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Comparative Analysis of the Data on the Surface Currents and Wind Parameters Generated by Numerical Models on the Szczecin Lagoon Area

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ABSTRACT: This study focuses on the investigation of available surface currents and wind parameters for employing them in order to predict the survivor movement in the Szczecin Lagoon waters. For this purpose, the surface currents and wind parameters were generated by selected numerical models and the wind parameters were also measured with the telemetry devices. In this paper, the PM3D hydrodynamic model and the NEMS, ECMWF, GFS weather forecast models have been investigated. The measurements of the wind parameters, recorded at the Brama Torowa I and Trzebież stations, were also analyzed. As part of the research, an expert method was used to evaluate the surface currents parameters. In turn, the method based on comparing the forecasted wind parameters with the measured wind parameters was applied in order to assess uncertainties of these parameters. The comparative analyses of the data on the surface currents and wind parameters have been done and probabilistic models for uncertainties of these forecasted parameters have been formulated. Additionally, relations between the surface currents speeds and the wind speeds, in the case when their directions were consistent, have been also discovered.

1 INTRODUCTION

The preparation of the studies on forecasting the drift of survivors in the Szczecin Lagoon waters was the inspiration for this topic. The long-term goal of the authors is to develop drift models of various objects for employing them in the search-and-rescue operations and for including them as an additional source of location data. Such algorithms are currently being developed and they fit into the area of modern navigation [2,14,23,24].

Small boats with limited drafts are main participants of sailing in the Szczecin Lagoon waters, due to the specificity of that reservoir. The Szczecin Lagoon characterizes low depths. The accidents with the participation of such vessels happen most often on the Szczecin Lagoon waters.

For example, on 08.05.2017 at noon, three sailors went on a cruise of the Szczecin Lagoon. On 09.05.2017 at afternoon, the rescue services found the capsized yacht of the BEZ type and the body of one of those sailors. The remaining two men were not found. The Rescue Station in Dziwnów and a rescue ship from Trzebież attended in the rescue operations. Additionally, the Border Guard also helped on the water and in the air. In turn, the WOPR and police searched an area from the land side [18]. At night, 19.06.2015, the man fell overboard from the S/y HAARLEM yacht. Despite an intensive search action, the survivor was not found. The yacht was towed on the island of Wolin. Six search-and-rescue units attended in the rescue operation. Additionally, the fire brigade and police searched an area from the land side [18].

The most important task of the SAR services is to look for the people who have fallen overboard or drifting in the water after overturning the boats. In the literature [3-7,9,10,13,17,20,21,25,27], the search-and-rescue areas, in waters used for the navigation, are determined by employing the Monte Carlo methods, Bayesian methods, regression models for an object's drift velocity, the Fokker-Planck equations or certain graph models. To determine such areas, it is necessary to obtain data about surface currents and wind. That data are often generated by numerical models. The access to such data might be obtained by, e.g., the Geographic Information System such as the Maritime Network-Centric Geographic Information System Gulf of Gdansk [16]. Sometimes, some relations between the wind and wind-driven currents are established [20]. Based on the wind parameters, the leeway parameters along with their uncertainties are determined, e.g., by the linear regression or on the basis of constructed probability distributions. The potential total drift of a survivor is the vector sum of the current and leeway. The position vector of a survivor at a given time t is calculated as the integral of the survivor's velocity vector from the initial moment to the time t increased by the velocity vector from the initial moment.

According to IAMSAR (International Aeronautical and Maritime Search and Rescue Manual) [8], an estimation of the surface current and wind parameters can be derived from direct observations, diagrams, charts, wind roses, reliable hydrodynamic models and weather forecast models. The direct observations may be obtained from the *in situ* measurements, from vessels passing through an area; aircrafts flying over an area, installed appropriately buoys, platforms or satellite measurements. However, such data are not always available. By diagrams and charts, the long-term average seasonal parameters of the currents and wind could be determined. However, these sources are employed in the areas far away from shores. Nevertheless, an estimation of these parameters provided by these sources should not be used in coastal areas, and especially in the offshore areas less than 25 nautical miles distance from the shore and less than 300 feet (100 meters) water depth. Reliable hydrodynamic models with high resolution and weather forecasts models are other sources of such. The authors consider these sources of data.

The first aim of this paper is to verificate the available data on the surface currents and wind parameters on the Szczecin Lagoon area for the summer season in 2017. The forecasted surface currents parameters have been examined with using an expert method. In turn, the real and forecasted wind parameters have been compared. Some statistical characteristics of the uncertainties of those parameters have been presented. Furthermore, some probabilistic models for the obtained uncertainties of the considered parameters have been determined. Additionally, linear relations between the surface currents and wind speeds were established.

The remainder of this paper is organized as follows. In Section 2, research area and its hydrology conditions are described. In Section 3, the materials and methods are presented. Section 4 contains a comparative analysis of numerical data on surface currents and wind parameters collected for the Szczecin Lagoon during the summer season in 2017. In Section 5, a discussion of errors in forcing fields is conducted. Section 6 concludes.

2 RESEARCH AREA AND ITS HYDROLOGY CONDITIONS

2.1 *Research area*

The Szczecin Lagoon (Polish: Zalew Szczeciński) covers waters at the mouth of the Odra River. From the northern side of this lagoon, the islands of Wolin and Uznam separate it from the Baltic Sea. In the middle part of this lagoon, it is subdivided into the Large Lagoon (Polish: Wielki Zalew), with the surface area of $488\,km^2$ lying within Poland, and the Small Lagoon (German: Kleines Haff), covering the area of $424\,km^2$, which belongs almost entirely to Germany. The Szczecin Lagoon lies on the longitude: approx. $13^\circ 53' E - 14^\circ 36' E$ and the latitude: approx. $53^\circ 42' N - 53^\circ 52' N$. It is about $28\,km$ long and over $52\,km$ wide [1]. The southern limit of the Szczecin Lagoon is designated by the Jasienica channel outlet (on the west bank) and the mouth of the Krępa River (in the east).

The Pomeranian Bay (Polish: Zatoka Pomorska) is connected with the Szczecin Lagoon via the straits: Dziwna, Świna and Peennestrom. Świna is the most important for the Szczecin Lagoon hydrological system. These straits are not the Odra River arms, because their current is not a river current, but it is the result of the constant sea and the Szczecin Lagoon water levelling.

The average depth of the Szczecin Lagoon is about $3{,}8\,m$. The largest natural depth of the Szczecin Lagoon is $8{,}5\,m$. However, it is not a region deprived of shoals and shallows. Nearly 25% of the area is $0-2$-meter deep, and the high average is due to the fact that there is the $10{,}5$-meter deep channel across the Szczecin Lagoon from Szczecin to Baltic waters [1]. This channel is called the Szczecin-Świnoujście fairway. The Szczecin-Świnoujście fairway is the dredged channel in the Szczecin Lagoon area.

2.2 *Description of the hydrological conditions on the Szczecin Lagoon*

The Szczecin Lagoon is perceived as a small and fairly safe area for sailing and motorboat sport. The danger is the shape of its coastline and bottom, which in a combination with varying hydrodynamic conditions led already too many woes. Particularly dangerous are squalls, which are strong and unexpected. In addition to the wind dynamic action, generated waves affect also boats. The wave height is directly related to the depth of a lagoon area.

Wind waves are the immediate threats. The wave dimensions are determined by the wind. The duration of the wind forcing practically does not affect the development of the wave. The full wave development can take place within a period of no more than one hour. After the wind stopping, the wave quickly disappears. The currents directions in the Szczecin Lagoon generally lay along the dredged channel. However, there may also be the currents which are perpendicular to it. The currents during the inflow of Baltic waters can reach $2-4$ kn on the straits: Świna and Dziwna.

The change of the water level may cause currents. It is important to note that large, sudden, but short-term fluctuations in the water level cause storms. The stormy winds from the northern sector cause the water level increasing of $0,7-1,0m$, while the southern winds – the decreasing of $0,6m$. The winds, with the speed of more than $10m/s$, cause the water-level variation. The north or south variations rarely exceed $0,1m$, and in the west or east direction – $0,2m$. However, the stormy southwest winds cause the water-level difference of $0,6m$.

The surface currents and also wind are important for establishing the parameters of the survivor's drift in the water. In order to develop and determine the potential search area, the direction of the water flow should be taken into account in addition to the direction and force of the wind parameters. The fluctuations in the water level depend mainly on the wind parameters. For the wind from NW to NE, the water level can rise by about $1m$ per day. In turn, for the wind from the southern sector, it decreases by $0,6m$ in the relation to the average level. The exemplary fluctuations of the water level on the indicator at the Trzebież hydrological station are presented in Figure 1. With such shallow water and mostly swampy and low banks, such amplitude of the water level radically changes the shape of the shoreline in some areas.

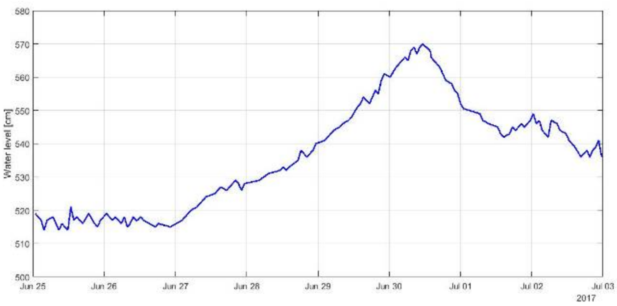

Figure 1. Change in the water level on the Trzebież indicator – from 25.06 to 03.07.2017.

3 MATERIALS AND METHODS

For analysis purposes, the authors chose the months: July and August in 2017, since experiments will be done by this season in the feature. The analysis covers only this season due to the unavailability of any forecasted wind parameters generated by the considered weather forecast models: ECMWF, NEMS, GFS from the previous summer seasons. In order to discuss the surface currents parameters on the Szczecin Lagoon, the authors generated the surface currents charts by the SatBałtyk system [19]. The parameters of the surface currents were derived from the PM3D hydrodynamic model [15]. The PM3D hydrodynamic model works at the Institute of Oceanography at the University of Gdańsk in Poland [11]. The PM3D model covers the Szczecin Lagoon with 1/6 NM resolution (approximately 300 m). It is worth adding that this high resolution of the PM3D model for the Szczecin Lagoon area affects the much better description of this area's bathymetry and coastline [12]. It may be seen that the widths of the narrow straits connecting the Szczecin Lagoon with the Pomeranian Bay (Świna, Dziwna, Peennestrom) are close to their real size [12]. The SatBałtyk system data, e.g., the surface currents parameters, are updated four times a day: 0000UTC, 0600UTC, 1200UTC, 1800UTC.

It is worth adding that the validation of the surface currents parameters with using the *in situ* measurements was not possible. By this reason, the generated surface currents fields were discussed by the expert method. The expert method utilizes the knowledge of experienced professionals in evaluating the goodness of the generated surface currents fields. The authors presented the generated charts of these fields to the experts – the group of port pilots – which know the hydro meteorological conditions of the Szczecin Lagoon. Additionally, the authors created the list of the questions which facilitated the evaluation of these charts. These experts assessed the received charts and responded to the submitted questions. These questions concerned the hydrological and meteorological conditions on the Szczecin Lagoon area, e.g., whether the information contained on the generated charts coincides with many years of experience of the practitioners – the pilots; what are the directions and speeds of the surface currents on the Szczecin Lagoon; what do their directions and speeds depend on; how the shaping of the shoreline and land affects the direction and speed of the wind at various points of the Szczecin Lagoon; due to the variability of parameters, i.e., the shape of the bottom profile and shoreline, the impact of the Odra River; in which areas of the Szczecin Lagoon the currents are the most variable and unpredictable, etc. It is worth noting that, up to this date, there exists no research work that has attempted to validate the surface currents fields presented in the SatBałtyk system.

In the world, currently in certain water areas, measurements of the sea currents are carried out using the High Frequency Surface Wave Radars (HFSWR). However, such radars are not available in the Polish zone of responsibility. Indeed, the typical range of the surface velocity measurements is $30-100km$ from the coast and in the case of high spatial resolution depending on the radar working frequency – a few kilometres. Due to the size of the Szczecin Lagoon, it is currently too expensive solution.

The authors further have established the linear relations between the surface currents and wind parameters at two points of the Szczecin Lagoon: Brama Torowa I (longitude: $014^{\circ}20^{'}$ E; latitude: $53^{\circ}49^{'}$ N) and at the point in the area nearby the Trzebież (longitude: $014^{\circ}28^{'}$ E; latitude: $53^{\circ}41^{'}$ N). The Szczecin Lagoon is a flowable reservoir and the water flow at these two points reflects to a significant extent the water movement in this lagoon. In turn, the probabilistic approach was used in order to describe uncertainties for the parameters achieved with the obtained formulas.

In turn, for a comparative analysis of the wind parameters, the authors firstly generated charts depicting the windy conditions for July and August in 2017. These charts were generated on the website https://www.windy.com For this research, the data on the wind parameters were collected from the Brama Torowa I and Trzebież meteo stations. These data were recorded by the Maritime Office in Szczecin (UMS) and the Institute of Meteorology and Water Management in Warsaw (IMGW). The forecasts of the wind parameters were obtained from the NEMS, ECMWF or GFS models. The data from these models are generally available in [26]. The NEMS (NOAA Environmental Modelling System) model has the resolution of approximately $4\,km$ and its data are updated every 12 hours: 0830UTC, 2030UTC. The ECMWF (European Center for Medium-Range Weather Forecasts) model, with the resolution of approximately $9\,km$, is updated every 12 hours: 0715UTC, 1915UTC. The GFS (Global Forecast System) model has the resolution of approximately $13\,km$ and it is updated every 6 hours: 0615UTC, 1215UTC, 1815UTC and 0015UTC. The NEMS model is a local European model. The ECMWF and GFS models are global weather models.

In this part of the paper, the authors compared the measured and forecasted wind parameters. Moreover, the authors described statistically the differences between these parameters. In turn, the probabilistic models for the absolute values of the differences between the measured and forecasted wind parameters are achieved.

4 COMPARATIVE ANALYSIS OF THE NUMERICAL DATA ON THE SURFACE CURRENTS AND WIND PARAMETERS COLLECTED FOR THE SZCZECIN LAGOON WATERS DURING THE SUMMER SEASON

4.1 *The surface currents parameters*

In general, the experts did not have any significant objections to the water circulation presented on the generated charts of the Szczecin Lagoon. They observed that, substantially the charts appropriately reflect the wind-driven currents. For example, the experts, analyzing the surface currents chart for 08.07.2017 at 12:00UTC, established that the impact of the wind field has been reflected in the surface currents field, that is, the surface currents field was directly dependent on changes in the air flow at the air-water interface. Moreover, they noted that the generated surface currents field was quite uniform. That is, this field was close to the stationary field. The differences in the currents directions and speeds were not significant in the central part of the Szczecin Lagoon. By these reasons, the experts recommended that downscaling could be considered in the feature. The hydrodynamic model, generating the surface currents, could be adapted in order to describe conditions in the Szczecin Lagoon almost two orders of magnitude smaller. Furthermore, this approach could unveil sub-grid water movements, providing a more complicated description of the water transport process on the Szczecin Lagoon. The experts also observed that the surface currents circulation was strictly connected with the shoreline’s shape, but the water exchange between the Szczecin Lagoon and the Pomeranian Bay was preserved.

However, in the area of complicated shoreline configuration and significant shallows, there are clearly noticeable differences between the display of the charts and the experts’ experience. Indeed, there are areas on the Szczecin Lagoon where the PM3D model forecasts the surface currents directions opposite to those estimated by the experts. In such areas, the surface current direction, forecasted by the PM3D model, is not justified by the bathymetry of the lagoon. During the backflow (that is, the water inflow from the Baltic Sea to the Szczecin Lagoon), particularly strong surface currents occur in the area of the mouth of the Piastowski Chanel to the Szczecin Lagoon. The similar phenomenon, wherein the current direction is opposite, occurs especially in the southern and southeastern winds at the mouth of the Oder river. The complicated shaping of the shoreline (especially, in the eastern part of the Szczecin Lagoon) causes a turbulent water flow and changes in the surface currents directions.

In addition, the experts noticed that the surface currents directions depend on: the depth of the Szczecin Lagoon (e.g., the area of the Szczecin-Świnoujście fairway), the shape of the bottom (e.g., shallows), the shape of the shoreline, the Odra river inflow to the Szczecin Lagoon or the backflow from the Baltic Sea to the Szczecin Lagoon.

As the next step, since the surface currents on the Szczecin Lagoon – in the experts’ opinions – were reflected with good agreement, the authors used them in order to establish some relations between them and wind parameters. This is a second approach in order to generate the surface currents on the Szczecin Lagoon. With this approach, there will be no problem with the computational complexity and there will be no need to writing further algorithms allowing for the assimilation of data on the surface currents parameters sent from another server after being generated by the PM3D model. This approach can be used when conducting pilot studies. Moreover, the parameters of the surface currents generated in such way may be used when the access to such data is limited or when the assimilation of such data generated from the PM3D model is required.

The authors observed that the surface currents directions, generated with the PM3D model by the SatBałtyk system, and the measured wind directions in the area nearby the Trzebież meteo station showed a satisfactory agreement. Such agreement also was observed at the Brama Torowa I. The authors determined that the differences between these parameters are insignificant when the wind conditions are stable or not very changeable. Due to this observation, some linear relations between the surface currents and wind speeds, when their directions were consistent, have been established. Moreover, probabilistic models of the uncertainties in the surface currents speeds founded with using those relationships have been achieved.

The formula was obtained with using the surface currents parameters generated by the SatBałtyk system and the measured wind parameters. These data were received with two months: July and August 2017 from two measuring stations: Brama Torowa I and Trzebież. The obtained formula for the area at the Brama Torowa I station is as follows:

$$V_c = 3,82\% \cdot V_w, \quad (1)$$

where:
V_w – 10-m wind speed [m/s],
V_c – surface currents speed [m/s].

The standard deviation between the surface currents speeds V_c obtained by formula (1) and the surface currents speeds measured in the SatBałtyk system at the Brama Torowa I station equals $0,06\ m/s$.

In turn, the formula for the Szczecin Lagoon waters at the Trzebież station is as follows:

$$V_c = 2,24\% \cdot V_w. \quad (2)$$

The standard deviation between the surface currents speeds V_c obtained by formula (2) and the surface currents speeds measured in the SatBałtyk system at the Trzebież station's waters equals $0,03\ m/s$.

The smaller coefficient in formula (2) than that in formula (1) results from the difference in the distance to the coastline between the Brama Torowa I and Trzebież stations and also from the smaller depth of the Szczecin Lagoon in the Trzebież area.

Moreover, at the Brama Torowa I station the differences between the surface currents speeds, calculated by formula (1), and the surface currents speeds, collected with using the SatBałtyk system, have been described by the t-Student distribution with the following parameters: the location parameter $\mu = -0,017$, the scale parameter $\sigma = 0,06$, and the degree of freedom $\nu = 240$ (Fig. 2):

$$f(x) = 4,3427 \cdot 10^{287} \cdot \left(\frac{1}{240 + 277,778 \cdot (0,017 + x)^2} \right)^{241/2} \quad (3)$$

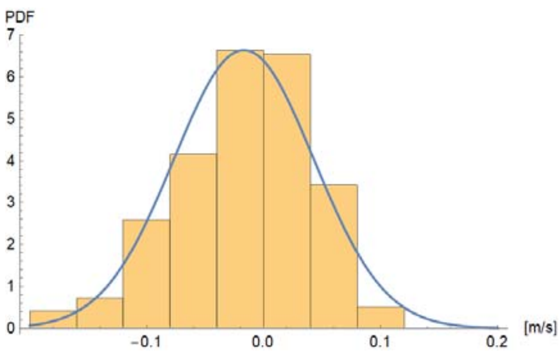

Figure 2. The histogram for the differences between the surface currents speeds calculated by formula (1) and the surface currents speeds collected at the Brama Torowa I station. The probability density function (PDF), fitted to the exposure data, is depicted the blue colour. The t-Student distribution have been employed.

In Table 1, the statistical tests' results are presented. The compliance tests provide the conclusion that there is no reason to reject the hypothesis that the t-Student distribution describes the differences between the surface currents speeds, calculated by formula (1), and the surface currents speeds, collected with using the SatBałtyk system, since P-Value is greater than $0,05$ (significance level) in three presented tests: the Anderson-Darling test, the Cramèr-von Mises test and the Pearson χ^2 test.

Table 1. The results of the statistical tests regarding the goodness-of-fit of the t-Student distribution to the differences between the surface currents speeds, calculated by formula (1), and the surface currents speeds, collected with using the SatBałtyk system.

"test"	"P-Value"
"Anderson-Darling"	0,22
"Cramèr-von Mises"	0,24
"Pearson" χ^2	0,06

In turn, in the area nearby the Trzebież station the differences between the surface currents speeds, calculated by formula (2), and the surface currents speeds, collected with using the SatBałtyk system, have been described by the t-Student distribution with the following parameters: the location parameter $\mu = -0,005$, the scale parameter $\sigma = 0,032$, and the degree of freedom $\nu = 150$ (Fig. 3):

$$f(x) = 2,4543 \cdot 10^{165} \cdot \left(\frac{1}{150 + 976,5625 \cdot (0,005 + x)^2} \right)^{151/2} \quad (4)$$

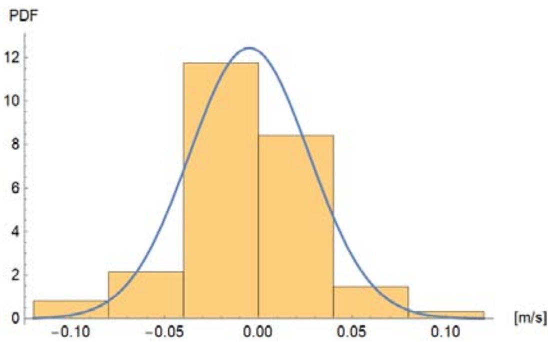

Figure 3. The histogram for the differences between the surface currents speeds calculated by formula (2) and the surface currents speeds collected in the area nearby the Trzebież station. The probability density function (PDF), fitted to the exposure data, is depicted the blue colour. The t-Student distribution have been employed.

In Table 2, the statistical tests' results are presented. There is no reason to reject the hypothesis that the t-Student distribution describes the differences between the surface currents speeds, calculated by formula (2), and the surface currents speeds, collected with using the SatBałtyk system, since P-Value is greater than $0,05$ (significance level) in three presented tests: the Anderson-Darling test, the Cramèr-von Mises test and the Pearson χ^2 test.

Table 2. The results of the statistical tests regarding the goodness-of-fit of the t-Student distribution to the differences between the surface currents speeds, calculated by formula (2), and the surface currents speeds, collected with using the SatBałtyk system.

"test"	"P-Value"
"Anderson-Darling"	0,41
"Cramèr-von Mises"	0,39
"Pearson" χ^2	0,07

It is worth adding that sometimes at the chosen measuring station significantly-different directions of surface currents and wind were measured in the same time from two above mentioned months (a little more at the Trzebież station than at the Brama Torowa I station due to, among others, the different accuracy of the measurement).

For July and August in 2017, the western direction of the surface currents was prevailing in the area nearby the Trzebież station (Tab. 3). The eastern direction of these currents occurred less frequently. Other directions have been sporadically reported.

Table 3. Frequency of the surface currents directions for the Szczecin Lagoon waters at the Trzebież station – July and August in 2017

Directions	Percent (%)
W	47
E	24
SE	9
SW	7
NW	5
S	4
NE	2
N	2

For the same season, the western directions of the surface currents were also prevailing for the Brama Torowa I station (Table 4), but these ones are not too significant (26%) like those for the area nearby the Trzebież station (47%).

Furthermore, many directions of the surface currents were coming from south-west and east (34%) at the Brama Torowa I station. Nevertheless, at the Brama Torowa I station the southern directions were coming less frequently and other directions constituted a few percent of all directions.

Table 4. Frequency of the surface currents directions for the Szczecin Lagoon waters at the Brama Torowa I station – July and August in 2017.

Directions	Percent (%)
W	26
SW	17
E	17
S	11
SE	9
NE	8
NW	7
N	5

The distributions presented by formulas (3) and (4) (or in Figures 2 and 3) have been described in both cases by the t-Student distribution, but with the different parameters. This results from: the neighbourhood of the Świna strait, the outflow of the water from the Świna during a backflow, the different distance to the Szczecin-Świnoujście fairway, the shape of the bottom in these locations (shoals, shallows), various shaping of the shoreline, a different number of the available data. Thus, in these two regions there is a different characteristic of the Szczecin Lagoon.

4.2 *The wind parameters*

The wind parameters for the Szczecin Lagoon, read from the charts generated by the NEMS, ECMWF, GFS models, indicated different agreement with those measured. In stable weather conditions, the good agreement was often maintained. However, some differences between the forecasted and measured parameters were also observed. For example, for 12.07.2017 at 16:00UTC at the Trzebież measuring station, one was measured the real wind direction 175° and the real 10-minute wind speed: the average speed - $1,8\ m/s$, the maximum speed - $2,7\ m/s$. In turn, by analyzing the wind charts for 12.07.2017 at 16:00UTC generated by the SatBałtyk system and on the website https://www.windy.com for the NEMS, ECMWF, GFS models, one could be seen that these models have generated the slightly different vector fields. For Trzebież, the NEMS model forecasts the wind blowing from the direction 100° and at the speed $2,7\ m/s$. The ECMWF model gives the direction: 220° and the speed: $3,6\ m/s$. In turn, the GFS model produces the direction: 210° and the speed: $2,7\ m/s$. One can observe that in this case the forecasted wind direction by the NEMS model has the smallest accuracy, but this is due to the long time since the forecast was calculated. In this case, the average absolute value of the difference between the measured and forecasted wind direction equals approximately 40° and the wind speed is closer to the maximal measured speed $2,7\ m/s$.

Due to the size of the differences between the measured and forecasted wind parameters and knowing that the measured wind parameters are 15-min or 10-min average values, one was decided in order to establish the absolute values of the differences between the measured and forecasted wind parameters. In Table 5, various statistics parameters describing the absolute values of the differences between the wind directions measured at the Trzebież station and the directions forecasted by the NEMS, ECMWF and GFS models at this station have been established. One can see that the average absolute value of difference between the mentioned directions equals 36°, the median of such absolute value of differences is 22°, the first quartile is equal to 10° and third quartile – 42°. This means that the most of these absolute values of differences are less than 43°. These absolute values of differences hardly ever achieve the maximum value 179°. The root-mean-square-error (RMSE) for the absolute values of these differences equals 54°.

Table 5. The statistics (m/s) describing the absolute values of differences between the wind directions measured at the Trzebież station and the directions forecasted by the NEMS, ECMWF, GFS models.

Parameter	Value (degree)
minimum	0
maximum	179
average	36
median	22
quartile 1	10
quartile 3	43
RMSE	54

In Table 6, the statistics parameters describing the absolute values of the differences between the wind speeds measured at the Trzebież station and the speeds forecasted by the NEMS, ECMWF, GFS models are presented. One can see that the average and median of such absolute values of the differences are not too much different from each other. Moreover, 75% of these absolute values of the differences are less than $2,8\ m/s$. The root-mean-square-error (RMSE) for the absolute values of these differences equals $2,4\ m/s$.

Table 6. The statistics (m/s) describing the absolute values of the differences between the wind speeds measured at the Trzebież station and the speeds forecasted by the NEMS, ECMWF, GFS models.

Parameter	Value (m/s)
minimum	0
maximum	7,5
average	2
median	1,7
quartile 1	0,9
quartile 3	2,8
RMSE	2,4

The absolute values of the differences between the measured wind directions and the directions calculated by the chosen weather forecast models at the Trzebież station have been described by the exponential distribution with parameter $\lambda = 0,0277$ (Fig. 4):

$$f(x) = 0,0277 \cdot \exp(-0,0277x) \quad \text{for} \quad x > 0 \qquad (5)$$

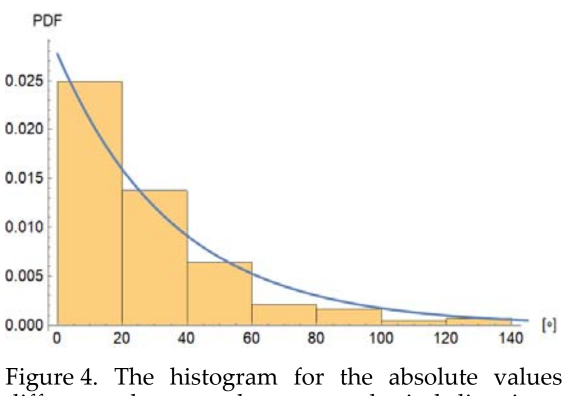

Figure 4. The histogram for the absolute values of the differences between the measured wind directions and the directions, calculated by the chosen weather forecast models, at the Trzebież station. The probability density function (PDF), fitted to the exposure data, is depicted the blue colour. The exponential distribution have been employed.

In Table 7, the statistical tests' results are presented. One might conclude that there is no reason to reject the hypothesis that the exponential distribution describes the absolute values of the differences between the measured wind directions and the directions calculated by the chosen weather forecast models at the Trzebież station, since P-Value is greater than $0,05$ (significance level) in the Cramèr-von Mises test.

Table 7. The results of the statistical test regarding the goodness-of-fit of the exponential distribution to the absolute values of the differences between the measured wind directions and the directions calculated by the chosen weather forecast models at the Trzebież station.

"test"	"P-Value"
"Cramèr-von Mises"	0,33

In turn, the absolute values of the differences between the measured wind speeds and the speeds calculated by the chosen weather forecast models at the Trzebież station have been described by the extreme value distribution with the location parameter $\alpha = 1,3$ and the scale parameter $\beta = 1,1$ (Fig. 5):

$$f(x) = 0,909 \cdot \exp\left(-\exp\left(0,909 \cdot (1,3 - x)\right) + 0,909 \cdot (1,3 - x)\right) \qquad (6)$$

In Table 8, the statistical tests' results are presented. One can gather that there is no reason to reject the hypothesis that the extreme value distribution describes the absolute values of the differences between the measured wind speeds and the speeds collected by the chosen weather forecast models at the Trzebież station, since P-Value is greater than $0,05$ (significance level) in three presented tests: the Anderson-Darling test, the Cramèr-von Mises test and the Pearson χ^2 test.

Table 8. The results of the statistical tests regarding the goodness-of-fit of the extreme value distribution to the absolute values of the differences between the measured wind speeds and the speeds calculated by the chosen weather forecast models at the Trzebież station.

"test"	"P-Value"
"Anderson-Darling"	0,46
"Cramèr-von Mises"	0,61
"Pearson" χ^2	0,19

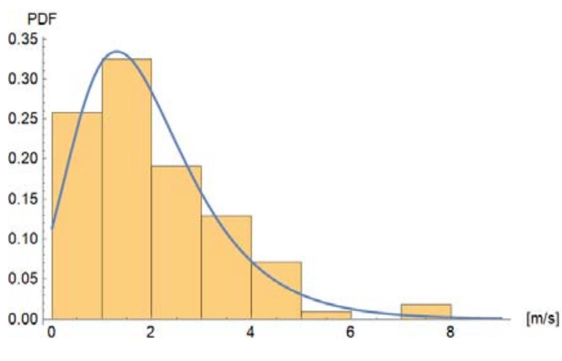

Figure 5. The histogram for the absolute values of the differences between the measured wind speeds and the speeds calculated by the chosen weather forecast models at the Trzebież station. The probability density function (PDF), fitted to the exposure data, is depicted the blue colour. The extreme value distribution has been employed.

In our case, on the Szczecin Lagoon in July and August in 2017 the average wind direction is 202° and its standard deviation equals 36°. In turn, the average wind speed is equal to $2,3\ m/s$ and its standard deviation is $2\ m/s$. Based on Tables 5 and 6, one can assume that the average fluctuation for the wind direction equals 36° and its standard deviation is 54°. In turn, the average fluctuation for the wind speed is equal to $2\ m/s$ and its standard deviation is $2,4\ m/s$.

5 DISCUSSION OF ERRORS IN FORCING FIELDS

The errors in the force fields are caused by many factors. The initial conditions and boundary conditions introduced into the models are one of such factors. These data being these conditions are burdened with the measurement uncertainties and the uncertainty of the model forecasts, from which the data are assimilated. In addition, an interpolation should be performed in order to establish the initial value of the parameter introduced into the model in many meshes of the discretization grid. The bilinear interpolation is most often performed. The interpolation's calculations also introduce some errors.

The selected numerical models have certain resolutions. On one hand, maintaining a high temporal and spatial resolution is desirable. On the other hand, the calculations have to be made in a huge number of meshes of the discretization grid. This is associated with a significant increase in computational complexity: time and/or spatial. Moreover, the spatial resolutions, at which the numerical models are applied, affect the solution of the equations describing the modelled phenomena. In many cases this also leads to being incapable to do such calculations. In spite of the huge modern computational memories and computing powers, they turn out to be insufficient for the requirements of the numerical models. The calculations are made on supercomputers doing them in petaflops, but this is not enough to get perfect forecasts.

A mathematical description of the phenomena occurring in the atmosphere is an another factor influencing the occurrence of the errors in the forcing fields. It results from the assumptions and the simplifications defined at the stage of designing the numerical model's concept. While the phenomena occurring on a global scale are quite well reflected, the local phenomena are often less well described. They are often treated as so-called the sub-grid processes. To a certain extent, these phenomena are taken into account when downscaling (nested) grids are created. In addition, the differential equations describing the changes in the state of the atmosphere, when solving them in a numerical manner, are replaced by the difference equations. The obtained solutions are an approximate solutions. This is also due to the occurrence of the rounding errors and calculation errors. From the point of view of modelling the survivor's drift route in the Szczecin Lagoon waters, it seems reasonable to model the uncertainty in the surface currents and wind parameters in order to minimize errors in the obtained forecasts of these parameters. Indeed, the probabilistic models of the absolute values of the differences between the real and modelled wind parameters have been presented.

An another direction of an improvement in the quality of forecasts of the surface currents and wind parameters is taking into account the real measurements of such parameters made by allocating the measuring buoys and meteo stations in the Szczecin Lagoon waters' area. As a result, the number of the real measurements entered into the numerical models as the initial data will be increased. Providing additional measurement data would certainly reduce the errors in the forecasted parameters.

It seems advisable to carry out: the *in situ* measurements of the surface currents and wind parameters in order to validate the predicted parameters in the open waters of the Szczecin Lagoon, a possible improvement of the forecasts generated by selected numerical models in the Szczecin Lagoon area or the selection of appropriate methods and tools to more accurately model the uncertainty of these parameters. The *in situ* measurements could also indicate possible locations on the Szczecin Lagoon, where automatic measuring stations could be allocated in order to increase the amount of the available data constituting the initial conditions for the selected numerical models.

6 CONCLUSIONS

The forcing fields always contain errors. Processes, that take place in the atmosphere and the hydrosphere, are different temporal and spatial scales. Furthermore, they are characterized by great complexity and variability. A model for a forcing field may well describe large-scale movements, but it can significantly underestimate or overestimate or even ignore small-scale movements. However, small-scale processes may, be relevant and, depending on the issue, their inclusion should be considered in order to predict as accurately as possible, for example, the surface currents and wind parameters.

Analyzing the surface currents charts generated by the PM3D model in the SatBałtyk system, one can observe that the impact of the wind field has been reflected in the surface currents field. Moreover, surface currents circulation was strictly connected with the shoreline's shape. The water exchange between the Szczecin Lagoon and Pomeranian Bay has been provided with good agreement. In the feature, it is worth doing real experiments in order to determine possible differences between the forecasted and real surface currents parameters. Furthermore, the impact of these differences on the survivor's drift will be also established. In turn, some fluctuations' models for the surface currents speed, when their directions are consistent, have been established. In this case, the t-Student distribution has been employed.

The wind fields, generated by weather forecast models such as the NEMS, ECMWF, GFS models, often differ slightly over the same time period. But sometimes the fluctuations in the wind directions and speeds are significant. In this paper, the models of the wind parameters fluctuations have been presented. In order to describe the absolute values of the differences between the forecasted wind directions and directions collected at the Trzebież station in the SatBałtyk system, the exponential distribution has been employed. In turn, in order to establish the absolute values of the differences between the forecasted wind speeds and the speeds recorded at the Trzebież station in the SatBałtyk system, the extreme value distribution has been used.

The fluctuations' models in the forcing fields (wind and surface currents) on the Szczecin Lagoon have been presented in order to employ the Monte Carlo techniques. These techniques will generate an ensemble which yields an estimate localization of the survivor evaluating over a time period.

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