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# Identifying potentially high risk areas for environmental pollution in the Baltic Sea

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The study aims at the identification of areas in the Baltic Sea from where potential pollution is transported to vulnerable regions. Generally, there is higher risk of ship accidents along the shipping routes and along the approaching routes to the harbors. The spreading of harmful substances is mainly controlled by prevailing atmospheric conditions and wind-induced local sea surface currents. Especially, spawning, nursery and tourist areas are considered high-vulnerable areas. With sophisticated high resolution numerical models, the complex current system of the Baltic Sea has been simulated, and with subsequent drift modeling areas of reduced risk or high-risk areas for environmental pollution could be identified. In a further step, optimum fairways of reduced risk could be obtained by following probability minima of coastal hits or maxima for the time it takes to reach the coast. The results could be useful for environmental management for the maritime industry to minimize the risk of environmental pollution in case of ship accidents.

## Introduction

Marine ecosystems are usually divided into open sea and coastal areas. The latter are generally known as the major life reproduction areas and play a major role in restoring natural resources for human consumption. Thus, they are most vulnerable to accidental discharges of harmful substances and can be considered examples of "highly valuable" sea regions. Variations in atmospheric forcing conditions result in variability of ocean circulation and hence in spatio-temporal differences of transport patterns of these substances. Thus, from these results, probably spatio-temporal separations of "high" and "low" areas of pollutional risk probability could be identified. However, combating environmental pollution at open sea is generally more effective and less expensive than in shallow coastal areas.

Since the political change in eastern Europe more than 20 years ago, the intensity of international cargo shipping has drastically increased, and is expected to increase further in future (BACC Author Team 2008). Presently, traffic in the Baltic Sea is heavy, accounting for approximately 15% of the world's cargo transportation. A growing tendency in cargo transportation was recorded for the most recent years, especially with respect to oil tankers (HELCOM 2010). In the Baltic Sea including the Kattegat, 76 ports handle more than 1 million tonnes of cargo per year. The busiest port is St. Petersburg, Russia, with more than 14 500 ship operations per year. The number of ship operations (passages,

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excluding ferry traffic) is estimated at 150 000 per year (Gollasch and Leppäkoski 2007), and it is assumed that shipping activities will considerably increase in the near future (Höglund and Meier 2012). Therefore, energetic measures have been applied in recent years by HELCOM (Helsinki Commission) and IMO (International Maritime Organisation) to minimize harmful impacts of maritime shipping on the Baltic Sea environment. Nevertheless, the Baltic's narrow straits and shallow waters, many of them covered by ice for prolonged periods in winter, make navigation very challenging, and increase the risk of shipping accidents. The main environmental effects of shipping and other activities at sea include air pollution, illegal deliberate and accidental discharges of oil, hazardous substances and other wasters, and the unintentional introduction of invasive alien organisms via ship ballast waters or hulls. Shipping also adds to the problem of eutrophication of the Baltic Sea with its nutrient inputs from sewage discharges and nitrogen oxides ($NO_x$) emissions (*see* HELCOM 2010 for details).

This work has been a part of the BONUS+ BalticWay project. The core objective of BalticWay was to establish key components of reliable, robust, and low cost technology for the environmental management of shipping, offshore and coastal engineering activities. The existence and location of areas of reduced risk was established through the use of massive numerical simulations. The method used contained four components: (i) an eddy-resolving circulation model, (ii) a scheme for tracking of trajectories of water or pollution particles, (iii) a technique for the calculation of quantities characterizing the potential of different sea areas to supply adverse impacts, and (iv) routines to construct the optimum fairway. The aim was to obtain probabilities of pollution transport to the vulnerable areas or the time pollution takes to reach these areas (Soomere *et al*. 2010, 2011b). Recently, this method has been applied to the southwestern Baltic Sea and the Kattegat. In general, the northern side of the Darss Sill area and the western domains of the Kattegat were safer to travel than the opposing coasts. The largest variability of obtained probabilities was found between in- and outflow situations (Lu *et al*. 2012).

The work presented here consequently follows the ideas of BalticWay and applies the method to the whole Baltic Sea including the Skagerrak and Kattegat.

The main aim of this study was to identify areas that are at high and low risk of pollution in the Baltic Sea in relation to atmospheric forcing conditions and ocean circulation patterns. Thus objectives were to perform (i) long-term risk assessments of different areas in the Baltic Sea, (ii) to analyze their intra- and inter-annual variability, and (iii) to identify areas of intrinsically small probability of coastal pollution by using the concept of equiprobability lines (Soomere *et al*. 2010). Finally, risk probability of coastal hits along these fairways were compared with that obtained along the most frequently used cargo ship routes in the Baltic Sea (HELCOM 2010).

## Methods and concepts

On the basis of 3-dimensional numerical model simulations of the whole Baltic Sea including the Skagerrak and Kattegat (Fig. 1), we used drift model simulations to identify areas from where potential pollution is transported to vulnerable regions. Circulation and drift models were operated subsequently. The advantage of an offline subsequent processing of drift models is that drifters can be released freely within the 3D model fields and drift tracking can be forward or backward (Hinrichsen *et al*. 1997, Lehmann and Javidpour 2010, Lehtiniemi *et al*. 2012).

Simulated hydrodynamic data to construct highly resolved spatio-temporal flow fields were provided by the existing Kiel Baltic Sea Ice Ocean model (BSIOM, Lehmann *et al*. 2002). The model domain comprises the entire Baltic Sea including the Skagerrak and Kattegat with an improved horizontal resolution of 2.5 km and 60 vertical levels specified. BSIOM has been proven to simulate the Baltic Sea hydrographic and hydrodynamical conditions realistically (e.g. Lehmann *et al*. 2002, 2012, Hinrichsen *et al*. 2009). BSIOM was forced by realistic atmospheric conditions for the period 2002–2010, taken from the Swedish Meteorological and Hydrological Institute (SMHI Norrköping, Sweden) meteorological database (L. Meuller

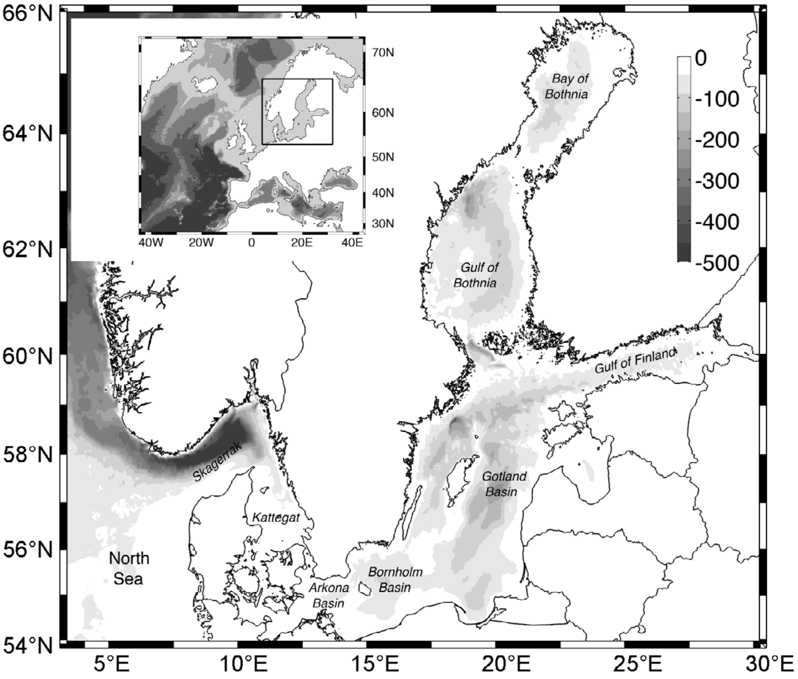


**Fig. 1**. Map of the Baltic Sea.

pers. comm.) which covers the whole Baltic drainage basin on a regular grid of 1° × 1° with a temporal increment of 3 hours.

For our drift model simulations, three-dimensional velocity fields were extracted (daily means) to be used for a Lagrangian particle tracking exercise on toxic and harmful substances in the Baltic Sea. Daily means were used to average out surface current variability due to inertial waves. For the particle tracking, subsequent daily mean current fields were linearly interpolated to allow for a three-hour time step. Although drifters can be placed at every location within the model domain (Hinrichsen *et al*. 1997), for our purpose drifters were launched on the basis of the models horizontal resolution which is 2.5 km resulting in a total number of 68 215 drifters for each release. The trajectories of the simulated drifters obtained from the Eulerian flow fields were computed using a 4th order Runge-Kutta scheme (Press *et al*. 1992). For every day of the year, a full set of drifters was released and subsequently tracked for a 10-day period. Coastal hits were detected if drifting particles for the first time entered a grid cell adjacent to land. The drifters remained fixed in the sea surface layer, because the purpose of this study was to mainly simulate the propagation of toxic substances or oil spills which specific densities are usually lower than those of the surrounding water masses. The 10-day drift period was obtained as an appropriate period for adequate risk analysis estimates of semi-persistent transport patterns in the Gulf of Finland (Viikmäe *et al*. 2010). Thus, every year was covered by at least 3650 days of drift tracking. For the subsequent statistical analysis, 3650 days × 68 215 drifters were analyzed. The high number of drift data guarantied a good resolution of temporal and spatial variability of the Baltic Sea current system.

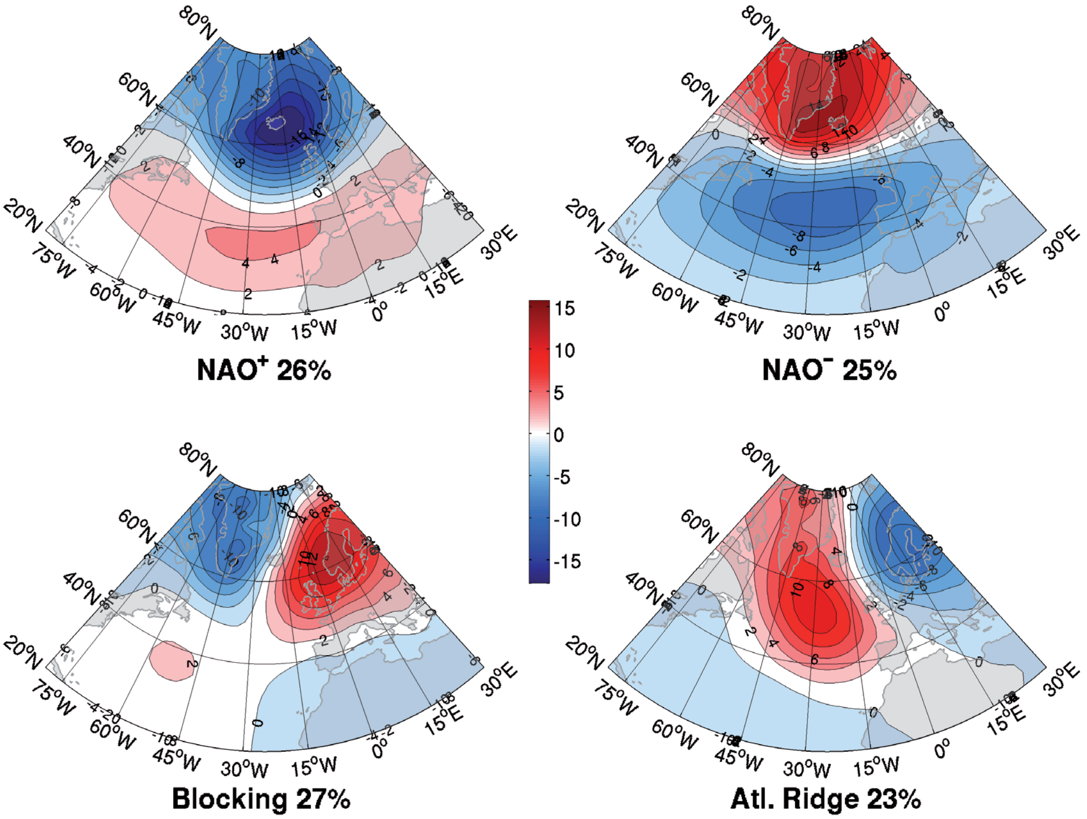
To identify high risk areas in the Baltic Sea from where pollution is most likely transported to the coastal zone, we followed the statistical method proposed by Soomere *et al*. (2010, 2011b). From a set of particle trajectories, various maps of probabilities of hits in vulnerable regions, or maps of time it takes for the adverse impact to reach these regions could be produced. Also, the concept of the equiprobability line was used to characterize optimum fairways in elongated basins (Soomere *et al*. 2010). The method for identifying the optimum fairway consists of four basic steps. The 3-dimensional dynamics of ocean currents is simulated numerically, and the results of the simulation were used to construct Lagrangian trajectories of selected water particles. Together with a cost function, these trajectories are used to construct maps characterizing the distributions of environmental risks associated with different coastal areas (Andrejev *et al.* 2011, Soomere *et al.* 2011a, 2011b). Coastal hits (environmental area of high risk) were defined when drifters move into the coastal area of 2.5 km off the coast. Thus, risk areas are a function of the distance from the point of release to the coast, the atmospheric forcing and underlying current fields which are mainly wind-driven or topographically steered. Based on the analysis of the Lagrangian trajectories, the results were used to construct (i) risk probability areas which are prone to serve as a source of coastal pollution, and (ii) time requirements of water particle transport towards coastal areas.

## Results

### Atmospheric variability

The climate of the Baltic area (Fig. 1), and thus the current system in the Baltic Sea, is controlled by large pressure systems that govern the air flow over the continent. From the cluster analysis of winter (Dec.–Mar.) daily mean sea level pressure (SLP) anomalies, using NCEP/NCAR re-analysis data for the period 1949–2008 (Kalnay *et al.* 1996) four winter climate regimes could be identified (Fig. 2; Lehmann *et al.* 2011). Two of the climate regimes correspond to the positive and negative phases of the North Atlantic Oscillation (NAO), while the third and fourth regimes display strong anticyclonic ridges over Scandinavia (the 'Blocking' regime) and off western Europe (the 'Atlantic Ridge' regime). In the period 1948–2008, all four regimes occurred with about the same frequency between 23% and 27%. The total contribution of the 'Blocking' and 'Atlantic Ridge' pattern was between 48%–50% and the total contribution of the NAO pattern was between 50%–52%. However, the relative contributions of the four patterns were different for different decades and years (Getzlaff *et al.* 2011). Hurrel and Deser (2009) concluded that a large amount of within-season variance exists in the atmospheric circulation of the North Atlantic and that most winters are not dominated by any particular regime alone. Similar large-scale atmospheric circulation patterns can be found over the whole year but they are not as pronounced as during the winter season. Generally, the high variability in atmospheric circulation patterns force corresponding responses of the Baltic Sea circulation. Lehmann *et al.* (2002) showed that different atmospheric climate regimes force different circulation regimes in the Baltic Sea. The resulting circulation patterns heavily depend on the direction and strength of the prevailing winds.

A key aspect of this study was to analyze intra- and inter-annual variability in terms of risk assessment in the Baltic Sea. Therefore, we selected two years, namely 2006 and 2007, showing strong seasonal as well as annual variability in the atmospheric wind situation (Fig. 3). The most prominent differences for these two years exist during the winter (Dec.–Feb.) and summer (June–Aug.) seasons. While during the winter season of 2006, occurrences of wind directions were rather equally distributed between easterly, southerly and westerly winds, in 2007 strong ($> 10$ m s$^{-1}$) and intense westerly wind situations occurred with a total frequency of more than 30%. During the summer of 2006, rather calm conditions existed with wind speed rarely exceeding 8 m s$^{-1}$, whereas during the summer of 2007 the predominant wind direction was westerly with a total frequency more than 25%. Additionally during the spring (Mar.–May), the major change appeared to be an increase in wind speed in the predominant wind directions from 2006 to 2007, while during the autumn (Sep.–Nov.) a slight shift in the predominant wind directions occurred within the westerly wind regime. These different wind situations, especially during the winter season (Dec.–Feb.), were strongly connected to a negative (2006 partly also a "Scandinavian blocking" situation) and a positive (2007) NAO indexes on the large-scale winter atmospheric conditions (Fig. 2; Lehmann *et al.* 2011, Cattiaux *et al.* 2010). Therefore, we expect to understand the connection of spatio-temporal variability of areas of high/low environmental risk and changes in atmospheric conditions by comparing results from



**NAO$^+$ 26%**

**NAO$^-$ 25%**

**Blocking 27%**

**Atl. Ridge 23%**

**Fig. 2**. Winter (Dec.-Mar.) climate regimes derived from the cluster analysis of daily mean SLP from NCEP/NCAR re-analysis data for the period 1948–2008.

seasonally averaged ensembles of drifter simulations for the years 2006 and 2007.

## Particle probabilities to hit the coastal environment

The spatio-temporal long-term mean distribution of the particle probability to hit coastal environments (Fig. 4) revealed relatively low values in most of the offshore regions of the Baltic Sea ($p < 20\%$). These low values of the probability of coastal hits are obviously linked to the relatively large size of the open Baltic and the relatively short time (10 days) of particle tracking. Areas predicted to have the highest probability to hit coastal environments are the narrow straits of the western Baltic, coastal regions as well as the vicinities of different islands in the central Baltic. They also correspond to coastal hits in relatively short time periods and, furthermore, they exhibit much stronger probability gradients as compared with offshore regions. It should be noted that generally the eastern and southern coasts of the Baltic Sea reveal relatively high probabilities of pollution for 10-day drift periods as compared with the western and northern coasts. The reason is that in the long-term, average southwesterly winds cause offshore transport off the western and northern coasts and onshore transport on the opposite coasts (Lehmann *et al.* 2012).

In contrast to the assessment of spatio-temporal long-term patterns, variability in the occurrence of high risk probability areas depends on the prevailing currents the drifters are exposed to. During calm atmospheric conditions, wind drift is suggested to be small and the dispersion is forced by the residual circulation only. Thus, drifters remain relatively close to the positions where they were released. Strong wind causes

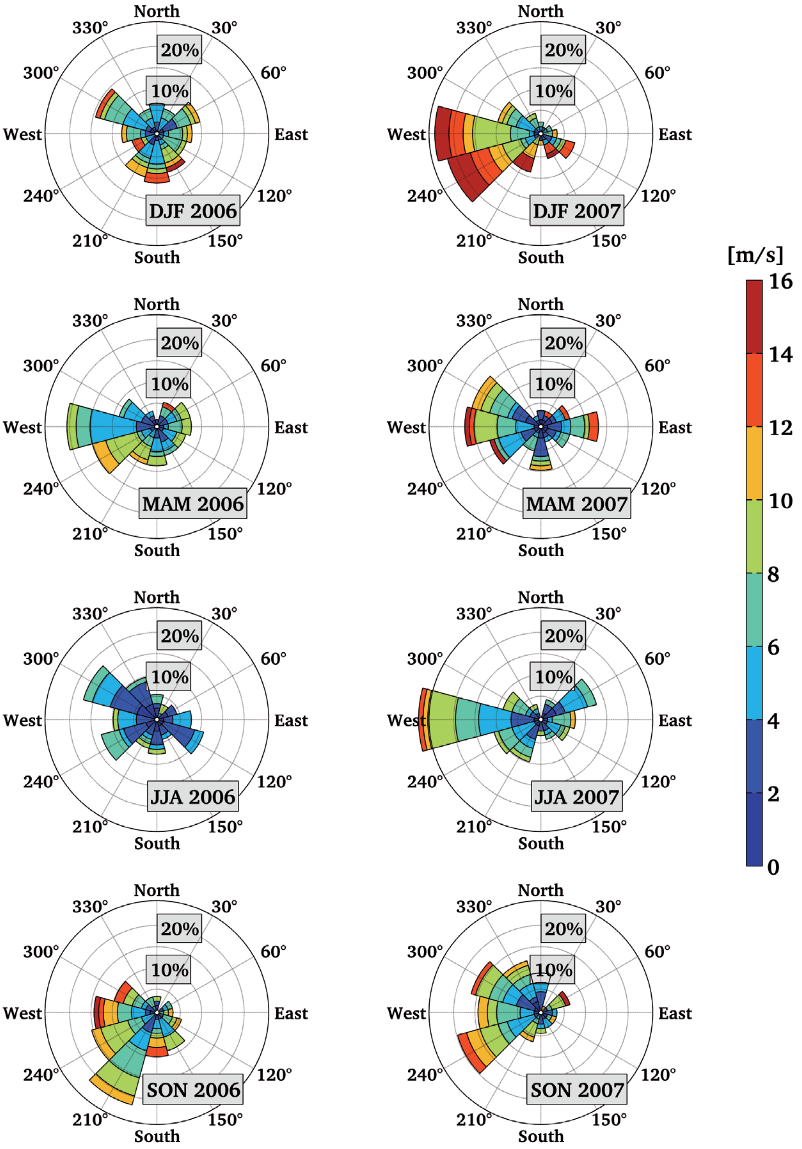


**Fig. 3**. Seasonally averaged distribution of 10-m-wind direction and magnitude at the south eastern coast of Sweden near Ystad for the year 2006 (left-hand-side column) and 2007 (right-hand-side column), based on the 3-hourly SMHI meteorological database. DJF = Dec., Jan., Feb.; MAM = Mar., Apr., May; JJA = June, July, Aug.; SON = Sep., Oct., Nov.

fast drift and increases the risk that pollution will hit the coast.

To account for the different atmospheric forcing conditions the probability of drifters to hit the coast if launched in the whole Baltic Sea area as well as along ship routes was calculated for different years. Mean seasonal probability maps of coastal pollution were determined from model simulation for the years 2006 and 2007 (Fig. 5). Here, the response of the particle drift to the atmospheric surface forcing becomes clear (compare Fig. 5 with Fig. 3). The distribution of high risk areas in the winter period (Dec.–Feb.) of the year 2006 differered from that in the winter period of the year 2007. While we find intense wind events during the winter of 2006, the winter of 2007 presents even stronger and more persistent wind forcing from west to southeast. This leads to an increase in the probability distribution for particles hitting the coast. In the winter of 2006, the largest parts of the main basins such as the Bornholm Basin, Baltic Proper, Sea of Bothnia and Bay of Bothnia (*see* Fig. 1 for reference) indicate low risk ($p < 20\%$) areas away from the coast. Contrary, during the winter of 2007 only smallest areas of the south-

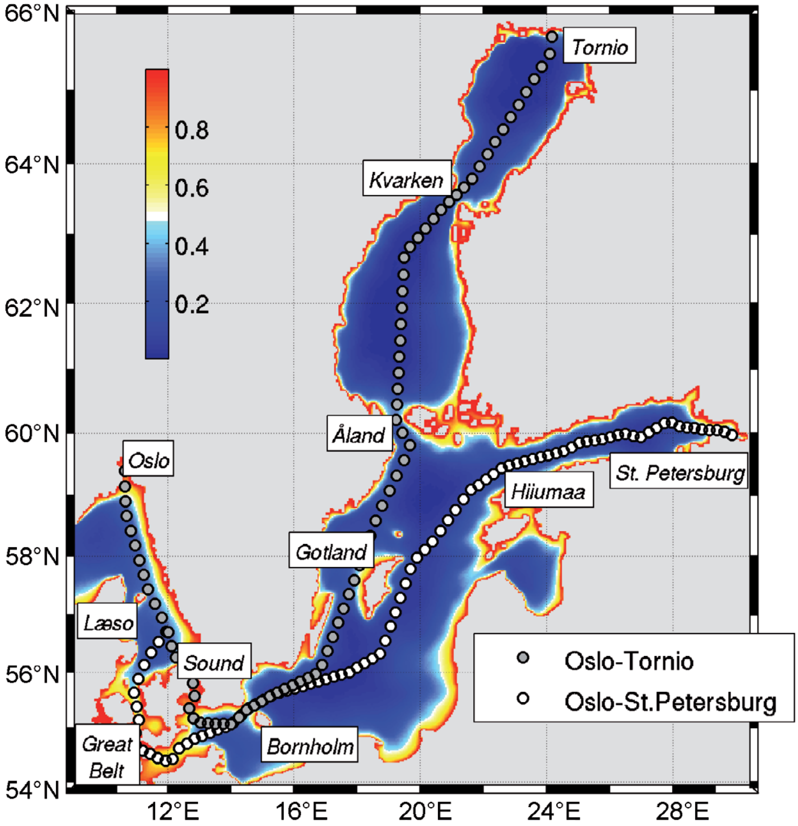


**Fig. 4**. Average probability to reach the coast for an ensemble of daily particle releases in 2002–2010 computed for 10-day particle drift. The dotted lines indicate two major frequently used shipping routes from Oslo to St. Petersburg (SR1; white dots) and from Oslo to Tornio (SR2; gray dots).

ern Åland Sea, the Bothnian Sea and the Bay of Bothnia indicate low risk areas. The whole Arkona Basin indicates high risk ($p > 60\%$) areas for particles hitting the coast within 10 days after release. The Bay of Gdańsk and the Gulf of Riga are under high risk during that period. Due to recurrent strong wind forcing from the south and southeast, high risk ($p > 60\%$) of coastal hits was found for the east coast of Sweden up to the area north of Stockholm. The situation of high risk areas during the winter of 2007 is completely different to the long-term annual mean (Fig. 4) and therefore highly important in the context of seasonal and inter-annual variability.

Despite the ephemeral nature of the atmospheric forcing conditions, probability patterns for the spring (Mar.–May) and summer (June–Aug.) of 2006 are relatively stable, which appeared quite similar as compared with the long-term annual mean (Fig. 4). Due to relatively low wind forcing mainly of variable direction, in the central and northern Baltic high risk areas ($p > 60\%$) were located only in the vicinities of coastal regions and islands with distances to coastal environments not exceeding 50 km. Due to stronger westerly wind forcing during the spring and summer of 2007, for the coastlines of Poland, the Baltic countries, Russia and Finland as well as the western coast of Gotland we identify weaker probability gradients, indicating risk of coastal pollution potentially starting farther away from the coasts. The Belt Sea as well as the western part of the Arkona Basin persistently showed high risk areas of coastal hits for all main seasons presented here.

During the autumn (Sep.–Nov.), relatively strong wind forcing mainly of variable directions generate weak probability gradients along all western coastlines producing higher risk ($p > 40\%$) areas farther off the coast. Nevertheless, along the east coast of Sweden only low risk of coastal hits was found.

Regarding the shipping routes from Oslo to St. Petersburg (SR1) as well as from the same destination to Tornio (SR2; *see* Fig. 4 for the positions of the shipping routes), generally high

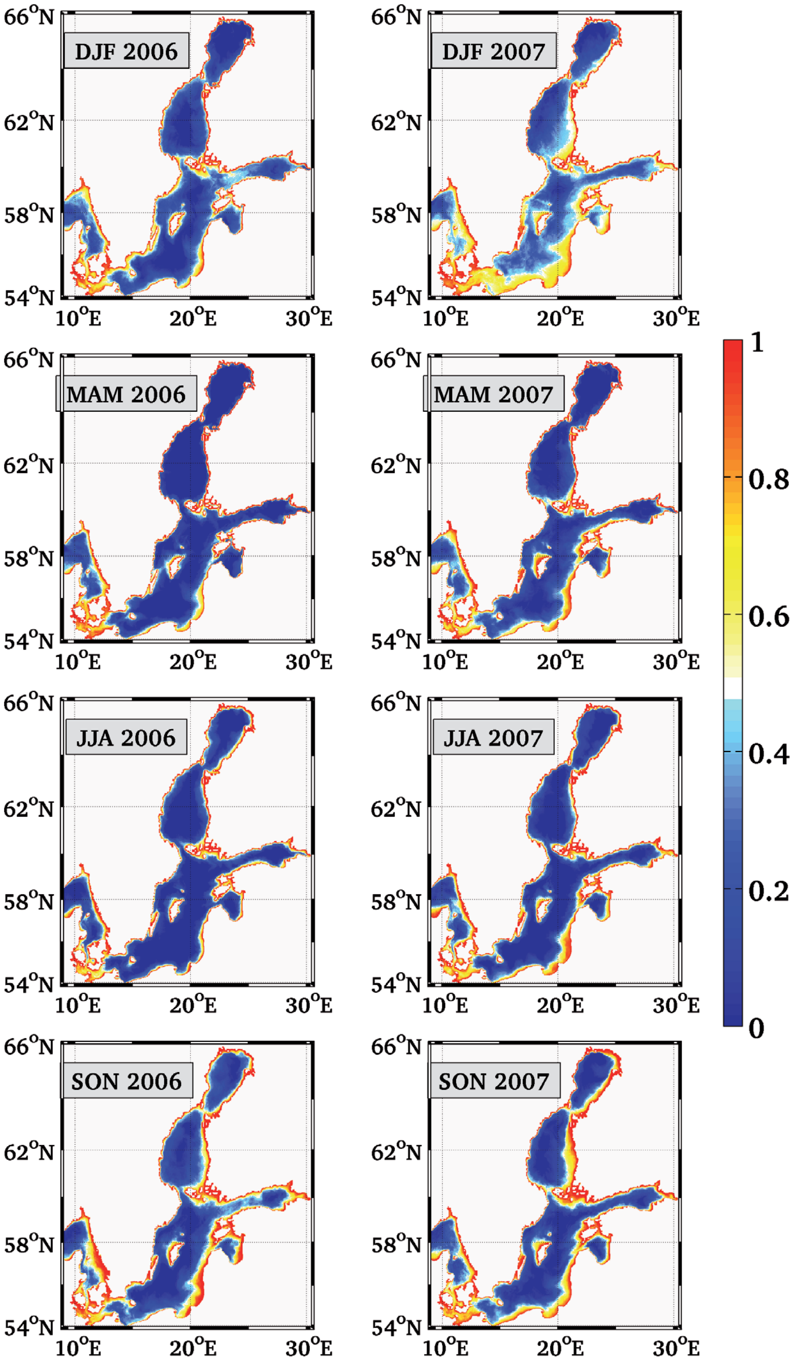


**Fig. 5**. Average seasonal probability to reach the coast for ensembles of daily particle releases for 2006 (left-hand-side column) and 2007 (right-hand-side column) computed for 10-day particle drift. DJF = Dec., Jan., Feb.; MAM = Mar., Apr., May; JJA = June, July, Aug.; SON = Sep., Oct., Nov.

risk probability to hit the coast appeared if the shipping route was located close to shallow water and coastal regions: Læsø, Great Belt, Bornholm, and Hiiumaa along track SR1, as well as Læsø, Sound, Bornholm, Gotland, Åland and Kvarken along SR2 (Fig. 6). Highest intra- and inter-annual variability of this high risk probability occurred close to the islands of Læsø, Bornholm and Gotland as well as close to Kvarken. The existence of the permanently appearing high risk area in the Sound, close to 100%, recommends to choose an alternative route via the

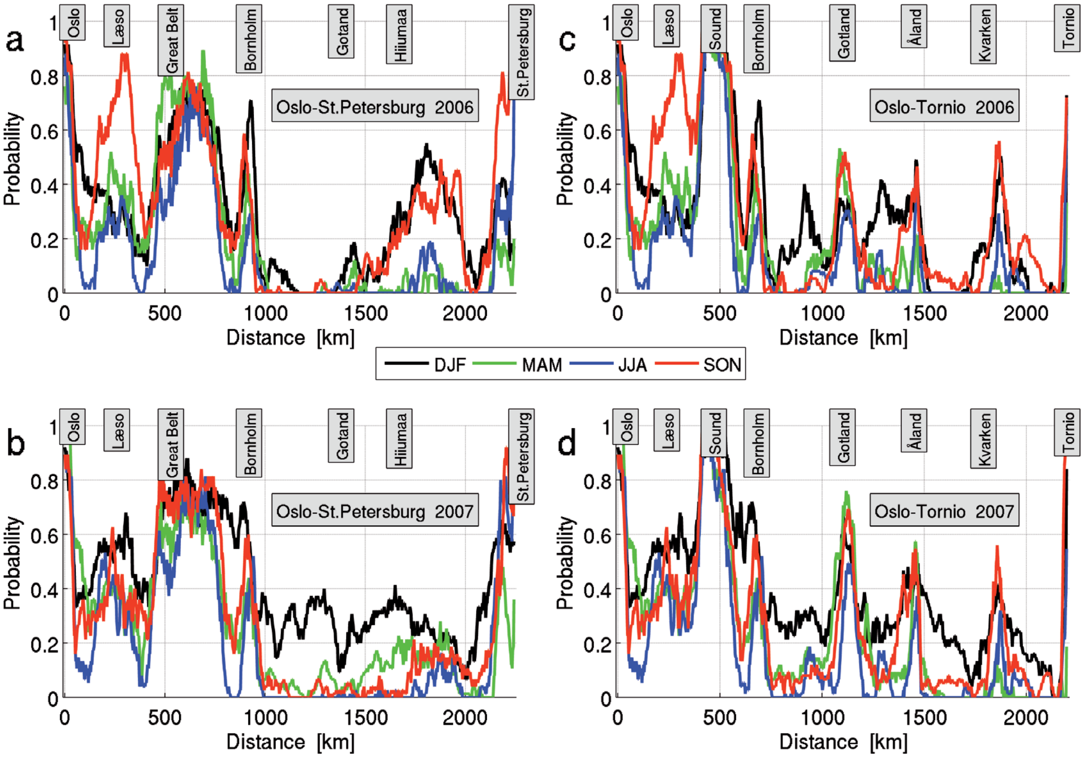


**Fig. 6**. Average probability to reach the coast for ensembles of daily particle releases along frequently used shipping routes from Oslo to St. Petersburg (**a** and **b**) and from Oslo to Tornio (**c** and **d**) for the years 2006 (**a** and **c**) and 2007 (**b** and **d**) computed for 10-day particle drift.

Great Belt, for which a permanent high risk area was obtained as well, but taking this route would reduce the risk by approximately 20%. Accordingly, along the shipping routes, the durations for water particles to reach coastal environments were 4–6 days in the Sound and Great Belt area (Fig. 7) and about 7 days near Bornholm and Gotland. While most of the other parts along the routes were less critical with durations greater than 8 days.

In the next step, we analyzed the consequences of current-induced propagation of substances released from ships, aiming to route ships along less dangerous paths. Following the concept of equiprobability lines (Andrejev *et al*. 2011, Soomere *et al*. 2011c), we calculated the environmentally safest fairways for cargo transports from Oslo through the Sound and the Great Belt each to St. Petersburg for the annual mean risk probability distribution. When these fairways are compared with the frequently used shipping route (Fig. 8), the general appearance of the probabilities are quite similar, however, the total distances of the optimum fairways are about 6% and 17% greater for the routes through the Sound and Great Belt, respectively. As we used the same shipping routes from Oslo to the entrance of the Sound and Great Belt there are no differences for Oslo and Læsø (Fig. 9). A risk reduction of about 25% is obtained if the route through the Great Belt is chosen. A further risk reduction up to 25% can be achieved if the route through Bornholm Gat is avoided (Fig. 9).

## Discussion and conclusions

In this study, we investigated the quantification of environmental risks associated with variable current-driven transport of harmful substances released from offshore sources. Our approach made use of spatio-temporal variations of ocean current patterns obtained from a high-resolution circulation model of the entire Baltic Sea.

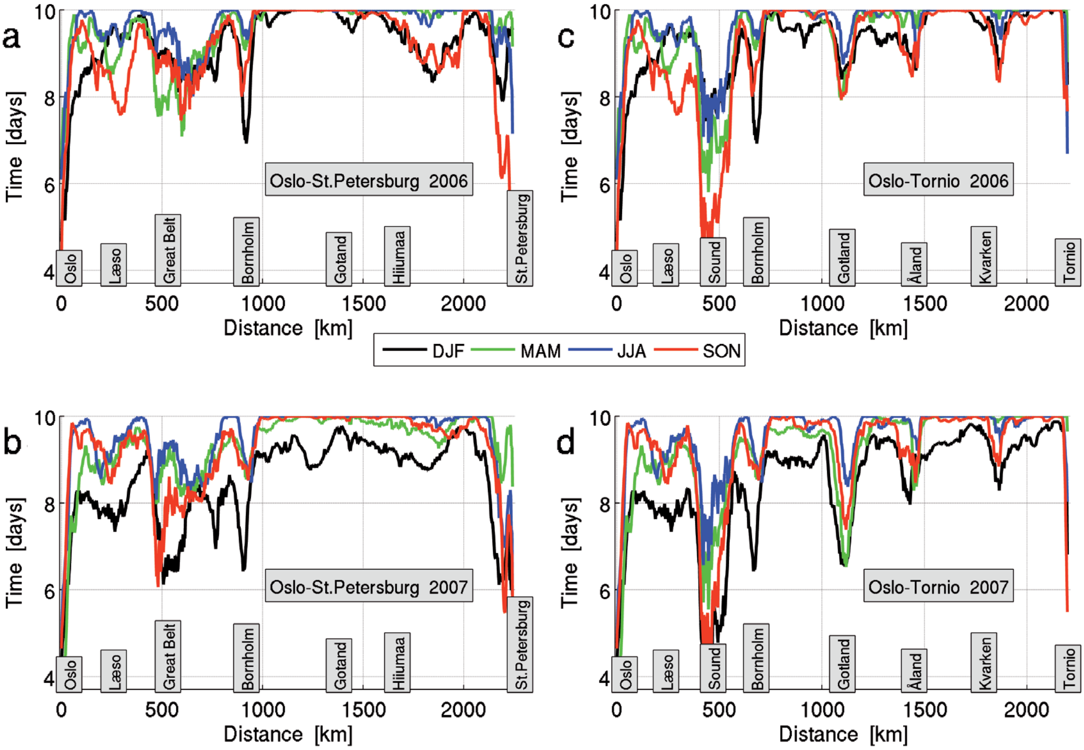


**Fig. 7**. Average time to reach the coast for ensembles of daily particle releases along frequently used shipping routes from Oslo to St. Petersburg (**a** and **b**) and from Oslo to Tornio (**c** and **d**) for the years 2006 (**a** and **c**) and 2007 (**b** and **d**) computed for 10-day particle drift. The maximum time to reach the coast (10 days) does not always represent the real propagation time, but reflects that in the model experiment particles were only tracked during 10 days.

The baroclinic Rossby-radius of deformation is approximately 3–10 km after Fennel *et al*. (1991), thus the hydrodynamic model grid size is fine enough to capture physical features and processes where rotational effects are important. Generally, it was expected from our results that strong temporal and spatial variability appears for the probability of coastal hits as well as for the time required for particles to reach coastal areas. However, despite the existence of non-persistent circulation patterns in the various areas in the Baltic (Lehmann *et al*. 2002), we showed that well-defined optimum locations for low risk cargo transports exist in many parts along the most frequently used ship routes. Nevertheless, in some areas, only small deviations from these locations could result in a rapid increase in the risk for coastal environments (Soomere *et al*. 2011b).

In principle, our study aimed to develop a scientific platform for the entire Baltic Sea presenting an innovative low-cost technology of environmental management of shipping and offshore activities (*see* also Soomere *et al*. 2011c). The impact of the wind-induced surface drift on the transport of particles representing accidental discharges of harmful substances was analyzed for two contrasting years (2006 and 2007). The findings of our study indicate that variations in the mean drift distances between the years and with respect to drift durations can be high, but surprisingly for the latter yielded no statistically independent results. This means that particle transport depends on atmospheric conditions in terms of the strength and the direction of the prevailing forcing. Whereas for many regions of the Baltic does not necessarily provide any reliable predictions when particles would reach coastal areas. Generally, for most areas of the Baltic Sea, discharges of harmful substances released along the major shipping routes, do not represent worst-case scenarios, because during short

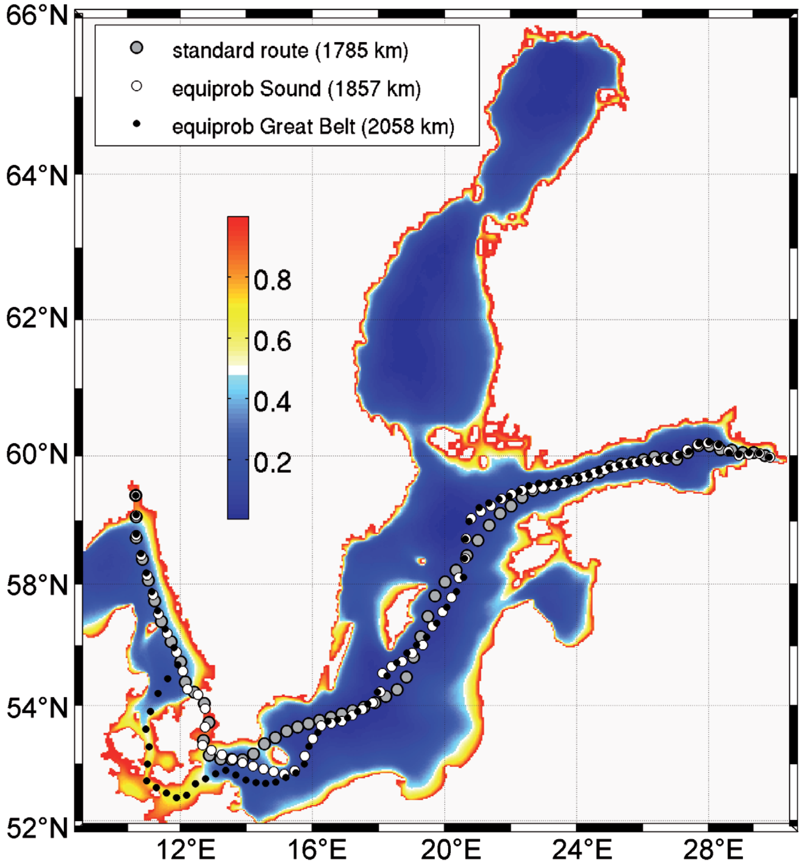


**Fig. 8**. Average probability to reach the coast for an ensemble of daily particle releases in 2002–2010 computed for 10-day particle drift. The dotted lines indicate the frequently used shipping route from Oslo to St. Petersburg (gray dots) and two environmentally safer fairways for the same connection one using the direct path through the Sound (white dots) while the other one uses the even safer fairway through the Great Belt (black dots).

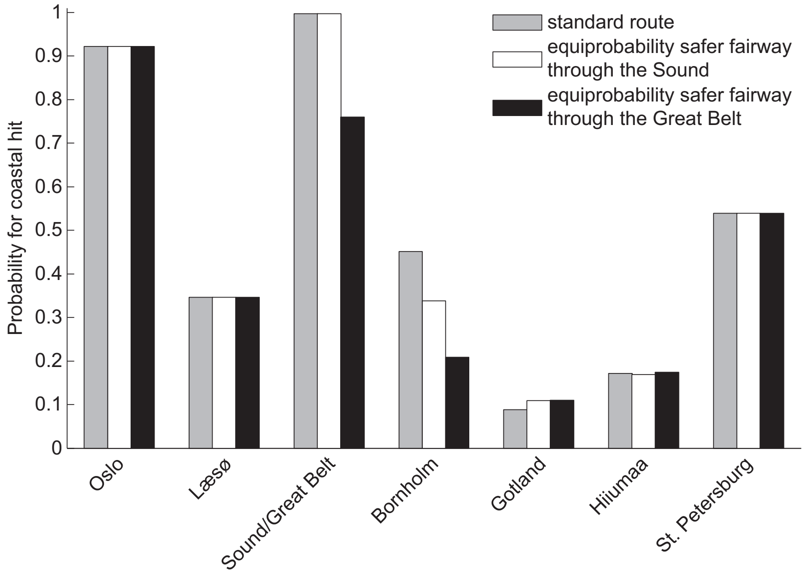


**Fig. 9**. Average probability to reach the coast for ensembles of daily particle releases in 2002–2010 at specific way-points along different shipping routes from Oslo to St. Petersburg.

periods coastal pollution could not be expected. However, in the western Baltic (Lu *et al*. 2012) as well as in the areas close to islands of Bornholm and Gotland, particle releases close to their coasts have to be seen as high risk probability areas.

The present study suggests the applicability of hydrodynamic models to assess the drift and resulting spatial distributions of oil pollutants and other harmful substances in the Baltic Sea. Because of the highly spatially and temporally resolved release locations of drifters (68 215 per daily release), the capacity of the model enables to realistically simulate Lagrangian dispersion in the Baltic to a high degree of confidence. Our model approach does not explicitly incorporate horizontal diffusion velocities, because the circulation in the Baltic, especially at the sea surface where the harmful substances mainly occur, is primarily wind-driven. Because of the ephemeral nature of the wind conditions over the Baltic, the current fields are only slightly influenced by small-scale processes not resolved by our hydrodynamic model. In case baroclinic currents become more important, transport and retention is mainly determined by the spatial distribution of the mass field (i.e. temperature and salinity). However, incorporating diffusion velocities will not generally alter drift patterns or reduce the uncertainty in the drift velocities, it only could give a general impression of small scale processes on the variability of the spatial distributions of drifting particles.

Our numerical simulations provide detailed information about the current patterns that allows to identify features of transport, which can be inferred neither from theoretical analyzes nor from extensive field experiments. The model results are expected to substantially improve our understanding of the current patterns in the Baltic Sea, thus leading to a better understanding of meteorological forcing on pollution transport. Secondly, our modeling approach reflects the high degree of the predictive capacity of circulation and operational models. We focused on current-induced drift of harmful substances released into the environment by ship accidents. The outcome of our approach could potentially contribute to the formulation of mathematical, engineering and technological problems being understandable for a wide range of experts to identify relevant risk categories which are widely known. Thus, knowledge obtained from our modeling exercise can be compared with existing concepts and results (Soomere *et al*. 2011c).

Independently of the specific results obtained from this risk analysis of coastal pollution, the study demonstrates that hydrodynamic models provide an effective tool to account for the passive movements of particles. Instead of identifying high-risk coastal pollution areas, the model is also suitable to identify areas with low probability of pollution impact, i.e. areas with low numbers of coastal hits. Hence, our model approach might be helpful for the establishment of "Marine Protected Areas" by using the information on "coastal areas with low risk of pollution" obtained from long-term spatial distributions of harmful substances.

Our modeling approach is quite simplistic and should be seen as a baseline exercise to be followed by more detailed and comprehensive analyzes. More detailed structured maps of probabilities can be obtained if the horizontal resolution of the underlying circulation model is further increased (Andrejev *et al*. 2011), but this would lead to even higher computational costs. The entire method is already computationally cost-intensive. On the other hand, an easier parametrization of transport processes responsible for the identification of high and low risk areas would be desirable. These areas may be identified from simplified but online-accessible physical forcing parameters, e.g. the Baltic Sea Index (BSI) (Lehmann *et al*. 2002, Hinrichsen *et al*. 2003). Generally, drift model approaches are numerical tools which might also be able to recapture observed patterns of environmental pollution in the Baltic Sea. Taking into account ocean current forecast fields defined as a model's operational mode could provide real-time assessments of spatio-temporal distributions of e.g. accidentally discharged harmful substances. Furthermore, such a tool could potentially be utilized as monitoring technique to back-track substances from observational locations to their initial sources.

Soomere *et al*. (2011c) suggested minimum values of probability of coastal hits as an obvious measure of environmental gain. On the other hand, sailing along environmentally safest fairways could result in significantly longer ship routes and hence in higher volumes of petrol needed for transportation (Soomere *et al*. 2011d). Hence, conditionally optimized fairways should consider a balance between ecological and economical gains.

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