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# Towards identification of areas of reduced risk in the Gulf of Finland, the Baltic Sea

Tarmo Soomere[a*], Bert Viikmäe[a], Nicole Delpeche[a], and Kai Myrberg[b]

[a] Institute of Cybernetics at Tallinn University of Technology, Akadeemia tee 21, 12618 Tallinn, Estonia
[b] Finnish Environment Institute, P.O. Box 140, FI-00251, Helsinki, Finland

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**Abstract.** A Lagrangian trajectory model, TRACMASS with the use of velocity fields calculated by the Rossby Centre (Swedish Hydrological and Meteorological Institute) circulation model, is employed to analyse trajectories of current-driven surface transport in the Gulf of Finland, the Baltic Sea, for the period of 1987–1991. Statistical analysis of trajectories is performed to calculate a map of probabilities for adverse impacts released in different sea areas to hit the coast. There is a clearly defined curve (equiprobability line) in the western part of the gulf from which the chances of the propagation of adverse impacts to either of the coasts are equal. The current-driven propagation of tracers from a wide area (of reduced risk) to the coast in the central and eastern parts of the gulf is unlikely within about three weeks. A safe fairway in terms of coastal protection goes over the equiprobability line and the area of reduced risk.

**Key words:** pollution transport, risk analysis, currents, hydrodynamic modelling, Gulf of Finland, Baltic Sea.

## INTRODUCTION

The existence of quasi-persistent patterns of currents in various parts of the Baltic Sea (Lehmann et al., 2002; Andrejev et al., 2004a, 2004b; Osinski and Piechura, 2009) leads to the interplay of the high variability and extreme complexity of the surface currents with the presence of rapid pathways of the current-driven transport (Soomere et al., 2010). This combination opens a principally new way towards a technology that uses the marine dynamics for the reduction of environmental risks stemming from shipping and offshore and coastal engineering activities. The key benefit is an increase in the time during which an adverse impact (for example, an oil spill) reaches a vulnerable area after an accident has happened (Soomere and Quak, 2007). The use of this technology, however, requires adequate estimates of the persistency and variability of the patterns, and of the confidence and uncertainty related to their practical use.

The drift of adverse impacts, oil spills, lost containers, ships without propulsion, etc. is jointly governed by wind stress, waves, and currents. The properties of transport by wind and waves are understood quite well (ASCE, 1996; Sobey and Barker, 1997; Reed et al., 1999; Castanedo et al., 2006). As the instantaneous field of currents is created under the joint influence of a large pool of local and remote forcing factors, the prediction of the current-induced contribution to the drift is still a challenge. Theoretically, transport of water particles and drift of tracers can be described to some extent with the use of deterministic circulation models. There is, however, not yet a model capable of sensibly forecasting the drift or a deterministic method to combine different models to reproduce the floating object drift (Vandenbulcke et al., 2009). The results are highly sensitive with respect to the particular model and small variations of the initial and forcing conditions (Griffa et al., 2004). The problem is even more complicated in strongly stratified sea areas such as the Gulf of Finland where the drift is frequently steered by multi-layered dynamics (Gästgifvars et al., 2006).

A feasible way to reduce the uncertainties of the current-induced drift patterns consists in the implicit or explicit use of statistical approaches. An attempt in this

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[*] Corresponding author, soomere@cs.ioc.ee

direction is made by means of numerical identification of patterns of net transport and the ratio of the net and bulk transport in the Gulf of Finland, the Baltic Sea (Soomere et al., 2010).

The focus of this paper is a statistical technique for the optimization of the potential risk stemming from anthropogenic activities in elongated sea areas. The classical definition of risk expresses it as the product of the probability of an accident and the cost of its consequences. The cost of the consequences of an accident in the marine environment substantially depends not only on the nature or magnitude of the adverse impact but also on the place hit. Moreover, the consequences could frequently be reduced by gaining some time to combat the adverse impact.

We aim at decreasing the risk by means of maximizing the time over which the current-driven propagation of the consequences of an accident will affect high-cost areas. As the nearshore frequently has the largest ecological value (Kokkonen et al., 2010), in this study we consider the coastal zone as a generic example of a high-cost area. The proposed approach is evidently independent of the particular definition of the coastal area and, equivalently, of the particular form of the cost function.

A direct application of the approach is a problem of the optimization of marine transport routes in order to minimize the probability of a coastal pollution and/or to maximize the time over which adverse impacts reach the coasts. For open ocean coasts this can be done by shifting the fairway offshore or by relocating it in a certain manner to minimize the adverse impacts to the environment (Stokstad, 2009).

A key question for narrow bays and elongated sea areas is how to minimize the joint probability of hitting either of the coasts. The first-order solution for narrow basins is the equiprobability line, from which the probability of propagation of pollution to either of the coasts is equal. If the transport patterns were completely isotropic and homogeneous, this line would coincide with the axis of the basin. For wider sea areas there may also appear quite a wide area of reduced risk, from which the propagation of pollution to any of the coasts is unlikely. The safest fairway would thus follow a combination of the equiprobability line and the area(s) of reduced risk.

A systematic solution to the formulated problem presumes inverse tracking of the propagation of adverse impacts. It is well known that neither a straightforward solution to this problem nor a universal solution method exists. We shall address it by means of statistical analysis of a large pool of numerically simulated trajectories of drifters in the surface layer. The key idea, therefore, is not to produce another operational model to represent the drift after an accident has actually happened but rather to identify beforehand the regions where it is statistically safer to travel.

The analysis is performed for the Gulf of Finland (Fig. 1), an elongated, stratified sub-basin of the Baltic Sea with a length of about 400 km, width between 48 and 125 km, and a mean depth of 37 m only. This region, declared a particularly sensitive sea area by the International Maritime Organisation (Soomere et al., 2008), hosts extremely heavy and rapidly increasing ship traffic.

The calculations are based on the results of long-term, high-resolution simulations of the circulation in the entire Baltic Sea. A Lagrangian trajectory model is applied to extract useful information from these simulations. The goal is to evaluate favourable features of the current-driven transport that have time scales of the order of a week and that can be extracted neither directly from the velocity data nor from the long-term average circulation patterns.

## MODELLING THE ENVIRONMENT

The tool for the analysis of current-driven transport of adverse impacts is a Lagrangian trajectory model, TRACMASS (Döös, 1995; Vries and Döös, 2001). It uses pre-computed three-dimensional Eulerian current velocity fields to evaluate an approximate path of water particles (equivalently, neutral tracer of an adverse impact) based on an analytical solution of a differential equation for motion that depends on the velocities on the grid box walls. This off-line method of calculation makes it possible to reckon a large pool of trajectories for different starting instants and positions once the velocity fields are available. The method was originally developed for stationary velocity fields (Döös, 1995; Blanke and Raynaud, 1997), then expanded to time-dependent fields (Vries and Döös, 2001) by implementation of a linear interpolation of the velocity field both in time and in space, and has become a standard tool for studies of complex motions of water particles in the marine environment (Jönsson et al., 2004; Döös and Engqvist, 2007).

In this study we use the surface-layer velocity fields calculated for 1987–1991 for the entire Baltic Sea using the Rossby Centre Ocean circulation model (RCO) with a temporal resolution of 6 hours. This time period was chosen in order to make the results comparable with circulation simulations (Andrejev et al., 2004a, 2004b) and studies of average transport patterns in the same basin (Soomere et al., 2010). The RCO is a primitive equation circulation model coupled with an ice model (Meier et al., 2003). It covers the entire Baltic Sea with the horizontal resolution of 2 × 2 nautical miles and uses 41 vertical levels in *z*-coordinates. The thickness of the uppermost layer is 3 m.

The model is forced by wind data on the 10 m level, air temperature and specific humidity on the 2 m level, precipitation, cloudiness, and sea level pressure fields, and it also accounts for river inflow and water exchange through the Danish Straits. This data set is calculated from the ERA-40 re-analysis using a regional atmosphere model with a horizontal resolution of 25 km (Höglund et al., 2009). As the atmospheric model tends to underestimate extreme wind speeds, the wind is adjusted using simulated gustiness. Further details of the model set-up and validation experiments are discussed in (Meier, 2001, 2007; Meier et al., 2003).

Trajectories of water particles (equivalently, current-driven propagation of an adverse impact) are simulated for a few weeks for certain distributions of the initial positions. The resulting trajectories are saved for further analysis and the simulations for the same initial positions of particles are restarted from another time instant. The process is repeated over the chosen time period.

High risk to a nearshore section is assumed when pollution reaches a distance of less than three grid points (about 11 km) from the coast (cf. Lessin et al., 2009). As a first approximation, the percentage of tracers that approach the nearshore zone of this width within a certain time interval is used as an estimate of the risk. Alternatively, the average time it takes the tracer to reach such points is a measure of risk associated with the starting point. In this study we use a simplified approach and rely only on the fact of reaching the nearshore.

In order to avoid problems connected with potentially insufficient accuracy of the representation of vertical velocities in the RCO model, the trajectories are locked in the uppermost layer. This is done by means of switching off the three-dimensional tracing in the TRACMASS model. The resulting trajectories are, thus, not truly Lagrangian: they are not passively advected by the velocity fields and rather represent motion of tracers that are slightly lighter than the surrounding water (such as oil in otherwise calm conditions) or are confined to the upper layer by other constraints. This set-up of trajectory modelling is best suited for representing, for example, the drift patterns of lost containers.

## TIME SCALES AND PATTERNS OF TRANSPORT

First a series of experiments was performed to estimate the typical time over which the particles reached the nearshore. The trajectories were started from centres of 96 cells located along the straight line in Fig. 1, roughly representing the axis of the Gulf of Finland (that is, at points remotest from the coasts). The simulations were started at midnight each calendar day in 1987 and run for 10 days. As discussed below, this is roughly the time during which the largest amount of tracers released along the axis of the Gulf of Finland reaches the nearshore.

The number of particles that entered the nearshore (called below hits of the nearshore) during these days showed very high variability (Fig. 2). The count (equivalently, the percentage of particles) varied from zero up to about 60. In general, the smallest number of hits occurred in the calm season (April–July) and the highest, not surprisingly, in the windy autumn and winter season. There was, however, also a certain time section of the calm period when the number of hits was close to 50.

On average, about 30% of the particles released along the axis of the gulf hit the nearshore of either of the coasts within 10 days. This estimate is in accordance with numerical results of Prof. S. Ovsienko (pers. comm.) and apparently reflects the lower bound of the probability for a hit of a coastal zone by an adverse impact released in a random location of the gulf. Other factors influencing the drift such as wind, waves, and spreading (of oil spills) apparently increase this probability as they generally magnify the excursions of the released substances and/or enlarge the sea area hosting the adverse impact.

The typical time for a hit in both calm and windy seasons also largely varied. For example, Fig. 3 illustrates that in May 1987 a few hits occurred already during the first day of propagation while in July the first hit took place only on the ninth day. The further behaviour of the particles was also substantially different. In May the maximum number of particles located in the nearshore was 19 and almost no hit was observed starting from day 8. The number of such particles was between 30 and 43 during almost a week (days 12–17) in July (Fig. 3). In total, no more than 19% of the particles simultaneously resided in the nearshore in May whereas this percentage reached 43 in July.

The typical time of the first hit to the coast was 3 days in 1987. A substantial number of hits, though, occurred already on the first day, which also was the median value of the number of days in question. This low number apparently is due to the smallness of the basin and the closeness of some of the release points to the coastal zone. The typical time when the largest number of particles was found in the nearshore was 11 days from the start of the simulations in 1987. This value is close to the median value (12 days).

The overall character of the current field is well known for the Gulf of Finland. The vertically averaged mean circulation of this basin is cyclonic with an average velocity of a few centimetres per second (Alenius et al., 1998; Lehmann et al., 2002). This overall scheme is superposed by numerous meso-scale baroclinic eddies and many local features (Andrejev et al., 2004a, 2004b; Soomere et al., 2008). The transport in the uppermost layer is largely governed by the Ekman drift, especially in relatively windy seasons when the dynamics of the uppermost layer is apparently to some extent decoupled from the underlying layers.

These motion configurations are, however, only valid on average. The above estimates suggest that the transport of adverse impacts to the coasts not necessarily follows the long-term average flows. Instead, it is governed by much faster processes and has the time scale of a few days up to a few weeks. One of the reasons for the extreme complexity of current patterns in this basin is that the internal Rossby-radius of deformation (which governs the size of meso-scale features) is only 2–4 km in the Gulf of Finland. This feature indicates the necessity of the use of high-resolution models $(\leq 1.5\ \mathrm{km})$ for this water body (Alenius et al., 2003).

A great role of local, short-term drivers is reflected in the extremely large variability of the probability of hitting the southern and northern coasts of the Gulf of Finland (Fig. 4) for different time periods. In the simulation started on 1 October 1987 almost all hits to the nearshore occurred along the northern coast whereas 59% of the particles reached the nearshore. The overwhelming majority of particles launched on 1 December, however, came to the southern coast (52% of the particles reached the nearshore in this case).

## THE EQUIPROBABILITY LINE

The presented examples show that there exists no a priori safe location in the Gulf of Finland in terms of a low probability of the propagation of adverse impacts to the coastal area. A first step towards solving the problem of minimizing the probability of hitting any section of the coast is to identify a line (or area) from which the probability of the propagation to the opposite coasts is equal. In simulations below, the southern coast represents the coastline of Estonia whereas the coasts of Russia and Finland are merged to represent the northern coast.

Below we use two methods (a direct method and a smoothing one) for numerical estimation of the location of the equiprobability line and areas of reduced risk. Both are based on tracking trajectories with the use of the TRACMASS code and differ only in how the trajectories are grouped in the evaluation of the probability the particles released in a particular sea area enter a nearshore region. The difference in the positions between the two estimates of the location of the line can be interpreted as a rough measure of the uncertainty of its location. The deviation of this line from the axis of the gulf characterizes the asymmetry of the surface-layer current-driven transport in this basin.

The simulation process is depicted in Fig. 5. In order to obtain reliable statistics of the transport patterns, the simulations cover a relatively long time interval $t_D$, which typically involves at least one season but frequently one or more years. It is divided into time windows of equal length $t_W << t_D$. The duration $t_W$ is chosen based on the above estimates of the typical time scales of phenomena under research and typically is from a few days up to a few weeks. The windows are separated from each other by the time lag $t_S << t_W$, the duration of which varies from 6 hours (which is the time step of available velocity fields) to 10 days.

A pool of trajectory simulations is started at a certain time instant $t_0$ when a cluster of particles is released into the Gulf of Finland. In the above examples one particle was released into the centre of each grid cell of a set of 96 cells along a straight line more or less coinciding with the axis of the gulf (Fig. 1). For the simulations below, one or more particles were released into each of 3131 sea points of the gulf.

The trajectories are first simulated over a time window $[t_0, t_0 + t_W]$. The results are saved for further analysis. The same cluster of tracers is then released at time instant $t_0 + t_S$. The trajectories are again calculated over a window with a duration of $t_W$. The process is repeated $(t_D - t_W)/t_S$ times. Finally, the outcome of simulations is averaged over all time windows. For example, for a yearly simulation with the time window of $t_W = 20$ days and with a lag $t_S = 10$ days, the averaging is performed over 35 ensembles of trajectories, the last examples of which start on 12 December and end at the midnight of 31 December.

Within each time window, the instantaneous position $[x_{ij}(t), y_{ij}(t)]$ and the distance $\Delta_{ij}(t)$ of the trajectory from the coast were calculated for the entire time window and for each of the released tracers. Here $i$ is the grid cell number, $1 \leq i \leq N$, $N$ is the total number of cells into which the tracer is released, $j$ is the number of a tracer particle in the *i*-th cell, $1 \leq j \leq N_i$, and $N_i$ is the total number of particles released into the *i*-th cell. The instantaneous location of the tracer is used to estimate whether the trajectory has entered the nearshore.

The direct method for the estimation of the location of the equiprobability line and safe areas in the Gulf of Finland is based on point-wise analysis of what happens with the trajectories for each of $N = 3131$ grid cells in the gulf with the time lag of 10 days. Four particles $(N_i = 4,\ \ 1 \leq i \leq N)$ are released in each grid cell (symmetrically with respect to the cell centre) at the beginning of each time window. A count is made if over 50% (that is three or all four) of the trajectories travelled to the same coast within the time window. If yes, the cell is assumed the value of $c = \pm 1$ depending on the count of the hits to the nearshore of the southern or the northern coast. If no more than two tracers reached a particular coast within the time window (incl. the situation when two tracers reached the southern and the other two the northern coast), the cell is assumed the value of $c = 0$. Finally, a map reflecting the probability of hitting the nearshore of either of the coasts is obtained as an average of the described distributions over all the windows of the time interval in question. From the construction of this map it follows that the range of the resulting values $\overline{c}$ for a cell is from –1 to 1 and an estimate of the probability for tracer drift to the southern or the northern nearshore can be obtained by means of cell-wise mappings $p_N = (1+\overline{c})/2$ or $p_S = (1-\overline{c})/2$, respectively.

The resulting distributions depend on a number of parameters used in the calculations. Quite substantial seasonal and less pronounced interannual variability of these maps and the resulting location of the equiprobability line are discussed below. We performed several sensitivity experiments by means of varying the length of the time window $t_W$ and the time lag $t_S$ between the time windows. The results were almost insensitive with respect to the variation of the time lag from one day up to ten days provided the entire time interval of interest $t_D$ was long enough compared to this lag. This feature is not unexpected because the averaging procedure over a pool of time windows suppresses the role of each single distribution. Also, the results showed almost no dependence on the length of the time window provided it was long enough to cover about 50% of the first hits of the tracers to the nearshore. Notice that the optimum values of the listed parameters are strongly site-specific and should be re-evaluated for each sea area and problem under investigation.

The use of the discussed time window means that only hits within the first 20 days of the dynamics are accounted for in the resulting maps. Strictly speaking, the results, therefore, are based only on a fraction of all the tracers and serve as an approximation of the desired spatial probability distribution. As the majority of particles have already hit one of the coasts within this length of time window, the resulting map reflects the behaviour of this majority. Also, it is natural to assume that the further hits have the same probability distribution of hitting the different coasts and thus the corrections potentially resulting from waiting until all the tracers hit a coast would be fairly minor.

The resulting map (Fig. 6) reveals the presence of two basically different areas of the gulf. In the western part there is a narrow sea area in which the average values for the cells are close to zero. Tracers released to either side of this area have a high probability of drifting to the relevant coast. This area evidently can be interpreted as the estimate of the location of the equiprobability line. In the central and eastern parts of the gulf, however, there is a wide area in which $|\overline{c}| \le 0.1$. Consequently, propagation of tracers from this area to either of the coasts is generally unlikely. Such areas apparently host no well-defined equiprobability line. Instead, they entirely serve as almost safe regions (areas of reduced risk) in terms of coastal pollution.

Both the locations of these areas, potentially impacting either of the coasts, and the location of the equiprobability line reveal substantial seasonal variability (which will be discussed in detail elsewhere). Consequently, a similar variability exists for both high risk and reduced risk areas in this basin. The variability is the largest for the entrance area of the Gulf of Finland, which apparently is strongly affected by the dynamics of the open Baltic Sea.

Similar maps for annual probabilities of hitting different coasts also reveal certain interannual variability (Fig. 7). There are, however, features that persist over many years and also become evident in analogous maps for different seasons. There is a persistent area of reduced risk in the central and eastern parts of the gulf approximately between the Tallinn–Helsinki line and the latitudes of Narva Bay. To the north of Narva Bay there usually is a high probability of the propagation of an adverse impact to the southern coast. The equiprobability line is usually located to the north of the axis of the gulf except for a small part of this water body. There is a characteristic area to the north of Hiiumaa stretching almost to the Finnish archipelago from where the transport of adverse impacts to the Estonian nearshore has a relatively high probability.

The described method of cell-wise analysis of the transport generally leads to a considerable level of noise that does not always result in a clear separation of sea areas with the prevailing direction of the transport to a particular coast, especially in the central and eastern parts of the gulf. A part of the noise apparently is connected with a small number of tracers (four) for each cell.

In order to suppress the noise and to estimate the uncertainty of the location of the line and areas in question, we use another method that involves an implicit local smoothing process. The sea area is divided into clusters of 3 × 3 grid cells. By tracing nine trajectories in each cluster (one from each cell) it is established whether the majority of the trajectories end up at one of the coasts or stay in the open sea area. The basic idea is the same as above, only the values of $N_i = 9,\ 1 \le i \le N,$ and the initial positions of the tracer with respect to the cluster centres are different. The equiprobability line and the low-risk areas are based on probabilities calculated for the centres of the clusters. The resulting maps of probabilities of hitting the opposite coasts (Fig. 8) are qualitatively similar to those in Fig. 6. The equiprobability line is located in almost the same position as for the above method. The locations for the line based on these two estimates practically coincide between Hiiumaa and the Finnish mainland, differ by 1–2 grid points (3–6 km) in the western and eastern parts of the Gulf of Finland, and reach 3–4 grid points (up to 14 km) in a small section between Tallinn and Helsinki.

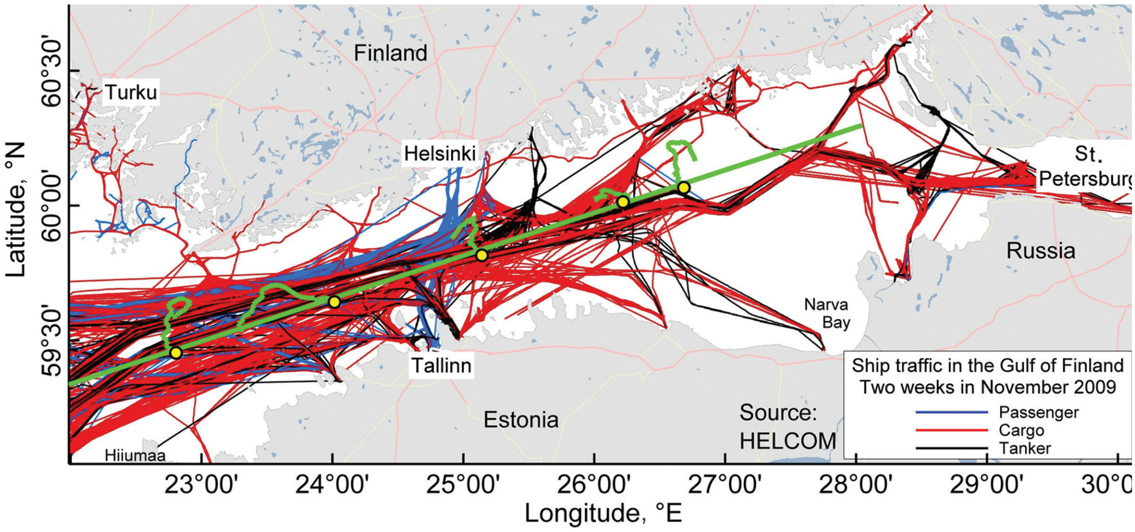

**Fig. 1.** Scheme of the current major fairways in the Gulf of Finland. The green straight line shows the initial location of tracers used for the construction of Figs 2–4 and the green curves show examples of trajectories, starting from points indicated by yellow circles.

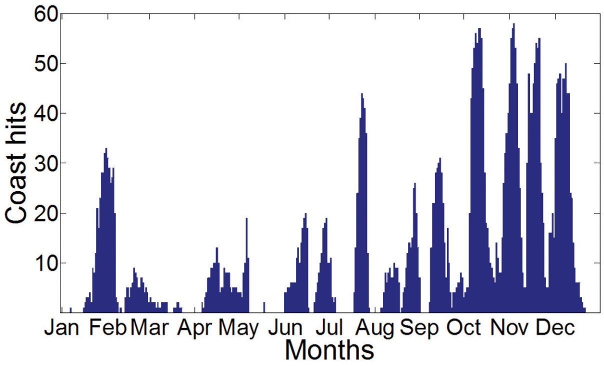

**Fig. 2.** Percentage of particles entering the nearshore during 10 days for the year 1987. The horizontal axis shows the starting time of calculations.

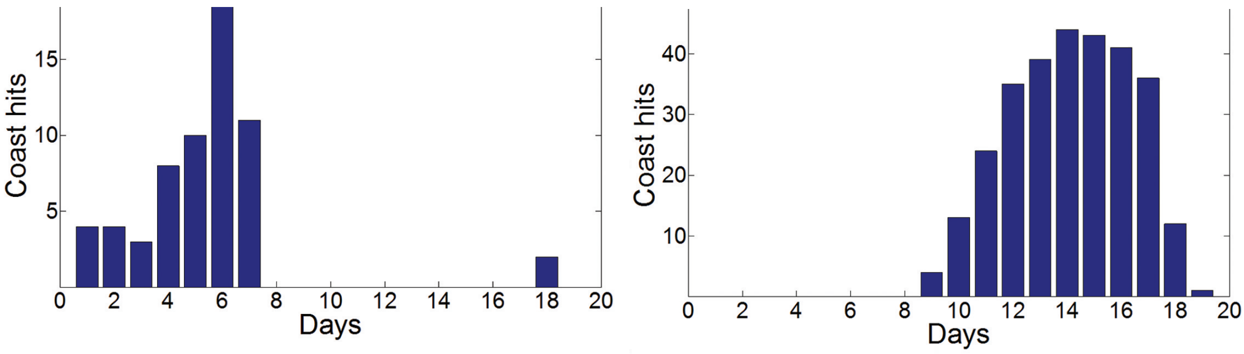

**Fig. 3.** Percentage of particles located in the nearshore on different days after their release on 1–20 May 1987 (left panel) and on 10–30 July 1987 (right panel). The horizontal axis shows the consecutive number of a day for the particular run.

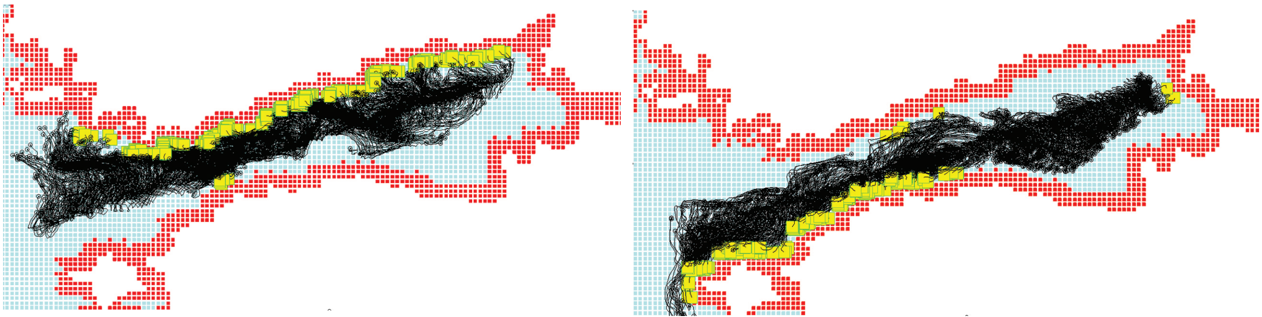

**Fig. 4.** Trajectories (black lines) and location of the hits (green squares) to the nearshore (red area) within 20 days for particles released on 1 October (left panel) and on 1 December 1987 (right panel).

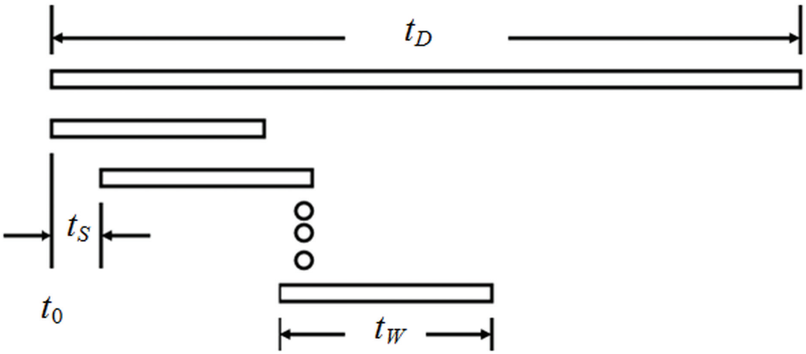

**Fig. 5.** Schematic diagram illustrating the overall simulation routine.

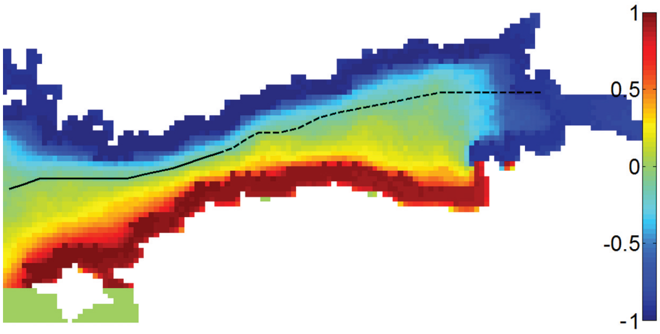

**Fig. 6.** Probabilities of hitting the nearshore of the northern or the southern coast for the years 1987–1991 calculated with the use of the direct method. The red colour indicates a high probability of transport to the southern (Estonian) coast and the blue colour, to the northern coast. The green colour marks the estimated location of the equiprobability line (black line) and the areas from which transport to either of the coasts is unlikely.

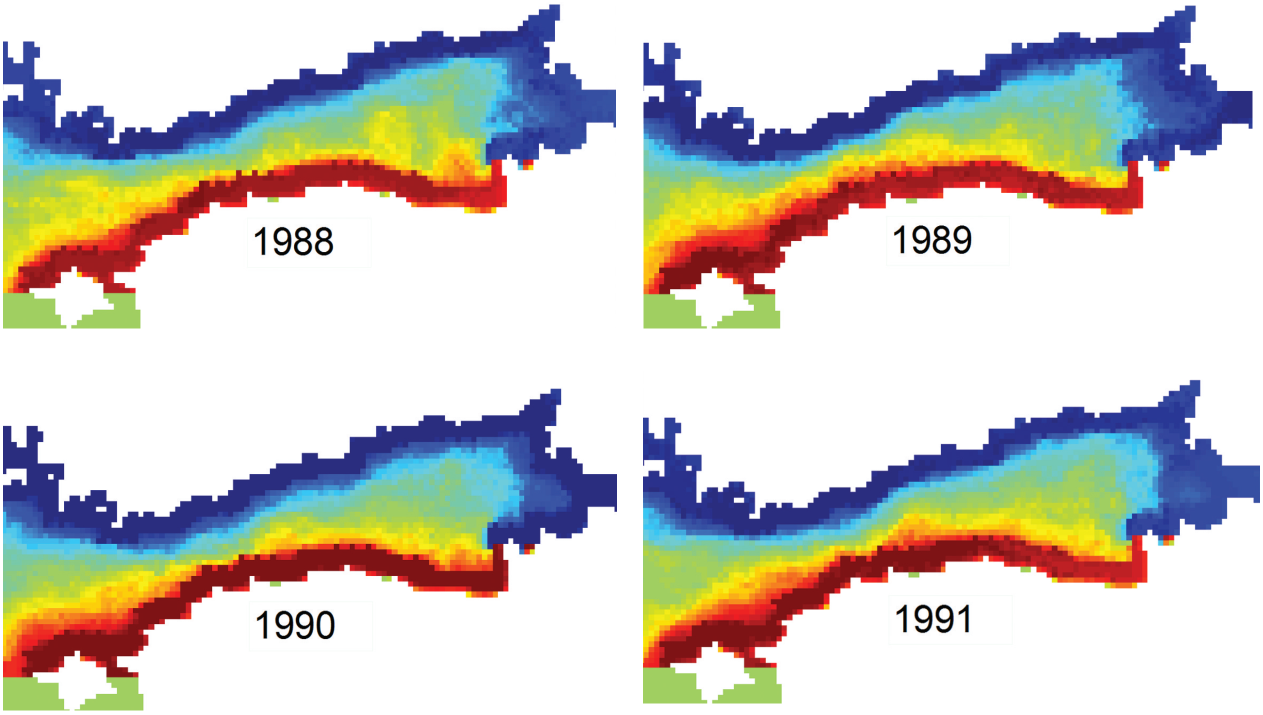

**Fig. 7.** Probabilities of hitting the nearshore of the northern or the southern coast for the years 1988–1991 calculated with the use of the direct method. Notations and scales are the same as for Fig. 6.

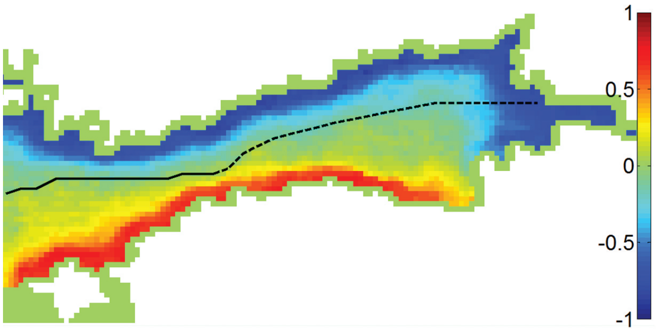

**Fig. 8.** Probabilities of hitting the nearshore of the northern or the southern coast for the years 1987–1991 calculated with the use of the smoothing method. Notations are the same as for Fig. 6. Notice that this method is only meaningful for the clusters whose centres are located at a distance of >11 km from the coast.

## DISCUSSION AND CONCLUSIONS

The primary purpose of this research was to find a first guess to the solution to a variation of the inverse problem of the identification of the areas in which an accident would least likely affect the coasts of the Gulf of Finland. The results revealed several unexpected features of the distribution of the probabilities of the transport to the different coasts. A well-defined equiprobability line is substantially shifted northwards from the axis of the gulf in its western part. The fairly small difference (usually below 6–7 km, at a few locations around 10 km) between its locations obtained by the two methods – an estimate of the uncertainty related with this type of solution – supports the reliability of the analysis.

Therefore, the probability that adverse impacts released to the entrance area and the western part of the gulf hit the southern coast is considerably larger than that they hit the northern coast. This property apparently matches the joint effect of the prevailing direction of strong and persistent winds (they are from the southwest) and the geometry of this basin. The resulting Ekman transport is predominantly to the east but also has a considerable component to the south (Soomere et al., 2010). This conjecture is consistent with the asymmetric distribution of the frequency of upwellings in the Gulf of Finland (which mostly occur along the northern coast of this water body (Myrberg and Andrejev, 2003)) and the accompanying prevailing transport of surface waters to the south.

In conclusion, application of a trajectory model and pre-computed velocity fields combined with relevant statistical analysis serves as a feasible method to determine areas of high and low risk in terms of coastal pollution in different basins of the Baltic Sea with their specific hydrographic characteristics, like in the elongated Gulf of Finland. This technology has a clear potential to reduce the consequences of an accident (equivalently, to impact the decision-making process concerning spatial planning of dangerous activities) in the statistical sense. Straightforward extensions of the proposed approach eventually are useful for preventively placing dangerous activities in regions in which an accident would have a minimum threat to vulnerable areas.

## ACKNOWLEDGEMENTS

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# Laevaliiklusega seonduvate keskkonnariskide optimeerimise võimalustest Soome lahes

Tarmo Soomere, Bert Viikmäe, Nicole Delpeche ja Kai Myrberg

On analüüsitud hoovuste tekitatud lisandite transporti Soome lahe pinnakihis aastatel 1987–1991. Rootsi Meteoroloogia ja Hüdroloogia Instituudi arvutatud hoovuste kiiruste andmestikust on tarkvara TRACMASS abil leitud lisandite edasikandumise trajektoorid. Nende statistilise analüüsi kaudu on hinnatud erinevatele merealadele sattunud lisandite randa triivimise tõenäosust. On näidatud, et Soome lahe lääneosas eksisteerib nn võrdtõenäosusjoon, millest põhja poole sattunud lisandid triivivad suurema tõenäosusega lahe põhjaranda, ja vastupidi. Soome lahe idaosa avamerel on piirkonnad, kuhu sattunud lisandite kandumine randa on vähetõenäoline. Ohutuim laevatee kulgeb piki kirjeldatud joont ja läbi selliste piirkondade.