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The use of current-induced transport for coastal protection in the Gulf of Finland, the Baltic Sea

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The existence of semi-persistent patterns of currents in various parts of the Baltic Sea leads to the interplay of the high variability of the surface currents with the presence of rapid pathways of the transport of adverse impacts. This variability and accompanying asymmetry of the current-driven transport opens a new way towards the use of marine dynamics for reducing the environmental risks. The key benefit is an increase of time during which an adverse impact (for example, an oil spill) reaches a vulnerable area after an accident has happened.

We attempt to identify the regions that are at high and low risk in terms of current-transported coastal pollution in the Gulf of Finland, the Baltic Sea. A solution to this inverse problem is sought by means of analysis of a large pool of solutions to an associated direct problem of the current-driven transport. The basic tool is a Lagrangian trajectory model, TRACMASS that uses 3D current velocity fields calculated by the Rossby Centre global circulation model. The goal is to evaluate the basic parameters of transport that cannot be extracted directly from the velocity data, such as the average net transport rate and the ratio of average net and bulk transport. These parameters allow estimating whether or not the proposed approach would lead to substantial benefit. Trajectories of current-driven pollution for each sea point are simulated for a few weeks and the simulations are repeated over several years. The average time it takes for the pollutants to reach the coastal zone is a measure of risk associated with the starting point.

A comparison of the average net transport with the velocity fields allows identifying the areas that may have very strong (or weak) flow and the direction of such flows. Similar patterns in the ratio of average net and bulk transport allows identifying both the areas of fast moving flow and the areas where mostly local eddy-driven circulation exists. The results show a substantial seasonal and interannual variation. For certain seasons, fast pathways of transport may also exist perpendicularly to the Gulf of Finland. Further analysis of the trajectories allows identifying the typical time scale it takes for pollutants to hit the coastal zone and the areas that are at high and low risk from the viewpoint of coastal protection.

A central question for narrow bays is how to minimize the joint probability of hitting of either of the coasts. We demonstrate the calculation of the equiprobability line, the probability of propagation of pollution from which to either of the coasts is equal. In the wider part of the gulf there exist regions, propagation of pollution from which to any of the coasts is unlikely. These areas and the equiprobability line provide low environmental risk and may host a safe fairway. The equiprobability line is located northwards from the axis of the Gulf of Finland indicating a larger probability of hitting the southern coast by adverse impacts. The current fields and the related derived properties exhibit strong seasonal variability. A similar variability exists for low-risk areas.

Thus utilizing a trajectory model combined with relevant statistical analysis serves as a feasible method to determine areas of high and low risk in terms of coastal pollution in the Baltic Sea. The technology has clear perspectives to be applied to place dangerous activities in areas, an accident in which will have a minimum threat to vulnerable areas.