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Verification of modelled locations of coastal areas exposed to current-driven pollution in the Gulf of Finland by using surface drifters

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Abstract. Statistical properties of the drift of floating items from the major fairway to the coast and numerically simulated transport of pollution by surface currents to the nearshore are compared for the Gulf of Finland. The comparison is based on tracks of 23 surface drifters that crossed the fairway in the central part of the gulf in 2011–2014 and 17 280 simulated trajectories of passive virtual parcels with starting points in the same section of the fairway and evaluated using velocity fields from the Rossby Centre Ocean (RCO) model in 2000–2004. More than 25% of the drifters that crossed the major fairway in the area north and north-west of Tallinn reached either the southern (Estonian) or northern (Finnish) coast. This probability matches similar estimates for single water parcels that are locked in the surface layer and exclusively carried by simulated currents. The probability of reaching the Estonian and Finnish nearshore by simulated parcels or the coast by drifters is roughly equal. Both surface drifters and virtual parcels generally drifted to the west before they reached the coast or nearshore, except for surface drifters that arrived on the Estonian coast.

Key words: Lagrangian transport, surface currents, pollution control, Gulf of Finland.

1. INTRODUCTION

The Baltic Sea is a relatively small water body but still hosts some of the heaviest ship traffic in the world [43]. Up to 15% of the world's international ship cargo is transported along its numerous fairways. Its fragile boreal environment is particularly vulnerable with respect to various kinds of human interventions and pollution. The largest threat to the environment is oil transportation [5], which increased by more than a factor of two in 2000–2008 and was expected to increase by a further 40% by 2015 [43].

This situation has triggered numerous attempts to prevent accidental release of various adverse impacts into the marine environment and to reduce the probability of ship accidents [22,28,29], in particular ship collisions, through the introduction of the Vessel Traffic Separation System [34]. These efforts have been complemented by attempts to track the propagation of oil spills [1] and to preventively minimize and mitigate the consequences of marine accidents [36] by means of optimizing the fairway location [20,25,38]. The largest problem in these efforts has been the largely chaotic and hardly predictable nature of motions in the surface layer of the Baltic Sea and its sub-basins [24,42].

The situation is particularly complicated in the Gulf of Finland [31]. A major marine fairway stretches from the Baltic Proper over this water body towards large harbours in its easternmost part. Surface currents in this basin are formed under the joint impact of wind stress, large-scale circulation patterns, water masses of the Baltic Proper from the west, and voluminous river runoff from the east, and develop in conditions of very small internal (baroclinic) Rossby radius [24]. Water masses are diverse and rich in fronts here due to the estuarine character of the gulf. This diversity is enhanced by the vigorous modulation of currents by bathymetry and frequently occurring upwelling events.

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As water masses of this gulf are often strongly stratified, motions above the main pycnocline are only weakly connected with the motions in the lower layer. The instantaneous field of mesoscale currents almost totally masks the mean circulation.

A specific feature of the Gulf of Finland is that motions in its uppermost layer are often almost detached from the dynamics of underlying water masses and follow the direct atmospheric forcing [23,31]. While the mean circulation is cyclonic here [24] and the subsurface circulation system is in some areas relatively persistent, numerically simulated currents at depths of 0–2.5 m in the central and eastern parts of the gulf have very low persistence [2] and may even be organized into a slow anticyclonic gyre [40]. Although the current-induced transport is generally oriented along the coasts, intense meridional (cross-gulf) transport may become evident during certain seasons [40]. All these features are expected to substantially affect the pathways of pollution propagation and to modify the locations impacted by pollution released in various regions of the sea.

A specific feature of marine accidents is that their impact is not local as the associated (e.g. oil) pollution may be carried over long distances. The largely chaotic nature of the surface currents suggests that probabilistic methods should be used for the quantification of accident-related issues [28,29] and for the optimization of fairways [36]. A meaningful application of any optimization process, including the efforts to mitigate the consequences of ship accidents, presumes specification of the cost function. Most studies in the Baltic Sea basin [20,42], the Atlantic [16,32], or the Mediterranean [7] have considered the nearshore as the most valuable area that usually has the greatest ecological importance. In essence, valuable or vulnerable locations may be concentrated in small areas (e.g. ports and tourist resorts with high commercial value) or partially extend to high seas (e.g. marine protected areas with high environmental value [7,8,36]).

We focus here on the pathways of potential pollution released from ships and passively carried further together with water masses. The problem for narrow bays, such as the Gulf of Finland, is how to minimize the probability of hitting any coast. A natural way to address this issue is by means of quantification of offshore areas in terms of their ability to represent a danger to the coastal environment via current-driven pollution transport [38,39].

A convenient way is to use statistical analysis of a large number of Lagrangian trajectories of (virtual or real) test particles passively carried by surface currents. This method relies on Eulerian velocity fields but allows identification and visualization of several properties of currents that cannot be extracted directly from the current fields [40]. Further analysis of these trajectories makes it possible to generate two-dimensional maps of the probability for different sea regions to serve as the starting point of pollution that drifts to the vulnerable area within a certain time interval or the time it takes pollution to reach the vulnerable area [25,38]. These maps can be used in various ways to optimize the location of the fairway [20,30,42].

Lagrangian trajectory methods are often applied as deterministic transport models, where transport is due strictly to advection [25]. This approach ignores many aspects of the dynamics and transport in the marine surface layer. The propagation of different substances in the water column is governed by an extremely complicated 3D system of currents but the simulated surface velocities ignore many processes that are not resolved by the circulation model. Moreover, the drift of various items and substances in the marine surface layer (e.g. oil pollution, marine litter, lost containers) [6,19] is additionally affected by direct wind impact [33] and wave-induced phenomena [15]. The wind-induced transport can be simply added to the current-driven advection [3] whereas the wave-driven effects are much more complicated to replicate [30]. As the properties and physics of some of the listed drivers are not exactly known yet, it is not unexpected that predictions of the floating object drift or of the fate of oil spills are often imperfect [1,6,17].

Drifter experiments indicate that the dynamics of currents in the Gulf of Finland is extremely complicated. For example, in May 2003, the *Current Spy* surface buoys with a drogue depth of 0.7 m [18] moved with a speed of about 2% of the wind speed and with a deviation angle of 0–10° to the right in moderate wind conditions. In weak wind conditions the buoys drifted ~60° to the left of the wind. Previous analysis of drifter tracks used in the present study revealed that the Lagrangian integral time scale (the time lag for which the Lagrangian velocity of a drifter is correlated with itself) is 7–12 h in the Gulf of Finland, which extends to 14–20 h when inertial and sub-inertial oscillations are filtered out [44]. By comparison, analysis of Surface Velocity Program (SVP) drifters in the Baltic Proper [21] found that the Lagrangian integral time scale varies from 12 to 48 h, with a maximum likelihood value in the range 21–27 h. As the SVP drifter measures currents at 15 m depth while the drifters used in the present study extend only to 2 m depth, it is to be expected that the time scale associated with the SVP drifters is longer than the time scale associated with our surface drifters, reflecting the difference in the surface-layer and subsurface-layer dynamics.

Several possibilities of addressing the described gaps and shortcomings of the techniques of fairway optimization based on the statistics of Lagrangian trajectories of passively advected pollution parcels were addressed in [48]. That study established which parts of the nearshore are hit more frequently than others and whether the parcels stem from specific parts of the fairway. The ignoring of subgrid processes and several external impacts in [38–40,42] raised questions about the validity of the results. Although reasonably good models exist that can accurately predict the wind- and wave-induced transport of the surface layer [45], their impact on the statistics of trajectories can be, to a first approximation, also parameterized as a subgrid-scale process. To compensate for the lack of subgrid-scale turbulence in the velocity fields obtained from circulation models, Lagrangian models often add a stochastic component either to the velocity field itself or to the displacement of Lagrangian particles [4,12]. The stochastic component generally increases the relative dispersion of Lagrangian particles [13,21] but also distorts the directional persistence of the motion of individual particles, hence altering the Lagrangian flow properties such as the time scale. Although statistical properties of individual trajectories may be influenced strongly by a stochastic flow component, the stochastic effect on a particle cloud also depends on the heterogeneity of the underlying velocity field. For instance, the pattern and frequency of pollution parcels' hits to the nearshore remained almost unchanged when simulated with and without a stochastic flow component [48].

In this paper we make an attempt to qualitatively validate some features of long-term transport of simulated passive particles located in the surface layer of the Gulf of Finland to the coastal regions of the gulf by comparison with parameters of the transport of several dozens of surface drifters. A replication of exact trajectories of drifters during a longer time does not seem feasible [45]. However, the pattern of coastal areas reached by virtual particles released in the middle of the gulf is almost invariant with respect to the method of replication of trajectories [48]. For this reason the analysis is limited to a comparison of the statistics of coastal areas reached by the drifters (called coastal hits) and the time it took the drifters to reach the nearshore (called nearshore hits) with similar values extracted from numerical simulations. An analysis of pathways of surface drifters from the major fairway in the Gulf of Finland to marine protected areas (that extend far to the offshore) is presented in [9]. To make the comparison more explicit, the focus is on the fate of pollution caused by ship traffic in the Gulf of Finland.

2. SURFACE DRIFTERS CROSSING A MAJOR FAIRWAY IN THE GULF OF FINLAND

The main shipping fairway in the Gulf of Finland is confined to a fairly narrow corridor located approximately along the south-west to north-east axis of the gulf (Fig. 1). The fairway is separated into two branches from the entrance of the gulf up to the Kunda–Kotka line [34]. The southern branch heads to the east and the northern branch to the west, thereby achieving a

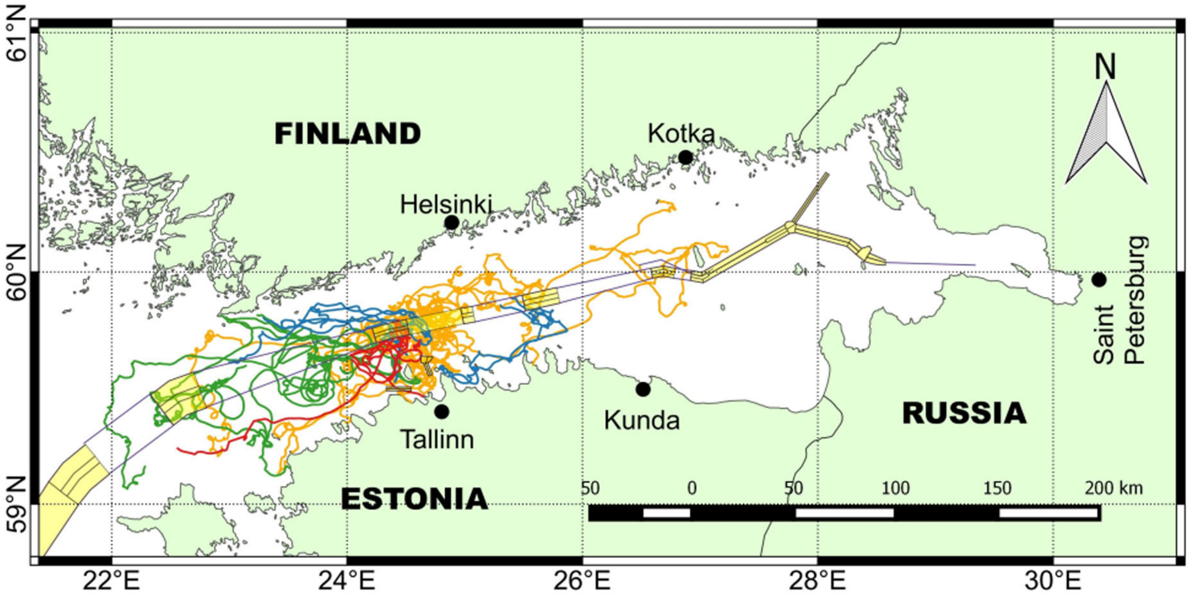

Fig. 1. Trajectories of 26 surface drifters crossing the ship fairway in the Gulf of Finland. Tracks of different colour represent deployments for different years: red 2010, blue 2011, green 2013, and orange 2014.

separation of vessels sailing in opposite directions. To realistically represent this situation, the northern and southern borders of the navigation areas and lines (HELCOM Baltic Sea data and map service) were used to define two possible fairways that are treated as a potential source of pollution.

Previous studies of Lagrangian trajectories of virtual passive parcels calculated from velocity field data of a numerical circulation model revealed a significant spatial variability in the level of exposure for different coastal sections [46]. The optimum fairway along the Gulf of Finland has a strong intra-annual variation, reflecting seasonal changes in the patterns of average surface currents [30]. However, as these studies relied exclusively on data from numerical circulation models, the results also reflected shortcomings in the modelling procedure, such as relatively coarse spatial and temporal resolution and inaccuracies in the forcing data. Hence it is necessary to examine the problem of surface current transport using other methods to assess the reliability of the numerical simulation results. One option is provided by the use of data from autonomous surface drifters.

A total of 78 surface drifters were deployed in the Gulf of Finland during the years 2010–2014 [41,44]. The lightweight, autonomous drifters (Fig. 2) were designed and manufactured by the PTR Group (Tallinn, Estonia). The basic design consists of a semi-submersible plastic tube, 2 m long and 50 mm in diameter. Each drifter contained a GPS/GPRS tracker (CT-24 or MU-201, Sanav, Taiwan) for recording and transmitting the drifter position and a battery pack serving both as power supply and deadweight. Drifters deployed in 2010–2011 had a battery lifetime of 2–3 weeks. A design modification made in 2013 in order to reduce the wind-induced drift extended the drifter length to nearly 3 m, and allowed the drifter body to be almost totally submerged. A separate compartment for the GPS/GPRS tracker was placed 85 cm above the main drifter body and connected with the drifter body by a narrow rod (10 mm diameter). The modified drifters had a battery lifetime of 4–5 weeks. The trackers sent the geographical coordinates of the drifter usually every 10 or 15 min.

The drifters were deployed during the relatively calm spring and summer seasons, from April to September, at locations close to the southern (Estonian) coast. A majority of the deployed drifters remained within close proximity of the Estonian coast. Only 26 of the 78 drifters crossed segments of the ship fairway. The instantaneous locations of these drifters (Fig. 1) were largely concentrated in the sea area north of Tallinn where most of the drifters were deployed. Their trajectories extend both eastward and westward from the common deployment locations [44], seemingly without any persistent pattern as expected for the mostly chaotic nature of current-driven surface transport in the Gulf of Finland [2]. The basic parameters (the maximum and minimum drift time after the drifter crossed both fairway branches, and the final location of each drifter) of these 26 drifters are illustrated in Fig. 3.

Fig. 2. A surface drifter constructed from a polyethylene tube and powered by eight standard D-size batteries used for the experiments in 2010–2011.

The duration of the tracks that terminated at the Finnish coast (from 2.3 to 14.2 days) was usually shorter than the duration of the tracks terminating at the Estonian coast (from 3.5 to 44.7 days). Also, four of the six tracks that terminated at the Finnish coast crossed both fairway branches only once. This indicates that the drifter motion towards Finland was mostly driven by fairly stable surface flow conditions, primarily towards the north-west. In contrast, the drifters that reached the Estonian coast usually crossed the fairway several times and hence were carried by more meandering motions. However, also for the drifters that were carried to the south the transport to the coast could be fairly rapid, often less than a week (Fig. 3). Interestingly, none of the drifters deployed on the same day reached the opposite coasts.

The transport time from the deployment sites (which were all relatively close to the Estonian coast) to the southern fairway branch was frequently only a few days and seldom (drifters #7 and #8; the drifters are labelled successively according to the deployment date) less than one day. This sort of jet-like cross-gulf transport is probably not a typical scenario, since the majority (52) of the 78 deployed drifters never reached the fairway. This feature, however, is consistent with the numerically simulated cross-gulf Lagrangian transport patterns [40] and demonstrates that under certain conditions drifters may depart rapidly from the coastal zone.

The drifters that did not reach any coastal area are denoted as ‘lost at sea’ or ‘Baltic Proper’ in Fig. 3. In the following analysis we distinguish between drifters that were lost at sea after reaching the Baltic Proper (eventually because of the loss of GPRS connection) and drifters lost at sea within the Gulf of Finland (mostly because of limited battery life). The drifters that entered the Baltic Proper for some time but were later carried back to the Gulf of Finland and finally reached a coastal area of this gulf (drifters #11 and #23) are counted as coastal hits similarly to those devices that stayed in the gulf during all their drift.

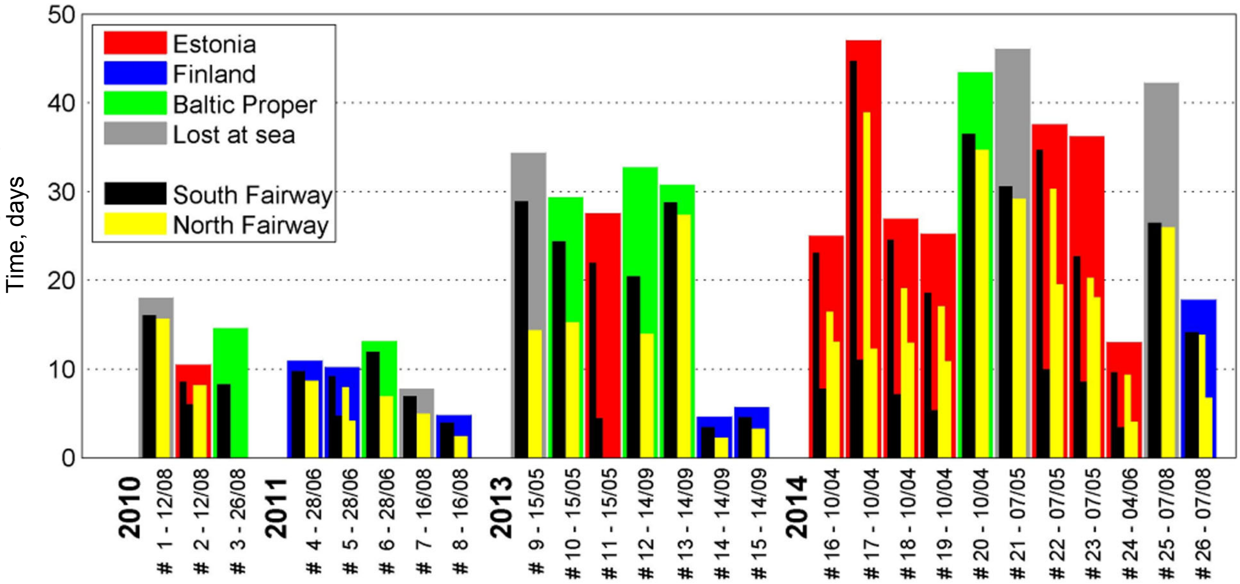

Fig. 3. Drift time for the 26 drifters that crossed the fairway. The colour of the wide bars indicates the final location for each drifter. Thinner black and yellow bars indicate the maximum and minimum drift time after crossing the southern and northern fairway branches, respectively, with minima only calculated for drifters that reached land. Drifters are labelled successively according to the deployment date [9].

The drifters lost at sea within the Gulf of Finland would eventually have reached either a coastal section within the Gulf of Finland or the Baltic Proper over a longer time interval. For instance, the battery of drifter #25 had become depleted while it was located in the open part of the gulf. The device was later recovered by a fishing vessel at a short distance from the Finnish coast. If the drifter had been tracked until that instant, it could potentially be counted among the drifters that reached the Finnish coast. It is therefore likely that the limited battery lifetime is a substantial reason why a relatively large number of drifters were lost at sea. However, this limited lifetime makes the statistics of coastal hits better (albeit not perfectly) comparable with similar statistics of numerically simulated virtual drifters that were only tracked during a few weeks [46].

In the western part of the Gulf of Finland, the fairway is located near the centre line between the Estonian and Finnish coasts. This location is close to the equiprobability line (the line from which the probability of current-induced drift of passive pollution parcels to either coast of the Gulf of Finland is equal) [38]. The drifters deployed in 2010 only sent data when connected with the Estonian GSM network. Moreover, they did not store any data internally; hence no tracks were recorded in the northern part of the Gulf of Finland that year. Thus, the three drifters that crossed the fairway in 2010 have been ignored in the analysis, and only the 23 drifter trajectories that crossed the fairway during 2011–2014 have been included (Fig. 3). Based on these data, there appears to be an almost equal probability for drifters that crossed the fairway to reach the Estonian coast (35%) and the Finnish coast (26%). Furthermore, the drifters had a relatively large probability of reaching the Baltic Proper (22%). These rough estimates have a fair match with the outcome of the analysis of the frequency of hits to the nearshore [47]. The fate of the remaining drifters lost at sea (17%) could not be determined. It is likely that the presented proportions could have been substantially altered if a few of the drifter tracks had deviated slightly from their actual tracks, or if the lifetime of the drifter battery packs had been longer.

3. MODELLING ENVIRONMENT AND METHODS

The above statistics of the surface drifter data is compared with the outcome of numerical replication of current-driven advection of passive water parcels that are locked in the surface layer. The simulations are based on velocity fields obtained from the Rossby Centre Ocean (RCO) circulation model [26,27] provided in the framework of BONUS BalticWay cooperation [42]. The horizontal resolution of the RCO model grid employed in this simulation is 2 × 2 nautical miles (about 3.7 km). The surface velocity field used in the transport calculations represents motions in the uppermost layer (depths 0–3 m).

Simulated velocity data for the time interval for drifter deployments were not available for this study.

Thus, our aim is not to reproduce individual drifter tracks but to compare statistical properties derived from the Lagrangian trajectory simulations, such as the probability of reaching the nearshore and the average time it takes the parcels to reach the nearshore, with data obtained from the surface drifters, similarly to the analysis in [21]. As the statistical properties and spatial patterns of hits to the nearshore are practically stationary in different decades [46], to a first approximation it is acceptable to use data from simulations covering the period 2000–2004 in the comparison.

Most of the surface drifters crossed the fairway in the region north and north-west of Tallinn. For the purpose of comparison, we have therefore restricted the parcel seeding to the fairway section between 24°E and 25°E (Fig. 4). This section contains the junction with the Tallinn–Helsinki ship lane and is therefore a region of increased risk for ship collision [28,29]. The advection of virtual parcels is simulated using the Lagrangian trajectory model TRACMASS [10,11,14]. It was applied as described in [38,40,48], using simulation time windows (drift duration) of 20 days, 6 simulations each month, and a time lag of 5 days between subsequent (partially overlapping) simulations. Model runs were made without invoking additional stochastic particle dispersion, as the statistics of coastal hits has been shown to be almost invariant to this effect [48]. The total number of time windows during the 5-year interval was 360 and resulted in 17 280 single trajectories (Fig. 4). The nearshore area was defined as the set of three model grid points closest to the mainland [47].

The simulated parcels had a high probability of reaching either the nearshore of Estonia or Finland (Fig. 5). The annual average count of parcels that

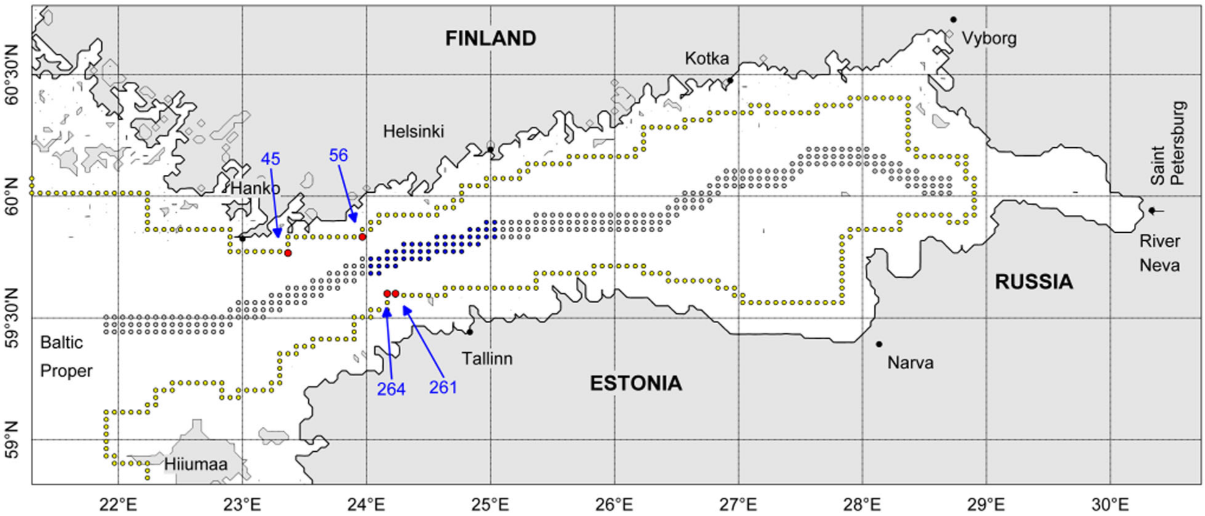

Fig. 4. Initial location of selected parcels (blue circles) on the major fairway (grey circles), the border of the nearshore (yellow circles) in the Gulf of Finland in numerical simulations [38], and the most frequently hit nearshore areas (red circles, >60% of the annual maximum number of hits at least in three model years out of 2000–2004).

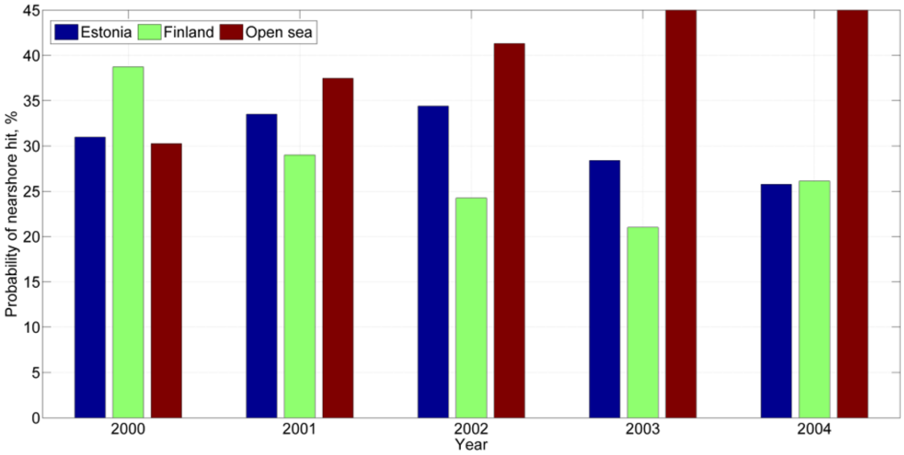

Fig. 5. Probability for the simulated parcels selected on the major fairway between 24°E and 25°E (Fig. 4) to reach nearshore areas of Estonia and Finland.

reached the nearshore ranged between 25% and 40%. Consistently with simulations in [38], neither the Finnish or the Estonian nearshore was regularly more exposed than the other. The probability of parcels hitting any of the nearshore regions varied from 20% to 45%, hence a large part of the seeded parcels would reach nearshore areas within the simulation time of 20 days (cf. [47]).

The locations of coastal hits were not uniformly distributed along the coastline. Seven sections of the nearshore frequently received a massive number of hits (Fig. 4). Four sections were highlighted by considering the nearshore domains that received at least 60% of the annual maximum number of hits in any three years out of the five consecutive years 2000–2004. Two of such sections were located at the coast of Finland and two at the coast of Estonia. Importantly, all frequently hit sections were located to the west of the centre of the area of parcel seeding. This westward transport of parcels was stronger for hits to the nearshore of Finland.

Further examination of these four sections established the likely seeding positions of the parcels hitting each section (Fig. 6). The frequently hit areas along the Finnish coast received parcels from a larger fairway section than similar areas along the Estonian coast. This suggests that the north-western nearshore of the Gulf of Finland is more exposed to events causing a general westward surface current in the northern part of the gulf rather than to cross-gulf currents that move parcels directly northwards. The Estonian nearshore appears to be exposed both to directly southward transport and to currents directed to the south-west.

Although the selected section of the fairway is relatively short, the count of nearshore hits for parcels from its different locations varies substantially (Fig. 7). Part of this variation reflects the different distances from the coast of the three model grid cells representing the major fairway. However, the systematic variation in the number of nearshore hits along the fairway for two points on the Estonian coast is roughly by an order of magnitude larger. This variation may reflect the existence of certain global transport patterns in the gulf [40].

The average time it took parcels to reach nearshore areas (called particle age in [39] and calculated here for all parcels that reached the coast) varied considerably along the fairway section in question (Fig. 7). It was 6–9 days in the western part of this section but clearly longer, 7–11 days, in its eastern part. This difference is counter-intuitive as the probability of a nearshore or coastal hit is often roughly inversely proportional to the distance from the initial location [8]. This feature suggests that the general westward surface transport in the gulf [24] may override the 'impact' of local geometrical features of the Gulf of Finland and may increase or decrease the exposedness of a particular nearshore or coastal section with respect to pollution or debris stemming from the offshore.

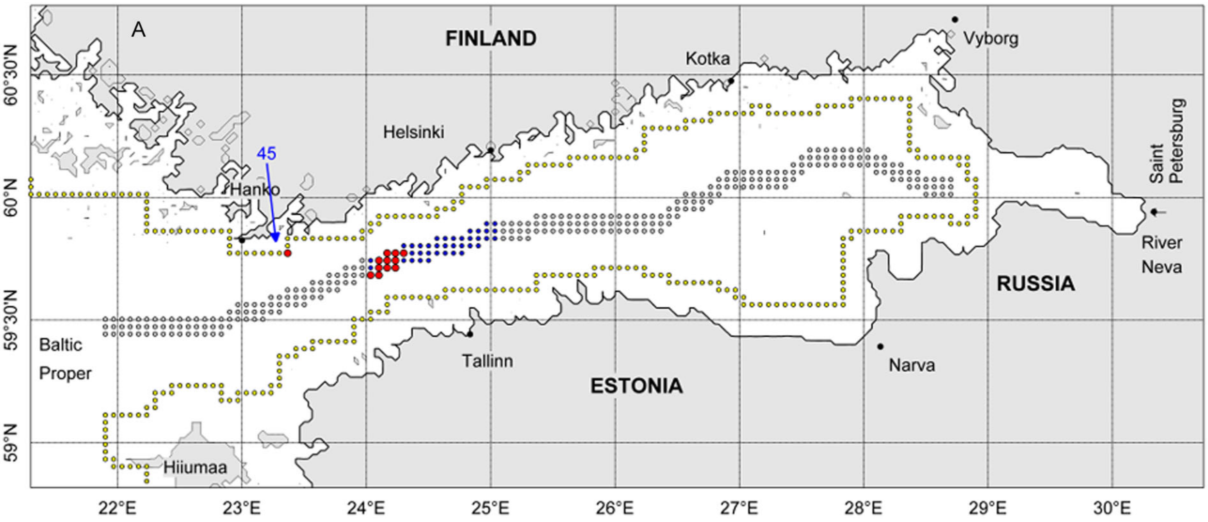

Fig. 6. Interconnections between the four most frequently hit nearshore sections (starting from the western part of the northern coast and ending in the western part of the southern coast) and the fairway sections between Tallinn and Helsinki. Only seeding locations with at least 10 hits (over the 5-year period) to a specific nearshore section are indicated. Panels A–D indicate the most frequently hit nearshore sections 45, 56, 261, and 264, respectively (Fig. 4).

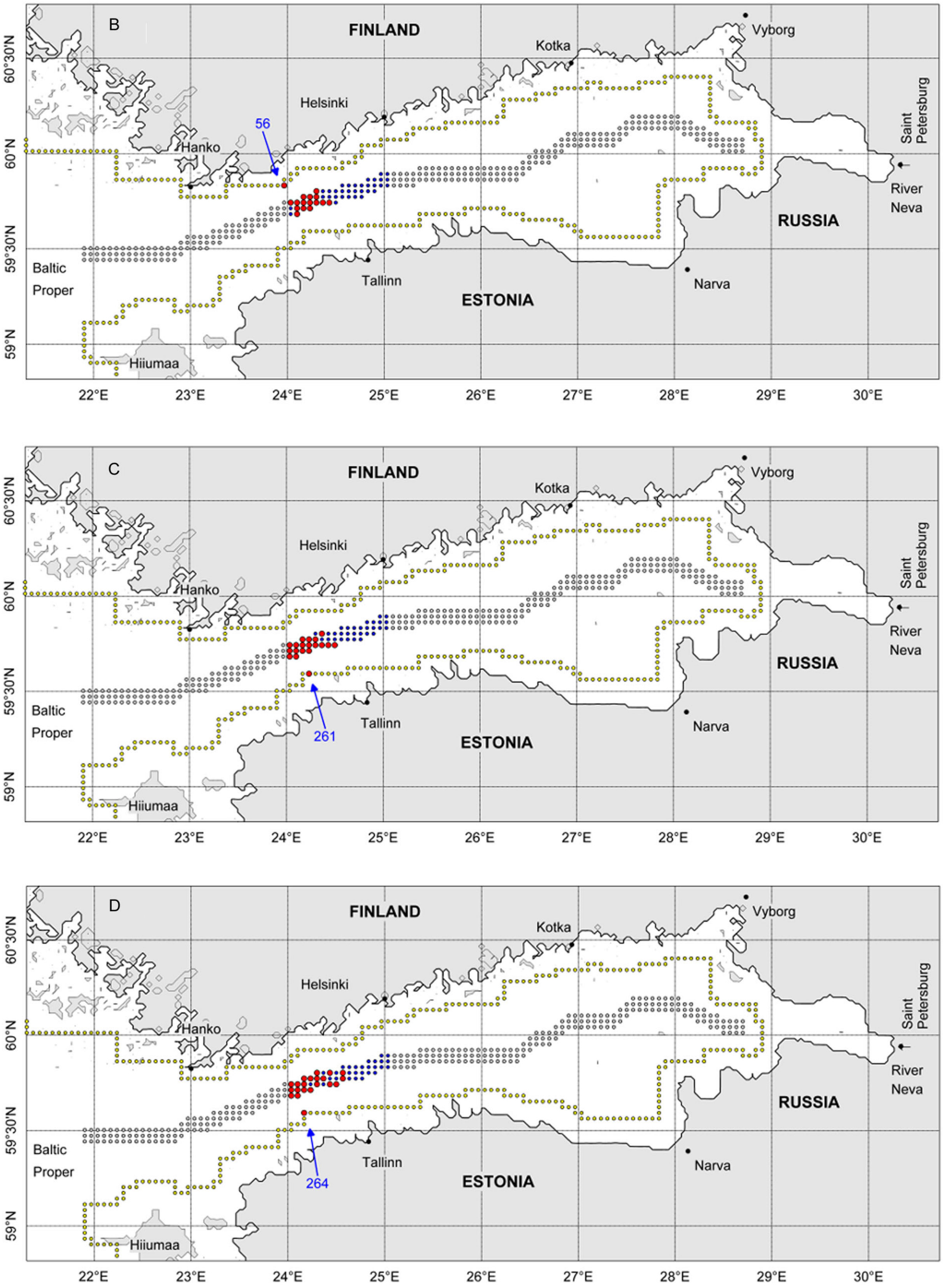

Fig. 6. *Continued.*

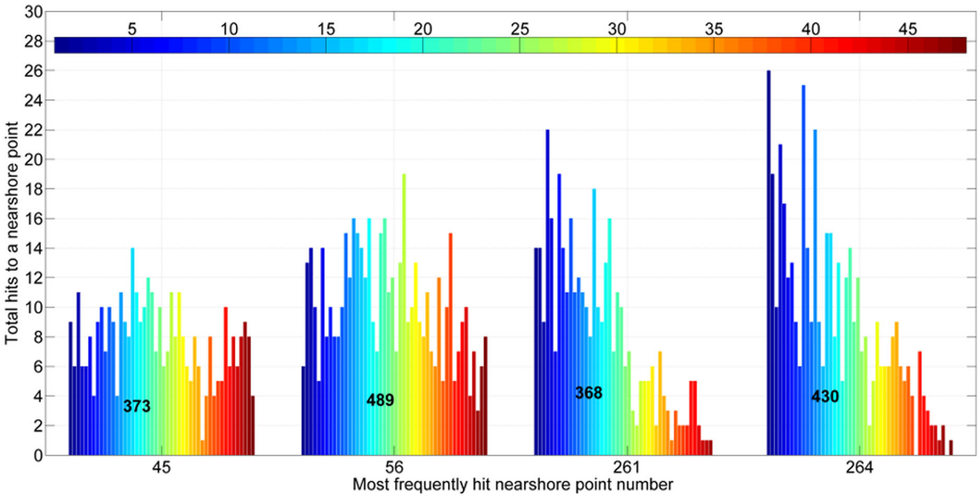

Fig. 7. Number of hits to the four most frequently exposed nearshore areas (Fig. 4). Colour code indicates the initial position of the parcels, equivalently, the location of the chosen 48 fairway points (blue points in Fig. 4) from the west to the east.

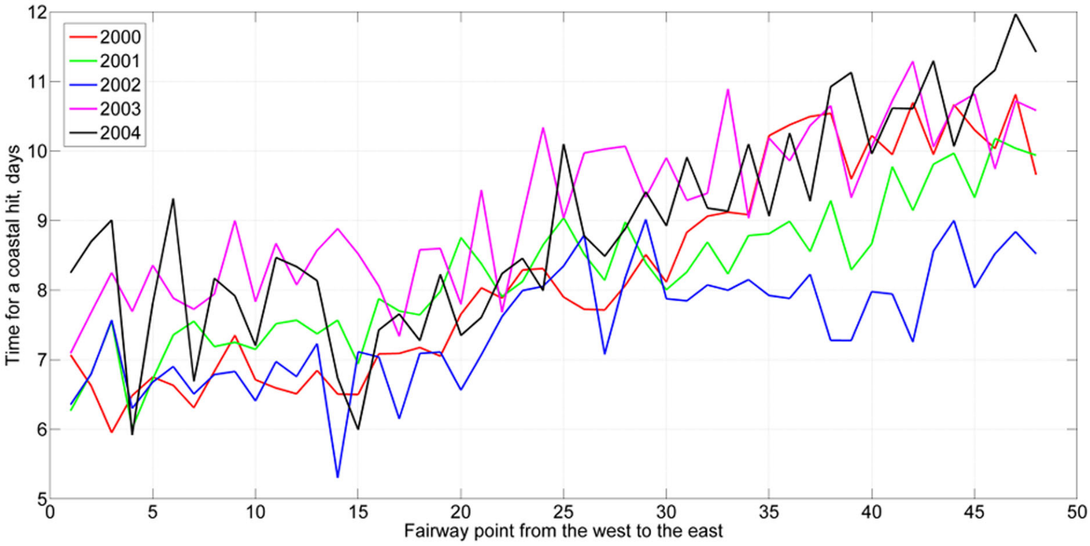

Fig. 8. Average time it took the chosen parcels (Fig. 4) to reach a nearshore area in 2000–2004.

4. DISCUSSION AND CONCLUDING REMARKS

In spite of obvious problems with the comparison of the statistics of the drift of real surface drifters to the coast with that of the advection of virtual water parcels to the nearshore (~11 km from the coast), the overall patterns of the behaviour of surface drifters and numerically simulated Lagrangian trajectories show some clear similarities. First of all, the drifters' motion confirms that there is a high probability (>25%) for floating items that originate in the major fairway in the area north and north-west of Tallinn to reach either the Estonian or the Finnish coast. The match of this probability with similar estimates for single water parcels that are locked in the surface layer and exclusively carried by simulated currents [38,46] signals that the results based solely on current-driven advection (i.e. the direct wind impact and wave-induced drift ignored) still to a large extent mirror the statistical properties of the real transport of items to the nearshore. This conjecture also supports the outcome of simulations of Lagrangian trajectories with and without local spreading [48].

There is also a significant probability that parcels will reach neither coast. This feature can partly be attributed to the fact that some parcels move out of the Gulf of Finland to the Baltic Proper [47]. This transport is evidently much weaker than hypothesized in [35] and most likely cannot be used to mitigate the problem of coastal pollution by substances released into the sea along the major fairway. An overall tendency of the relocation of both the surface drifters and virtual parcels to the west before they reach the coast or nearshore is clearly visible for drifters and parcels that head to the north: hits to the Finnish coast primarily occur at locations to the west of the initial location of parcels or the points where the drifters cross the fairway. A similar tendency was evident for numerically simulated parcels that reached the Estonian coast, but this was not apparent for trajectories of surface drifters. This asymmetry probably reflects the overall circulation pattern in the gulf where the surface water enters the gulf along the southern (Estonian) coast and exits along the northern (Finnish) coast [37].

The travelling time of the surface drifters that reached the coast varied considerably. It was in the range of 2–14 days for the Finnish coast and 4–44 days for the Estonian coast. The average time for the simulated parcels to reach the nearshore (6–11 days) falls within this range. Since only 14 drifters reached coastal areas, the surface drifter data are not sufficient to assess the accuracy of numerical simulations in this respect. Importantly, the maximum drift time of a real device from the fairway to the nearshore was much longer than the time window selected (20 days) for the simulations. Hence it is reasonable to assume that the probability of nearshore hits calculated from numerical simulations would have been higher than shown in Fig. 5 if the simulation window had been extended.

Finally, we emphasize that the definition of a ‘coastal hit’ is different in the numerical simulations compared to the surface drifter analysis. The surface drifters were considered to have reached the coast once the drifter had grounded. Such events were indicated by a significant reduction in drifter speed. For the numerical simulations one could define the coastline as the grid cells bordering at least one point on land. However, this would result in an artificially low number of coastal hits, since the numerical boundary conditions between water and land points (no flux condition) severely reduce current velocities perpendicular to the coast for these grid cells. The border of the nearshore in the simulations has therefore been set at a distance of 3 grid cells away from a land point, that is, well offshore [47]. This can to some extent be justified for the Finnish coastline, where an extensive (unresolved in the model) archipelago area extends far offshore. This approach is to a lesser extent justified for the Estonian coast where only a few islands are present.

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Reostuse hoovustransport laevateelt Soome lahe randadesse: arvutisimulatsioonide ja triivpoide teekondade võrdlus

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Soome lahte sattunud reostuse edasikandumist ja rannalõike, kuhu reostus võib sageli jõuda, on analüüsitud pinnahoovusi järgivate triivpoide teekondade ning pinnakihis paiknevate virtuaalsete veeosakeste arvutil rekonstrueeritud trajektooride alusel. Vaatluse all on hoovustransport lahe keskosas paiknevalt ida-läänesuunaliselt laevateelt randade poole, triivpoide puhul jõudmine lahe randa ja veeosakeste puhul kandumine rannalähedasse piirkonda. Aastail 2011–2014 paigaldatud 23 poi salvestusi (mis ületasid vähemalt ühe korra kõnesoleva laevatee Tallinnast põhja ja loode pool) on võrreldud 17 280 veeosakese trajektooriga, mis algasid laevatee samast piirkonnast ning on konstrueeritud Rossby Centre tsirkulatsioonimudeliga RCO aastaiks 2000–2004 arvutatud hoovuste kiiruste alusel. Enam kui 25% poidest jõudis kas Eesti või Soome rannikule. Pinnahoovustega edasi kanduvatest veeosakestest jõudis ranniku lähistele samuti ligikaudu veerand. Triivpoid ja veeosakesed kandusid üldiselt lääne poole (välja arvatud need poid, mis saabusid Eesti rannikule) ning jõudsid erinevatele rannikuosadele sarnase tõenäosusega.