Surf Zone Currents in the Coastal Zone of the Southern Baltic Sea – a Modelling Approach

Aleksandra Dudkowska[1*], Aleksandra Cupiał[1]

[1] Division of Physical Oceanography, University of Gdańsk (8 Jana Bażyńskiego Street, Gdańsk, Poland)

* Correspondence author: aleksandra.dudkowska@ug.edu.pl ; ORCID: 0000-0001-9781-8826

Abstract

Nearshore currents in a multi-bar non-tidal coastal zone environment located in the Southern Baltic Sea are studied. Spatiotemporal seaward-directed jets – so-called rip currents – are an important part of the nearshore current system. In previous research, Dudkowska et al. (2020) performed an extended modelling experiment to determine the wave conditions that are conducive to the emergence of rip currents. In this paper, the collected dataset is presented to facilitate the reuse of this data for other purposes.

Keywords: Southern Baltic Sea; coastal currents; rip currents

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Introduction

The Baltic Sea is a non-tidal inner sea, thus surf zone currents are generated mostly by waves. The dominating part of the current system is the so-called longshore current, and the other important part is the undertow. In such hydrodynamic conditions, a multi-bar seabed forms. Apart from these two typical flows in some specific hydro- and lito-morphological conditions, so-called rip currents can occasionally form, which are seaward-directed quasi-steady jets. Flows of this type may initiate a recess in the bar and even form a channel in some specific conditions. This type of rip is called a channel rip current and is the most commonly documented in barred surf zones (Castelle et al., 2016)

The most widely used method of observation of such kind of flows in the environment is carried out using free-floating drifters placed on the surface of the water. Such measurements, which belong to the group of Lagrangian measurements, were carried out on diverse coasts, for example in Western Australia (Johnson and Pattiaratchi, 2004), and along the coast of the Gulf of Guinea (Castelle et al., 2016; Floc'h et al., 2018). In the

Southern Baltic coastal zone, the occurrence of rip currents was confirmed by Schönhofer in 2014, who designed and used the drifters shown in Fig. 6.1 (Schönhofer and Dudkowska, 2021). In the series of Lagrangian measurements performed during field surveys at Coastal Research Station (CRS) Lubiatowo, he registered several cases of a flow with features characteristic of rip currents. The same drifters were used in subsequent research in this region, described in (Dudkowska et al., 2020).

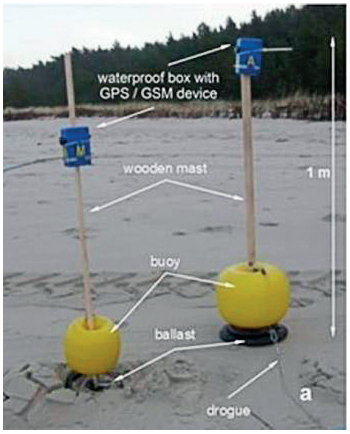

Fig. 6.1. Drifters designed for rip current measurement (Schönhofer and Dudkowska, 2021)

With the current technique, Lagrangian measurements in storm conditions are very difficult and perhaps impossible. Therefore, it is problematic to study near-shore flows at the site in a wide range of water and morphological conditions. Dudkowska et al. (2020) applied the modelling approach to comprehensively investigate this phenomenon. They carried out simulations for all wave conditions likely in the studied region. The range of the sea states was determined based on long-term buoy measurements. The tracks of virtual drifters were simulated by the XBeach numerical model (Roelvink et al., 2010). Another numerical model – SWAN (Booij, Holthuijsen and Ris, 1996) – was used for the purpose of calibration. The dataset published in the MOST Wiedzy repository (The Bridge of Knowledge) contains all of the data collected during this study. It was used to determine the incidence of rip currents on the Polish coast of the Baltic Sea. However, the modelled flows can be the basis or inspiration for further research into the characteristics of flows in the surf zone. The data from stored files can also serve as boundary conditions for detailed modelling of flows on nested grids.

Study area

The research was conducted for an area which is located in the southern Baltic Sea, in Polish Marine Areas adjacent to the coastline in the vicinity of the village of Lubiatowo. Hydrodynamic and morphodynamic phenomena in this area are well studied as The Coastal Research Station (CRS) – field laboratory of the Institute of Hydro-Engineering of the Polish Academy of Sciences (IBW PAN) – is situated here. This part of the coast is considered to be a representative part of the southern Baltic coast. The nearshore bathymetry is characterised by: the gentle slope of the seabed of about 1.5%, locally near the coastline up to 4%; the occurrence of usually five offshore bars: four fixed and one temporarily, at a distance from the coastline approximately: 100–120 m, 200 m, 400–450 m, 650–850 m. The typical bathymetry for the Lubiatowo area was used for modelling (Fig. 6.2). The main depth of the water is about 8 m at 1 km from the shoreline and increases to about 15–17 m at 2 km and up to 25 m at 9 km.

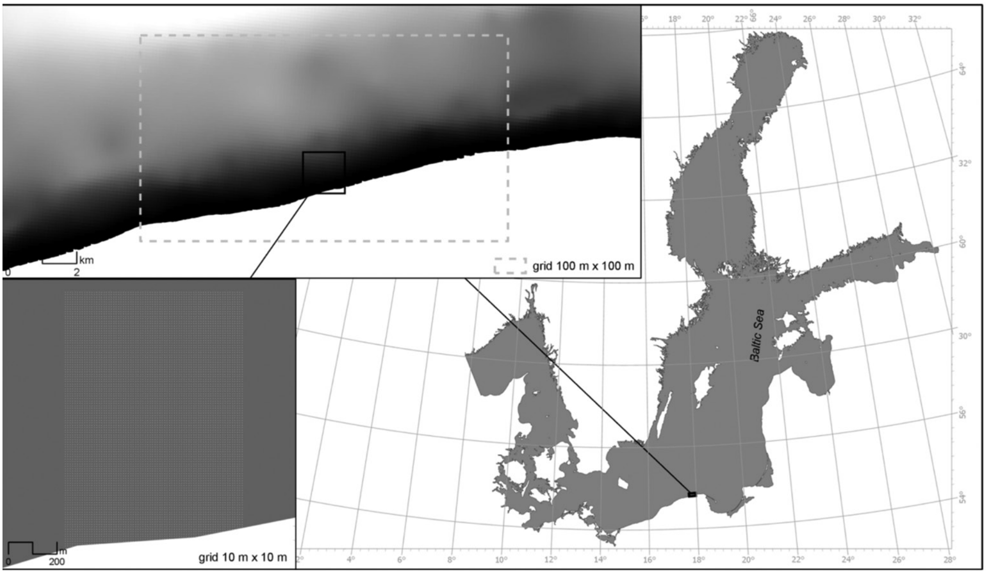

Fig. 6.2. Area of interest and the computational meshes used in numerical modelling: SWAN external grid 100 m ×100 m; SWAN (internal) and XBeach grid 10 m ×10 m (Dudkowska et al., 2020)

Methods

The numerical reconstruction of the coastal flow was performed with the use of the following spectral numerical wave models: SWAN (Simulating WAves Nearshore) cycle III (Booij, Holthuijsen and Ris, 1996) and XBeach (Roelvink et al., 2010). The XBeach model solves coupled 2D horizontal equations for wave propagation, flow, sediment transport, and bottom changes. The applied model setting are: (i) neglecting of sediment transport and bottom changes, (ii) wave-current interaction option, (iii) stationary wave boundary condition at the seaward boundary, which means that a uniform, constant wave energy distribution is set, based on the given values of wave height and period; Neumann lateral boundaries, (iv) the roller model which can provide a shoreward shift in a wave-induced setup, return flow and longshore current. In order to simulate the rip channel, the gap in the bar was artificially introduced into the bathymetry. The presented dataset consists of the output of the XBeach model simulations (xboutput.nc) for the wave conditions described. The model parameters are included in text file (params.txt).

Fig. 6.2 shows the two numerical meshes used for the calculations. (1) SWAN external grid, with generalised bathymetric data over the area between the coastline and a certain location offshore; spatial resolution: 100 m x 100 m. (2) Internal grid, used both for SWAN and XBeach, distributed over the area up to 1 km offshore with detailed bathymetric data; spatial resolution: 10 m × 10 m. All SWAN parameters were chosen according to the previous extended studies, including the model configuration and results validation in the area of study (Gic-Grusza and Dudkowska, 2014).

Two integral wave parameters, calculated form the wind wave spectrum, are used in this work. The first one, significant wave height (Hs), is a statistical parameter that is used as a representation of the state of the sea at given place and time. Calculated from the energy variance of the spectrum (by means of a zero-order spectral moment), it corresponds to the average height of the highest one-third of all of the waves in the given time interval. In the most general terms, this parameter might be interpreted as the wave height as seen by a human observer. The second considered wave parameter, mean wave period (T), is calculated from the spectral moments of higher order. It represents the averaged time interval between the instances of two consecutive wave peaks (or other corresponding points on the wave, i.e. troughs) passing through a certain point in space. In other words, by corresponding to the average time of upward or downward zero crossing in an analysed time series, this parameter provides insight into the present state of the sea as well as the speed of wave propagation.

Data

Data stored in the Bridge of Knowledge, Research Data Catalog repository are in the NetCDF format. NetCDF is a commonly used data format that allows for easy storage and transfer of large sets of multidimensional data. Information is stored in binary format in the form of multidimensional arrays. Apart from the data itself, NetCDF files have a header with metadata, which makes them self-describing. In a NetCDF file, one can find the following components: dimensions, variables and attributes. Time and geographic coordinates as well as station numbers can be dimensions; variables store actual data: i.e. millimetres of rainfall, height of the significant wave in metres, wind speed in metres per second, etc.; attributes describe individual variables as well as the whole NetCDF file. Information about the dimensions, variables and attributes is stored in a header. Even though the files can contain large datasets, NetCDF allows for access of a selected subset of data without the need to read the entire file. The NetCDF format is independent of the operating system and program that is used to open and analyse the files.

This format is widely used on various platforms that share all kinds of scientific data, from satellite observations, wave data measured in situ with buoys, to meteorological forecasts, and so on. It is commonly used by spatial analysts working with geographic information systems (GIS). This data format, which is built from software libraries for data management and storage and an accompanying interface, was created at the University Corporation for Atmospheric Research (UCAR) which curates its development (Esri 2020, Physical Sciences Laboratory NOAA 2020, Unidata 2020).

Results

The drifters' movement, which depends on the direction of the wave propagation, can be seen in Fig. 6.3 and Fig. 6.4. These figures represent two exemplary wind wave conditions, described by pairs Hs = 4 m and T = 9 s, and Hs = 1 m and T = 7 s, respectively. The red arrows show the direction of the wave propagation. As expected, the velocity of the drifters increases faster and reaches higher values during more severe conditions (Hs = 4 m). When waves propagate parallel to the shore, the modelled drifters follow the direction of wave propagation independently of the modelled conditions (left columns of Fig 6.3 and Fig. 6.4). During more severe conditions, the maximum drifter velocity is 1.5 m/s. Such drifter velocity is simulated by model runs with wave propagation directions between NNW and NWW (panels 2–4 in the left column, and panels 1–2 in the right column of Fig. 6.3). When the direction of propagation is set up as perpendicular to the shore, the drifter's velocities, especially for the drifter that is released in the vicinity of the rip channel, are lower or reach higher values with a delay. In the 4th and 5th panel in the right column, the drifter released in the vicinity of the rip channel moves off shore before turning and changing direction towards the shore, although it still moves at a certain angle to the shore, unlike the two remaining drifters that follow the direction of wave propagation.

During calmer conditions, the highest velocity drifters reach around 0.5 m/s (Fig. 6.4). The lowest velocities, below 0.5 m/s, occur in the instances of wave propagating perpendicular to the shore (directions: NNE to N, or panels 2–4 in the right column of Fig. 6.4). In panels 2–5 in the right column, the drifter released in the vicinity of the rip channel moves off shore before turning and moving alongshore. In one instance (2nd panel) the middle drifter is only visible moving away from the shore. In panels 3–5, all drifters are driven by another/additional force than just wave propagation, since they are not moving with the direction of wave propagation. In the 5th and, in part, in the 4th panel, the blue and red drifter move alongshore.

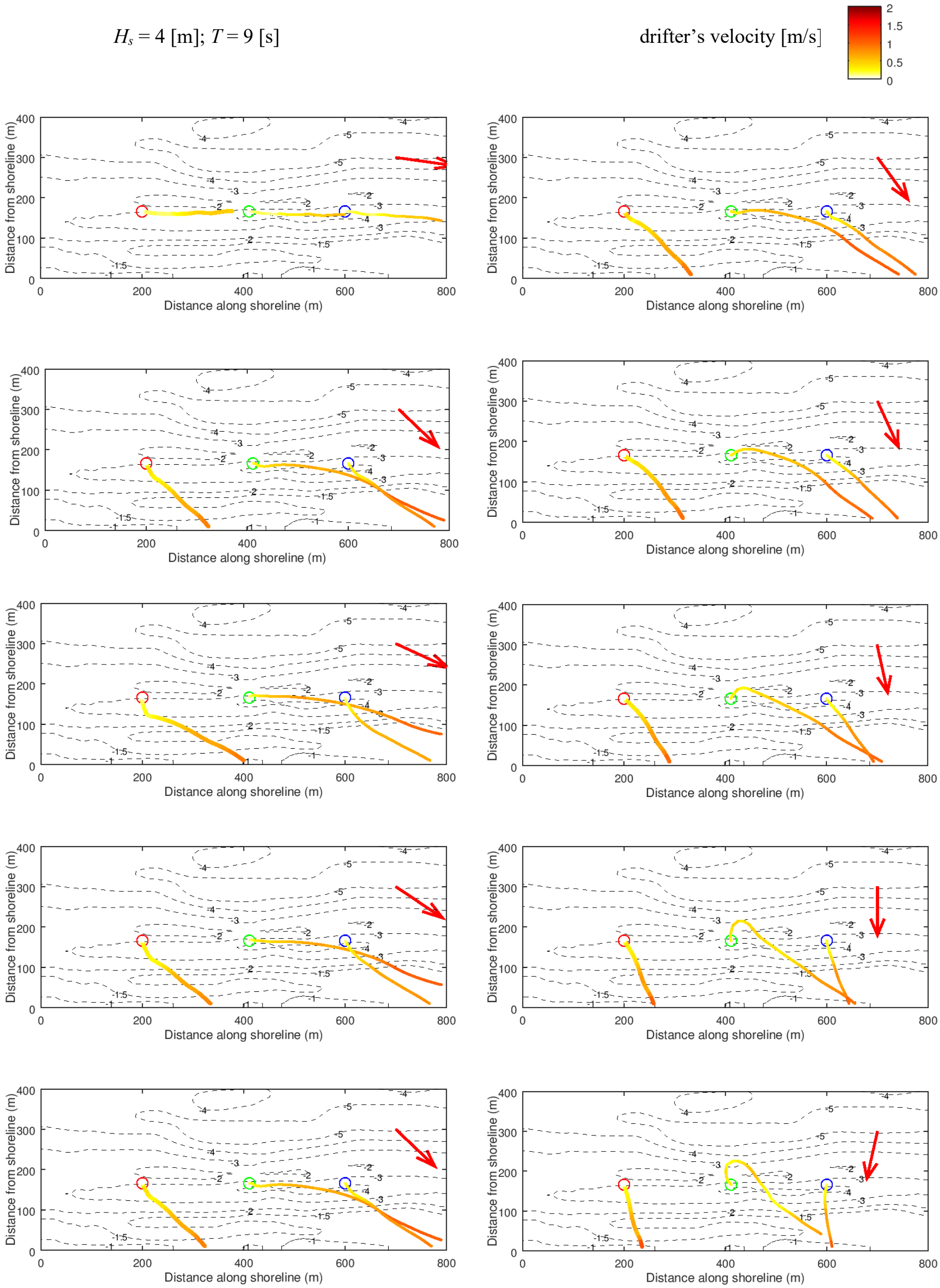

Fig. 6.3. Tracks of virtual drifters obtained by numerical simulation, example 1

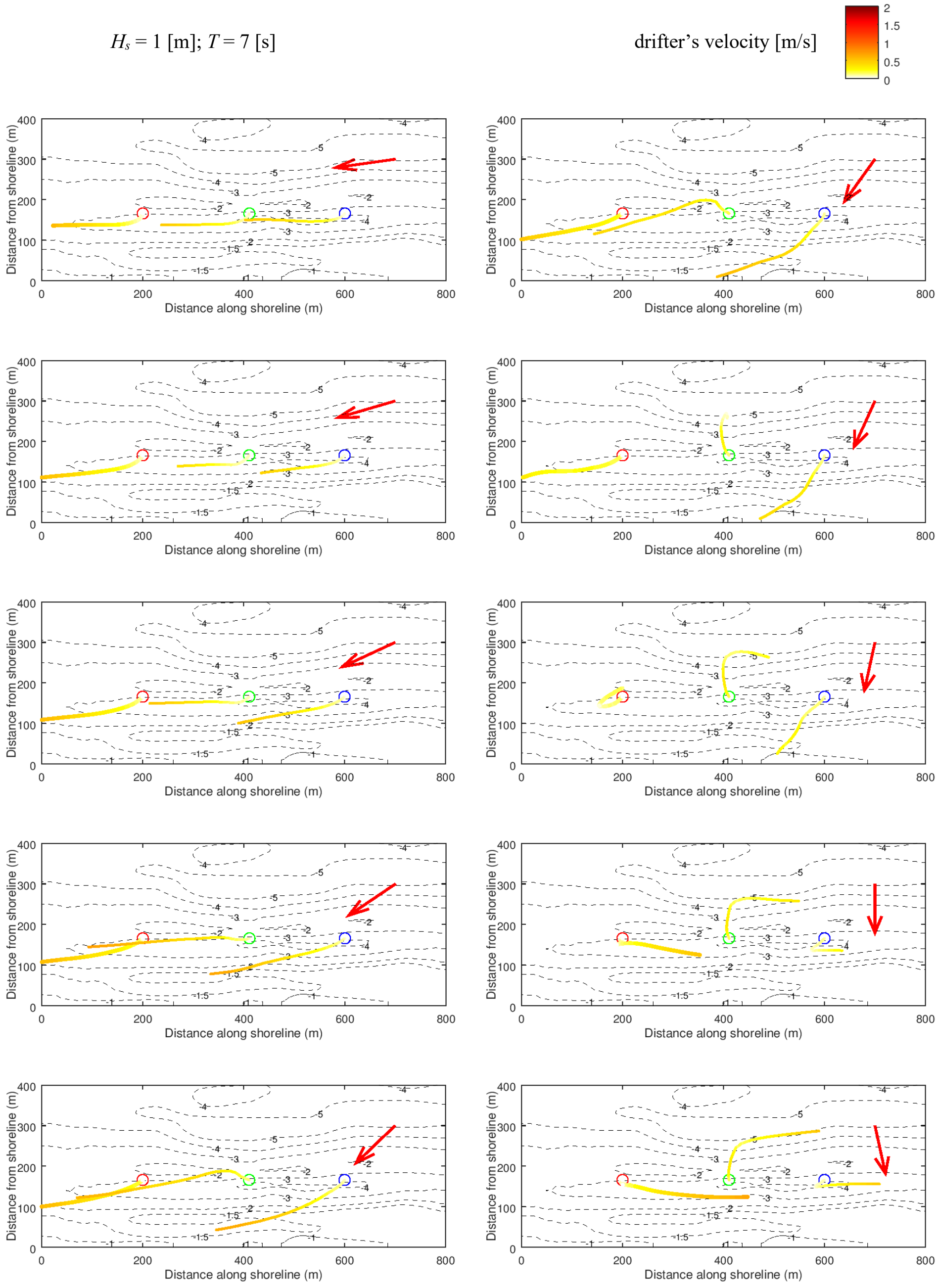

Fig. 6.4. Tracks of virtual drifters obtained by numerical simulation, example 2

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