in the North Sea is a serious problem with consequences such as bird die-offs occurring along the German coast. An increased awareness of the distinctive effects of chronic oil pollution has resulted in great efforts to reduce the amount of oil spilled into the sea (International Maritime Organization, 1982, 2002; Reineking and Vauk, 1982). Finally, in 1999 the North Sea was declared a so-called "Special Area" (International Maritime Organization, 2002) resulting in the prohibition of any oil discharge, including oil dumping from ships. Discoveries of oil-contaminated seabirds that were not correlated with recorded ship accidents (Fleet and Reineking, 2000), as well as oil spills observed by aerial surveillance (Carpenter, 2007), provide evidence that chronic oil pollution is a persisting problem. The quantification of continuous oil pollution, however, is difficult. Schallier et al. (1996), for instance, estimated that approximately 90% of chronic oil pollution in the North Sea has not been detected by aerial surveillance (Schallier et al., 1996). On this account and in addition to the statistics of observed oil spills, other indicators are used to estimate changes in the general level of oil pollution, e.g., the results from beached bird surveys.

In the present paper, we compare the exposures of different coastal areas in the German Bight to ship-related oil pollution by simulating the drift of hypothetical oil spills from various locations. A large sample of simulations was performed using model-based reconstructions of realistic weather conditions that occurred within a 46-year period (1958–2003). The assumption of traffic-related, spatially inhomogeneous oil inputs allowed for a quantitative estimate of wind-related temporal variability in coastal oil pollution. Correlations between prevailing sea level pressure (SLP) fields and the advection of oil spills towards the coast were statistically analyzed with Canonical Correlation Analysis. Finally, we employed survey data on beached, oil-contaminated seabirds for a qualitative validation of our simulations. The investigations presented here contribute to a better understanding of the inshore advection processes of oil pollution and may provide useful information to improve monitoring strategies.

The paper is structured in the following way: Section 2 outlines our general approach (Section 2.1). The hydrodynamic data upon which our Lagrangian simulations were based is described in more detail in Section 2.2. The description of model aspects is followed by a short summary of beached bird survey data (Section 3). Section 4 discusses the outcomes of our Lagrangian tracer simulations (Section 4.1) and their dependence on the mean prevailing weather conditions (Section 4.2). In Section 4.3, the results of our simulations are contrasted with the beached bird survey data. Finally, we summarize our conclusions in Section 5.

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doi:10.1016/j.marpolbul.2009.03.009

2. Drift reconstructions

2.1. Conceptual design

Variability of the exposure of German North Sea coastal regions to chronic marine oil pollution was estimated by means of hydrodynamic drift simulations. Past research involving the analysis of oil samples taken from beached bird corpses has ascertained that heavy fuel oil (deliberately) discharged from ships is the main pollutant in this area (Dahlmann et al., 1994). Aerial observations reveal that the majority of illegal and accidental oil spills in the North Sea are encountered along the busy shipping routes (Reineking, 2005). Hence, source regions for hypothetical oil spills were defined to contain the main shipping lanes in the southern part of the North Sea (cf. Fig. 1a). We confined ourselves to the investigation of regional differences and weather-related variation. The effects of possible changes in the magnitude of oil discharge were not the subject of our study.

Oil drifts were represented by simple Lagrangian passive tracer transport calculations. However, by re-weighting the tracer particle density according to an assumed exponential particle decay time of 21 days (overall integration time was 60 days), we approximated the effects of oil-weathering processes. A realistic spectrum of prevailing weather conditions was taken into account by performing the trajectory calculations based on reconstructed atmospheric wind and two-dimensional North Sea current fields. High-resolution simulated fields stored on an hourly basis, for a 46-year period (1958–2003), were taken from the coastDat database (cf. Section 2.2). In addition to current-induced particle drift components, an extra wind drift factor was introduced (for details see Section 2.2).

The relative extents to which different areas along the German North Sea coast are exposed to hypothetical oil spills (see Section 4.1) were assumed to be proportional to the number of simulated particle trajectories that reach the different target regions (cf. Fig. 1b). The assumption of a limited particle lifetime gives more importance to particles that originate from source regions closer to the coast.

Initially (Section 4.1.1), spatial variations of the probability that an oil spill occurs are not taken into account. In this case, model simulations describe the extent to which coastal regions would be affected by a hypothetical oil spill as a function of their locations, irrespective of the oil spill's incidence rate. In a second step (Section 4.1.2), we assume that the probability of an oil spill is proportional to the density of vessel traffic, which leads to a re-weighting of the trajectory drift calculations. From large ensembles of detailed simulations, we derive the annual mean conditions for summer (April–September) and winter (October–March), respectively. In Section 4.2, multivariate statistics are used to describe the relationship between spatial variations in the potential endangerment of the German North Sea coastal areas and changing weather conditions as represented by SLP fields. Inter-annual variations in advection processes caused by changing weather conditions are also investigated. For this analysis, we focused on the

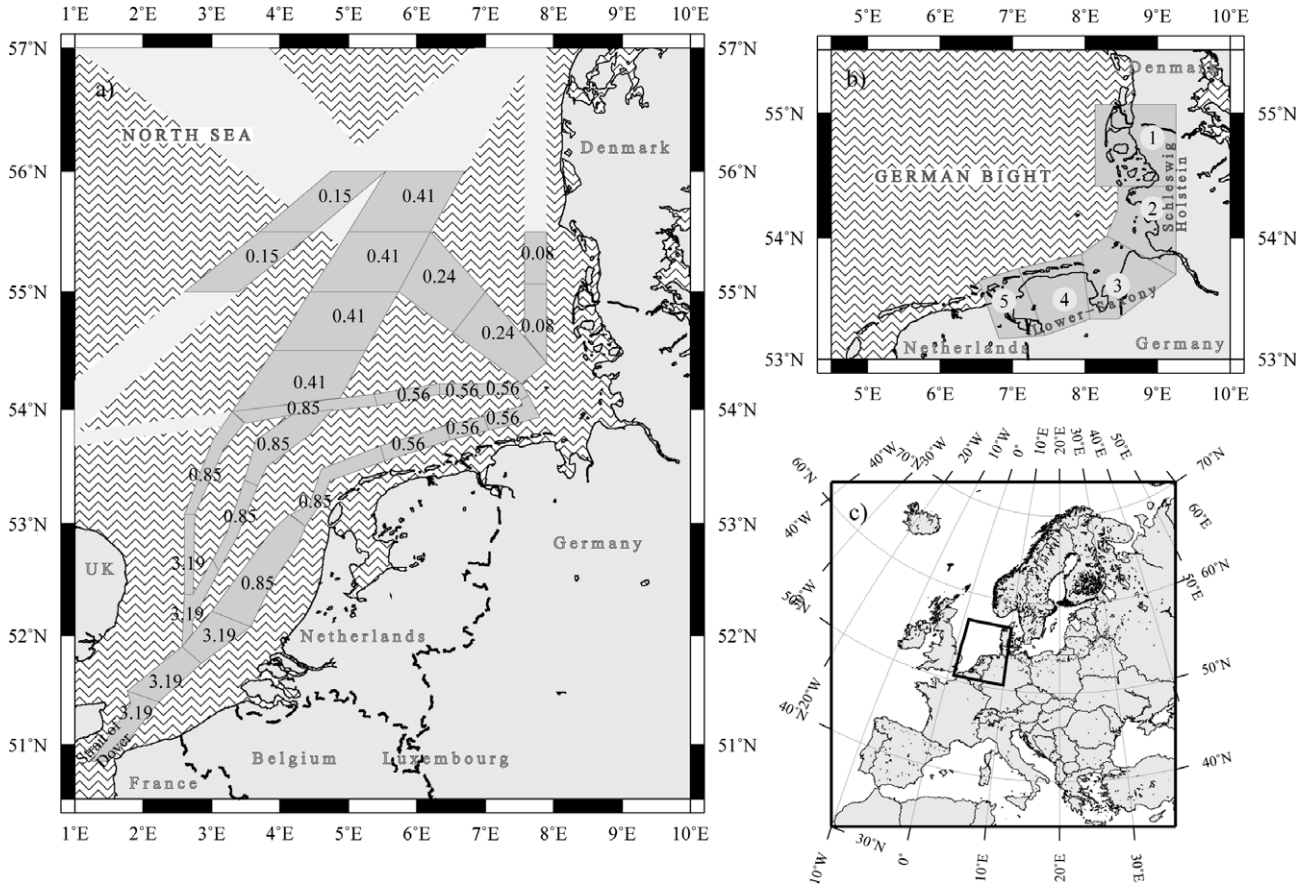

Fig. 1. Particle source and target regions of the model set-up. The particle source regions along the major shipping routes of the North Sea (gray shaded areas in panel a) show the assumed weighting factors for modeling oil incidence rates as proportional to the ship traffic density (derived from ship occurrence estimations from Golchert and Benshausen (1987)). Because of the distance to the coast, the bright regions of the shipping lanes were not included in the simulations. Target regions (panel b) along the German North Sea coast are labeled 1–5 for further reference. Panel c provides the geographical orientation of the region of interest (framed).