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Temporal scales for nearshore hits of current-driven pollution in the Gulf of Finland

Bert Viikmäe [a,*], Tarmo Soomere [a,b]

[a] Institute of Cybernetics at Tallinn University of Technology, Akadeemia tee 21, 12618 Tallinn, Estonia
[b] Estonian Academy of Sciences, Kohtu 6, 10130 Tallinn, Estonia

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ABSTRACT

Lagrangian trajectories of water parcels reconstructed using the TRACMASS model from three-dimensional velocity fields by the RCO model for 1965–2004 are used to analyse the temporal scales and the probability for the hits to the nearshore by pollution originating from a major fairway in the Gulf of Finland and transported by surface currents. Increasing the simulation length from 10 to 20 days induces a linear increase in particle age, but the pattern of nearshore hits remains the same. A reasonable benefit can be reached by relatively small shifts of certain parts of the present fairway in a few locations. The overall probabilities do not reveal any trend for 1965–2004. The largest changes in the nearshore hits are revealed for the proportion of hits to the opposite nearshore areas. This feature probably reflects an abrupt turn of the geostrophic air-flow over the southern Baltic Sea by ~40° since 1987.

1. Introduction

The Baltic Sea, which is designated as a Particularly Sensitive Sea Area (PSSA) by the International Maritime Organisation (IMO, 2007; Kachel, 2008), is the host to one of the most fragile boreal brackish-water environments and many marine protected areas. Still up to 15% of the world's international ship cargo is carried over this relatively small water body. The intensity of ship traffic is gradually growing. For example, oil transportation over this sea has increased by more than a factor of two in 2000–2008 and has nearly quadrupled in the past ten years in the Gulf of Finland, and a further 40% increase is expected. In 2012, almost 342 million tonnes of oil and oil products were transported via the Baltic Sea, of which >50% via the Gulf of Finland (Fig. 1) where every year, more than 40,000 ships sail, and 7000 of these are oil tankers (Brunila et al., 2014). Sustainable management of this traffic flow is a major challenge. The shallow and rocky waters, narrow navigable areas and severe ice conditions add to the risks of navigation in the Baltic Sea and, more particularly, in the Gulf of Finland. It has been estimated that the clean-up costs of a 30,000 tonnes shored oil spill could reach up to € 1 billion. Damages to the vulnerable Baltic Sea region and its unique fauna and flora could be irreplaceable (Brunila et al., 2014). During the years 1989–2010, approximately 1400 ship accidents happened in the Baltic Sea. Most of the accidents were groundings and collisions, followed by releases of pollution, fires, machinery damages and technical failures (Brunila et al., 2014).

The Gulf of Finland (Fig. 2), located in the north-eastern extremity of the Baltic Sea, is an elongated sub-basin with a length of 400 km, width of 48–125 km and a mean depth of 37 m. The gulf exhibits large spatio-temporal variability in salinity and temperature, both in vertical and horizontal directions has small internal Rossby radius (typically 2–4 km, Alenius et al., 2003) and hosts very complicated dynamics (meso-scale eddies, fronts, specific mixing conditions, optional ice cover and the possibility of anticyclonic gyres in the surface circulation) (Andrejev et al., 2004a,b; Soomere et al., 2008, 2011c).

The problems of detection, modelling and forecast of the fate of oil spills in the Baltic Sea have been extensively addressed from the viewpoint of oil spill detection (Tufte et al., 2004; Lavrova et al., 2006; Uiboupin et al., 2008), the relevant econometric issues (Gottinger, 2001; Aps et al., 2009; Elofsson, 2010), statistical models of collision and grounding (Gucma, 2008), optimum allocation of resources (Deissenberg et al., 2001) and propagation of pollution under ice cover (Alhimenko et al., 1997; Wang et al., 2007). The official HELCOM oil spill forecast system Seatrack Web, launched at the turn of the millennium (HELCOM, 2009; Ambjörn, 2000; Gästgifvars et al., 2002) and regularly updated (Ambjörn, 2007), has become an important constituent of operational oceanography in the region (Ambjörn, 2008; Kostianoy et al., 2005, 2008).

Similarly to oil pollution, a variety of adverse impacts, (chemical) substances or items, are often released into the marine environment. They may be carried to substantial distances by the complex interaction of different meteorological and hydrodynamical drivers (currents, waves, direct impact of wind) and modified by a number of physical and chemical processes (e.g. weathering of the oil pollution, dispersion of chemicals, or change in the radioactivity level of nuclear wastes).

* Corresponding author.
E-mail addresses: bert@ioc.ee (B. Viikmäe), tarmo.soomere@cs.ioc.ee (T. Soomere).

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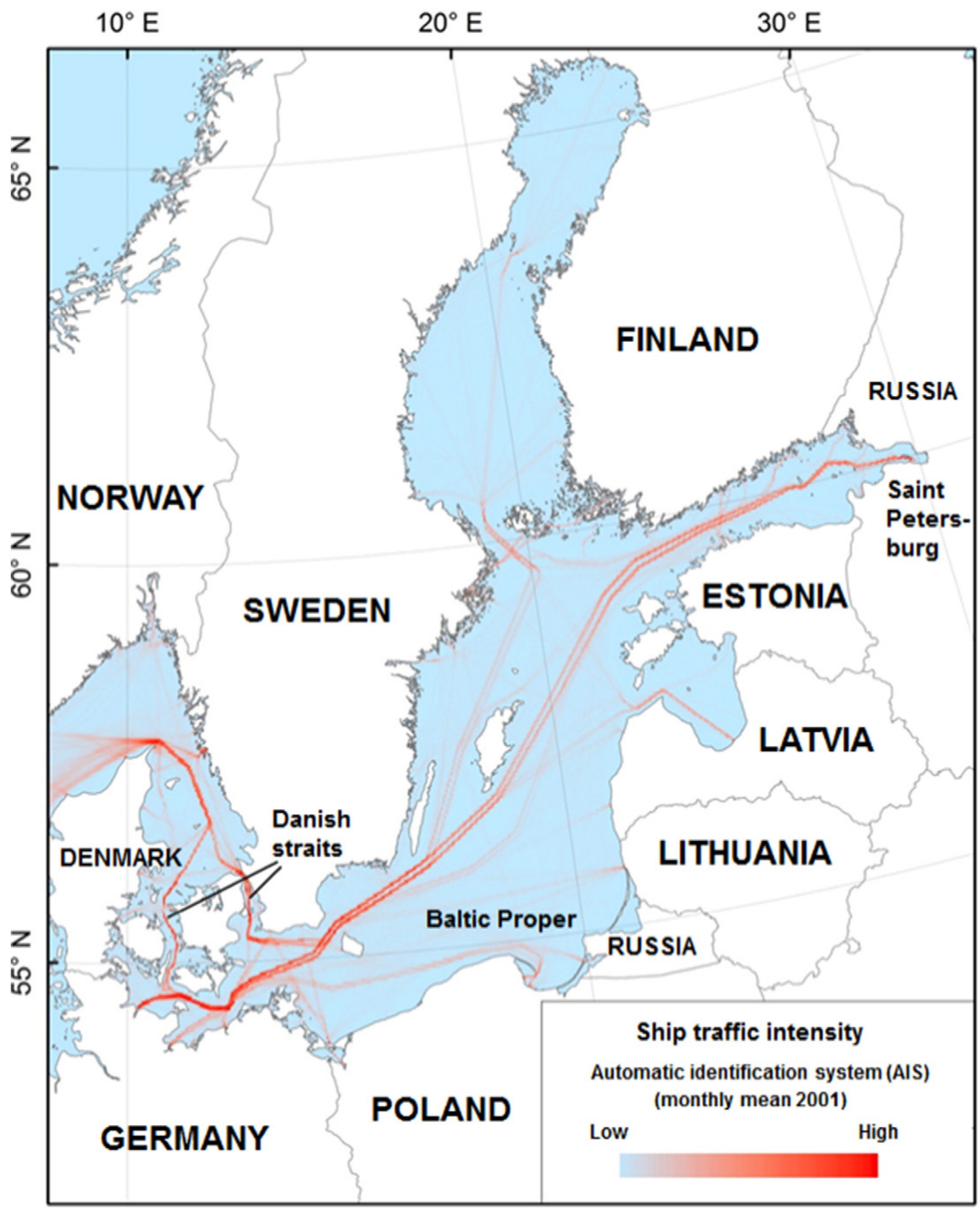

Fig. 1. Scheme of the Baltic Sea with major fairways. Map by M. Viška.

The relevant models can be quite demanding computationally and suffer from some limitations that result in imperfect predictions (e.g., Ambjörn, 2007). The direct impact of wind and waves on the transport in the upper layer of the sea is relatively well understood (Ardhuin et al., 2009; Breivik et al., 2011). The situation with current-driven transport is much less satisfactory (Ardhuin et al., 2009; Breivik et al., 2011). It is thus likely that an improved representation of the properties of statistics of currents (Kjellsson et al., 2013) and current-driven transport contributes towards more exact representation of the propagation of various substances and items in the surface layer.

In this study we focus on this part of the transport of various adverse impacts and employ the framework in which the direct impact of wind and waves on their drift is ignored (Soomere et al., 2010, 2011b; Viikmäe and Soomere, 2014). Strictly speaking, this approximation is directly applicable for persistent substances that are dissolved in strongly stratified environments, largely remain in the uppermost layer and are mostly carried by surface currents (e.g., Periáñez, 2004). It is only conditionally valid for, e.g., drift of oil pollution and thus not always justified in applications, especially during stormy seasons when wind impact may override current-driven transport. Wave effects (Stokes drift) are usually much smaller than the wind impact but they may in extreme cases become even larger (Murawski and Woge Nielsen, 2013). Similarly to the wind field, wave properties are highly variable in the Baltic Sea and the direct wave impact on the drift can be modelled to some extent as a random disturbance to the trajectories of pollutant parcels (Viikmäe et al., 2013). Such disturbances do affect single trajectories and their spreading but the pattern of frequently hit nearshore areas, the time of drift and the frequency of hits are almost invariant (Viikmäe et al., 2013).

Based on this experience, we employ the field of currents to simulate the first approximation of the drift of pollution parcels in the surface layer (Lončar et al., 2012; Meier and Höglund, 2012). This option is