European Research Studies Journal
Volume XXV, Issue 3, 2022

pp. 483-499

Time Shift of Wind Influence on the Movement of Surface Water Masses in the Szczecin Lagoon

Submitted 04/09/22, 1st revision 24/09/22, 2nd revision 14/10/22, accepted 30/10/22

Lech Kasyk[1], Krzysztof Pleskacz[2], Tomasz Kapuściński[3]

Abstract:

Purpose: *The study's specific objectives were to analyze the interaction between the prevailing hydrometeorological conditions and the trajectory of water layer movement in the Szczecin Lagoon (southern Baltic, Poland).*

Design/Methodology/Approach: *Research experiments verifying the drift movement trajectory under various hydrometeorological conditions were carried out in the Szczecin Lagoon. In the presented analysis, 17 fragments from ten drift trajectories were selected, in which there was a clear time shift in the influence of the wind direction on the change of the drifting direction. Statistical analysis of directional and linear data allowed us to link the directions and speeds of drifters moving with the wind parameters recorded in two places, Świnoujście and Trzebież, with an appropriate time shift.*

Findings: *As a result of the research, it was found that the change of the wind direction influences the direction change of the flow of surface waters in the Szczecinski Lagoon with an unavoidable delay. A significant correlation was found between the speed of changes in the wind direction and the initial wind direction. A relationship was also shown between the distance of the test site from the weather station and the registered wind direction change.*

Originality/value: *The presented relationships between some fundamental processes in the energy transfer between wind and water surface may be beneficial for the maritime administration, which is responsible for the safety of navigation in the studied water area. The analysis results can be used in SAR actions and to project the track of water pollutants.*

Keywords: *SAR, shipwreck drift modeling, Szczecin Lagoon safety, wind parameters modeling, wind parameters and forecasting, pollution drift modeling, directional correlation.*

JEL classification: *C69.*

Paper Type: *A research study.*

Acknowledgments: *This research outcome has been achieved under research projects No 1/S/INM/18 and 1/S/RN/22, financed with a subsidy from the Ministry of Science and Higher Education for statutory activities.*

---

[1] *Department of Mathematics, Institute of Mathematics, Physics and Chemistry, Maritime University of Szczecin, l.kasyk@am.szczecin.pl;*

[2] *Department of Marine Navigation, Faculty of Navigation, Maritime University of Szczecin, k.pleskacz@am.szczecin.pl;*

[3] *Department of Mathematics, Institute of Mathematics, Physics and Chemistry, Maritime University of Szczecin, t.kapuscinski@am.szczecin.pl;*

1. Introduction

The authors of this paper are trying to work out a method of predicting the route of pollution movement in the waters of the Szczecin Lagoon. However, to determine this route, appropriate wind parameters must be available. Based on the conducted research, the causes of forecast errors are analyzed in this paper, and possible directions for improvement of the quality of forecasted wind parameters are indicated.

During the in situ research, consisting of the analysis of buoy movements, it was noticed that in some cases, a delay of 1 to 2 hours was recorded before the change of wind direction registered in Świnoujście or Trzebież was reflected in the shift of buoy drift direction. This article presents the results of detailed research and answers for which directions and what strength and value these time shifts were.

The problems connected with a prediction of the movement of surface water layers in the Szczecin Lagoon depending on available and practically usable hydrometeorological data are presented in this paper. The data were obtained from meteorological stations in Świnoujście and Trzebież. The studies and results obtained and presented here refer to such a specific reservoir as the Szczecin Lagoon. It is tiny, shallow water with an irregular coastline, and at the same time, it is a part of sea waters with navigable channels to seaports: Szczecin/Police, Nowe Warpno, and Stepnica.

The presented results of the study will make it possible to answer the question: how to determine in an individual optimum way the regions of transportation of the surface water masses of the Szczecin Lagoon in the aspect of pollution or contamination with Escherichia coli.

The proposed results should ultimately lead to an optimal system for forecasting and controlling the movement of surface water layers. The developed system should be universal and used for all services, directly by SAR services and its branches, police, and fire brigades operating in the Szczecin Lagoon area.

"We can have transport as safe as we want - it is just a question of means, time, and procedures," - said Loyola de Palacio - EU Commissioner for Energy and Transport. Current trends in determining the causes of transport accidents are geared towards measuring the safety culture at work. The professional literature presented the correlation between accident probability and safety culture (Pidgeon, 1991). He also defined the concept of a safety culture. Safety culture expresses a community's attitude to risk, hazards, and safety and what values are considered necessary.

It is important to remember that a good safety culture will enhance the reputation of an area, a body of water, or a country. At the same time, a single significant incident can ruin that reputation. Indeed, it is the case that a significant incident can determine the importance of an entire industry and cause damage that will hit many independent organizations that contribute to and are dependent on the industry's success. Therefore, it is essential to be mindful of the links that can benefit everyone.

The initial driving mechanisms of atmospheric movements, both vertical and horizontal, are related directly or indirectly to solar heating and the rotation of the Earth. Horizontal motions of air masses are typically driven by near-surface air density gradients resulting from diffusive heating and compensatory motions associated with mass conservation, such as land-sea breeze circulations. Pressure fluctuations in the wind field disrupt the stability of the water surface and cause it to move. These pressure fluctuations moving in the direction of the wind resonate with the water surface and further cause ripple formation.

Although the generation of the movement of surface water masses induced by wind action is complex, it is possible to predict the parameters of this movement from wind data at a steady if data on its speed and direction are available, even though these data may not be available at a given position (Ozeren and Wreng, 2009).

The paper highlights the need for predicting the route of movement of surface water masses in the Szczecin Lagoon, which may result in more efficient localization of pollutants such as oil stains or other chemical pollutants or Escherichia coli bacteria.

However, to determine this route, appropriate wind parameters must be available, and these parameters can be obtained from hydrometeorological stations or numerical weather prediction models. In this paper, based on the research carried out, the reasons for errors in forecasts are analyzed, and possible directions for improving the quality of the forecasted parameters of movement of surface water masses in the Szczecin Lagoon are indicated.

2. Research Area

The Szczecin Lagoon covers the waters of the Odra River estuary (Poland's second-largest river) and the southern Baltic Sea. The following positions bound the area: latitude ca. 53º42' N - 53º52' N, longitude ca. 013º53' N - 014º36'. In the north, the islands of Wolin and Uznam separate it from the Baltic Sea. The Lagoon is subdivided into the Large Lagoon (Polish: Wielki Zalew), with a surface area of 488 km², lying within the territory of Poland, and the Small Lagoon (German: Kleines Haff), covering an area of 424 km², which belongs almost entirely to Germany.

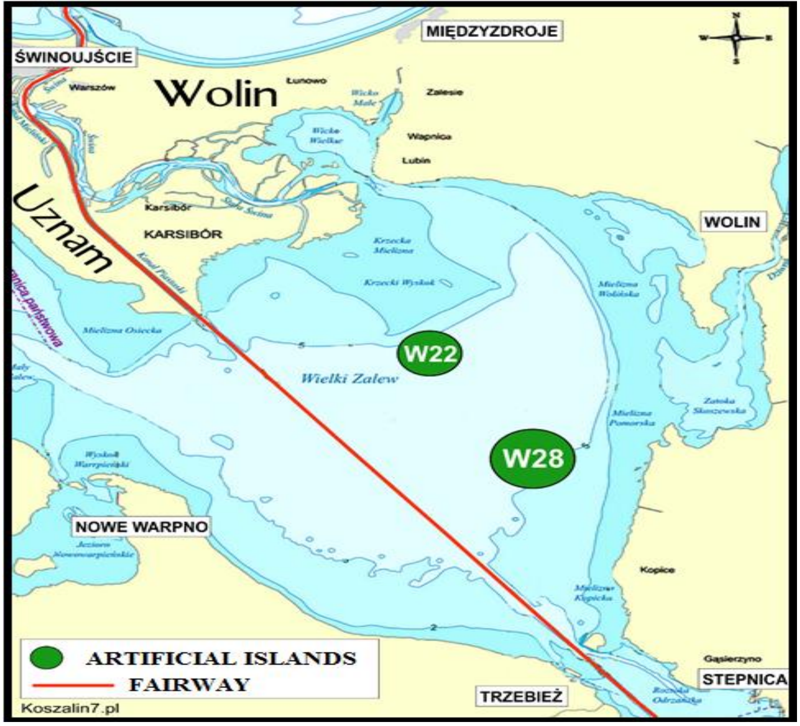
The southern limit of the Large Lagoon is designated by the Jasienica channel outlet (on the west bank) and the mouth of the Krępa River (on the east). The Szczecin Lagoon, which is the main link in the estuary system of the Oder River, is a significant basin for the Polish maritime economy, as the Szczecin-Świnoujście shipping fairway runs through it (Figure 1).

After last year's slight decline in transshipments, the ports of Szczecin and Świnoujście have returned to growth. Ongoing and upcoming investments, such as the "Polimery Police" project, which is "Grupa Azoty" response to the growing demand for polypropylene in Poland, Europe, and worldwide, should make the offer even more attractive and increase transshipments.

In addition, there is the modernization of the Świnoujście-Szczecin waterway, which includes the deepening of the waterway to 12.5 m, along a stretch of about 62 km, with its simultaneous widening to 100 m. As a result of the investment, the permissible draught of ships entering the Szczecin port will be increased to 11 m from 9.15 m. This will increase accessibility for a specific group of large ships.

There will no longer be a need for de-bottoming in Świnoujście before continuing to the port of Szczecin. According to the Maritime Office - a vessel, which presently enters with a cargo of about 20 thousand tons after the dredging of the track, will be able to join with a load almost twice as oversized (https://inzynieria.com/). The dredged material was used to create two islands, at the 22nd and 28th kilometers of the waterway, with a diameter of about 1.3 km and about 1.8 km, respectively. One of these is intended to be a bird habitat.

Figure 1. *The Large Lagoon – the estuary of the Odra River, Świna, Dziwna, and part of the Szczecin – Świnoujście fairway*



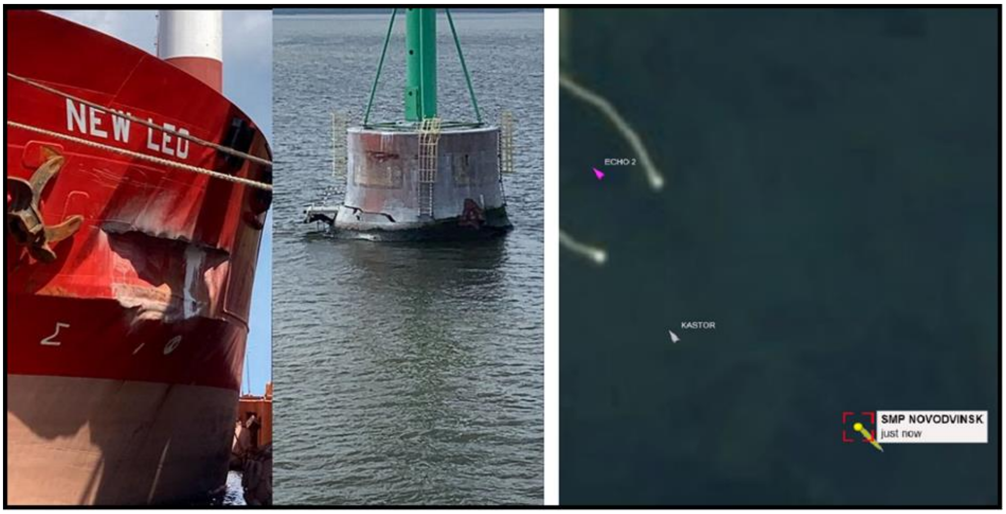
Source: *Own study, based on NAVI-SAILOR 3000 ECDIS-i and www.online/seterra.com.pl.*

In addition, the Szczecin Lagoon is also used for tourism and recreation, and a specific part of it is also used as a fishery. The Szczecin Lagoon is a small and shallow reservoir with limited water exchange and a high-water exchange time - of 55 days Its waters are mostly undrained. Therefore, the waters of the Szczecin Lagoon can be regarded as homogeneous except for the areas in the direct vicinity of the straits connecting the reservoir with the Baltic Sea and the estuary of the Oder River (Schiewer, 2008).

At the same time, despite the development of navigation systems and equipment, the number of accidents in the Szczecin Lagoon area can already be observed. For example, on 14-15 May 2021, a dangerous collision occurred on the Świnoujście-Szczecin waterway. A 100-meter general cargo vessel, "NEW LEO", sailing from the Szczecin harbor towards Świnoujście, hit the "Torowa Gate."

On 12 January 2022, the Russian-flagged "SMP Novodvinsk" ran around after leaving the Piastowski Channel south of the "1st Torowa Gate" on the Szczecin Lagoon (Figure 2).

Figure 2. *Presentation of damage m/v" New Leo" and position of „SMP Novodvinsk"*



Source: *Own study, based on NAVI-SAILOR 3000 ECDIS-i and www.online/seterra.com.pl.*

Increased vessel traffic and the risk of accidents can translate directly into spill hazards. Be it fuel or cargo.

3. Literature Review and Discussion

The paper's authors try to develop a method for predicting the route of movement of surface water masses. In turn, the surface drifts of two buoys launched in the Adriatic Sea during the DART06 (Dynamics of the Adriatic Sea in Real-Time in

2006) sea trials and in the Liguria Sea during the MREA07 (Maritime Rapid Environmental Assessment in 2007) experiment were predicted in (Vandenbulcke *et al.*, 2009). Many studies of a similar nature have been reported in the literature.

However, they mainly concern open-sea areas. There is a lack of studies on such specific areas as the Szczecin Lagoon. An analysis of a drifter's drift depending on the prevailing wind conditions was carried out for the Gulf of Finland in different seasons in 2011 and 2013 (Delpeche-Ellmann *et al.*, 2016). However, in the paper (Chang, 2012), the authors received a relation between the observed near-surface current vectors and surface wind vectors for the north-western part of the Pacific Ocean, with strong winds (20-50 m/s).

Research on hydrodynamic models of reservoir surface waters is conducted in many research centers. Findings on the distribution of surface drifters in the Baltic Sea in 2010 and 2011 are described in (Kjellsson and Döös, 2011). The authors compare drifter trajectories with trajectories generated by a numerical model using fields, i.e., wind forcing with parameterization of gusty winds, from a regional ocean model.

In Vandenbulcke *et al.* (2009), a sea surface drift analysis of two buoys launched in the Adriatic Sea during the DART06 sea trials and in the Ligurian Sea during the MREA07 experiment was performed. In this study, hyper-ensemble techniques were used, i.e., combining different models to obtain the best possible prediction of their trajectories. A surface drift model of drifters based on wind models was also used.

The drift study of MH370 debris was conducted using numerical modeling using a forward particle tracking technique (Nesterov, 2018). In Abascal *et al.* (2012), data from high-frequency (HF) radar ocean observing technology were analyzed. This technology is unavailable for the Szczecin Lagoon due to its small size and shallow depth.

The effect of wind on the different types of buoys was analyzed and described based on experimental data (Poulain *et al.*, 2009). Analyses of wind parameter data in the southern Baltic can be found in Schiewer (2008), and Zhang *et al.* (2011). The authors conducting the study have also previously published articles presenting the components of the study (Kijewska *et al.*, 2017; Kasyk *et al.*, 2018; 2019a; 2019b).

4. In-Situ Survey Data Acquisition Methods, Data Analysis, and Results

In this paper, the authors present the limitations in developing a method for predicting the route of movement of surface water layers in the Szczecin Lagoon, which they encountered during their research. The studies were carried out in-situ using drifters, as pictured in Figure 3.

The drifter is a waterproof measuring buoy with a volume of 1.0 dm^3 made of polypropylene. The shape of the casing is in the form of a truncated cone with a colored cover, allowing the object to be easily located in the water. The weight of the buoy is adjusted so that about 20% of its volume protrudes above the water's surface.

On the side surface of the buoy, there is an inscription confirming its purpose and owner. The SPOT Trace position locator determines coordinates with the GPS, and the coordinate data is sent to the server using satellite communication. The locator is IP67 certified. The locator is located just under the cover. Along with the locator, a subscription is purchased to track and record the position of the buoys on the findmespot.com website. Moreover, they were continuously available to the Maritime Academy researchers.

To make comparisons and analyses, the appropriate wind parameters had to be available, and these parameters were obtained in Świnoujście or Trzebież. When studying the movement of surface water masses, which are to some extent affected by wind, it is essential to carry out in-situ experiments. During such studies, the authors noticed that in some cases, a delay of 1 to 2 hours was recorded before the change in wind direction recorded in Świnoujście or Trzebież was reflected in the shift in buoy drift direction.

Figure 3. *Drifters used during the study*

Source: *Own study.*

The study's specific objectives were to analyze the interaction between the prevailing hydrometeorological conditions and the trajectory of water layer movement. To achieve the assumed goals, research experiments were carried out to verify the trajectory of drifter movement in different hydrometeorological conditions through in-situ research. Part of the research was carried out during the summer (end of June - mid-October).

On top, the comparative analysis combining the determination of the most probable drifter trajectory in given hydrometeorological conditions with actual results (in-situ research) was carried out.

The specific and detailed objective of this described research is to analyze the temporal shift between the change in wind direction and speed recorded at the measuring station and the corresponding change in the direction of drift of free-drifting buoys in the waters of the Szczecin Lagoon, discarded as part of the project discussed in (Kasyk, Kijewska, and Pleskacz, 2019). Such a shift was noted in the graphs but was not uniform in different meteorological conditions.

Therefore, the authors searched for a common denominator, a measurable relationship between wind and buoy drift parameters - including this shift - so that a model of the drifter's movement (and therefore of the surface water layers of the Szczecin Lagoon) could be built on its basis regardless of the prevailing meteorological conditions.

So far, no other works have analyzed the movements of surface water masses in this body of water. At the same time, there is existing literature on analogous bodies of water in the world (Fitzenreiter, Mao, and Xia, 2022). The authors also aimed to analyze the quality and consistency of wind strength and direction data from the stations in Świnoujście and Trzebież to decide which station observations to base future SAR models, algorithms, and procedures on.

It should be mentioned that the route of the drifters used in the experiment can be very random, i.e., not solely and mainly influenced by the wind, even if they were released under similar meteorological conditions (Gough *et al.*, 2019; Aksamit *et al.*, 2019). This is because, in Lagrange experiments, where the gauge moves with the water/air mass, small changes accumulate quickly, making significant differences visible in the drifter's path. The paths of particles - that is, surface water masses - are very complicated and sensitive to initial conditions and even small changes (Liu *et al.*, 2011).

In this study, the authors measured the correlations between wind and drifter speeds and directions. The parameters were calculated without considering the offset and with a time offset. For speed correlations, the classic Spearman's correlation was used. For the correlation of wind directions and drift, the correlation coefficient (Jupp, Mardia, 1999) was used, where the measure of the relationship between two angular quantities θ and φ is expressed by the square of the coefficient:

$$r^2 = \frac{[(r_{cc}^2 + r_{cs}^2 + r_{sc}^2 + r_{ss}^2) + 2(r_{cc}r_{ss} + r_{cs}r_{sc})r_1r_2 - 2(r_{cc}r_{cs} + r_{sc}r_{ss})r_2 - 2(r_{cc}r_{sc} + r_{cs}r_{ss})r_1]}{[(1 - r_1^2)(1 - r_2^2)]}$$

Where:
$r_{cc} = corr(cos\theta, cos\varphi) etc,\ r_1 = corr(cos\theta, sin\theta),\ r_2 = corr(cos\varphi, sin\varphi)$ are simple parameter correlations.

The correlation between wind speed and direction and drifter without an offset is shown in Table 1.

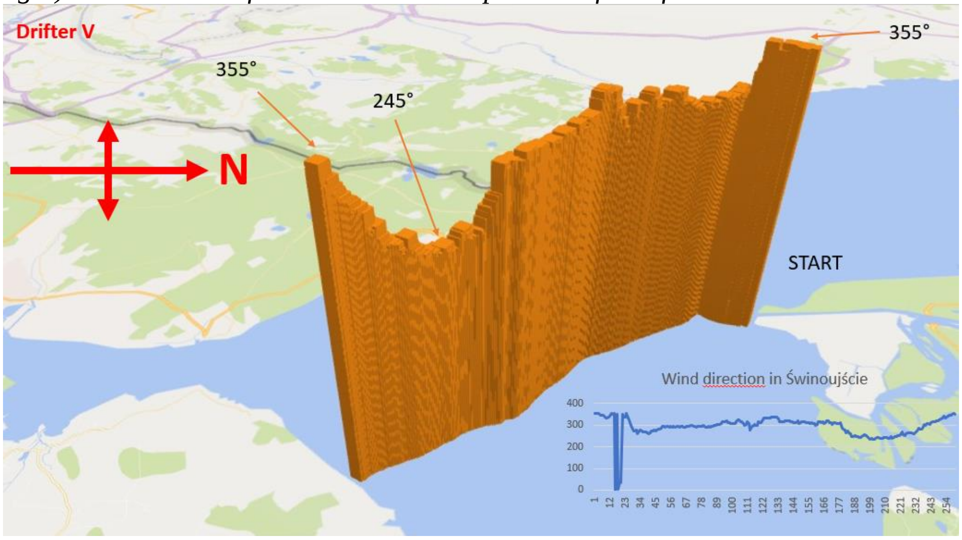
Table 1. *Correlation coefficients between drifter directions and wind (top) and drifter directions and speed (bottom)*

	Drifter vs. wind direction in Trzebież	Drifter vs. wind direction in Trzebież considering the shift	Drifter vs. wind direction in Świnoujście	Drifter vs. wind direction in Świnoujście considering the shift	
Drifter number	correlation between quantities expressed as angles				
1	0,20	0,49	0,83	0,57	WIND/DRIFTER DIRECTIONS
2	0,05	0,44	0,11	0,54	
3	0,20	0,25	0,41	0,70	
4	0,47	0,92	0,60	0,87	
5	0,51	0,52	0,68	1,26	
6	0,11	0,19	0,11	0,15	
7	0,86	0,86	0,85	0,85	
8	0,96	1,41	0,98	1,19	
9	1,26	1,38	1,20	1,21	
10	0,14	0,08	0,26	0,11	
	Spearman’s correlation				
1	0,35	0,67	0,71	0,88	WIND/DRIFTER SPEED
2	0,68	0,62	0,66	0,83	
3	0,20	0,49	-0,51	-0,25	
4	0,61	0,58	0,53	0,69	
5	0,49	0,77	0,53	0,82	
6	0,58	0,61	0,47	0,61	
7	0,32	0,34	0,39	0,51	
8	0,52	0,62	0,13	0,23	
9	0,35	0,51	0,22	0,38	
10	0,10	0,29	0,12	0,30	

Source: *Own study.*

For drifts with observed higher correlation levels, it can be seen that a small range of wind direction changes goes hand in hand with minor modifications in the drifter's course, so in stable winds, the surface water layers move stably and predictably (Figure 4).

Figure 4. *Drifter's route from Drift 5 and wind directions (reflected as column height). Some values of the wind direction provided for reference*



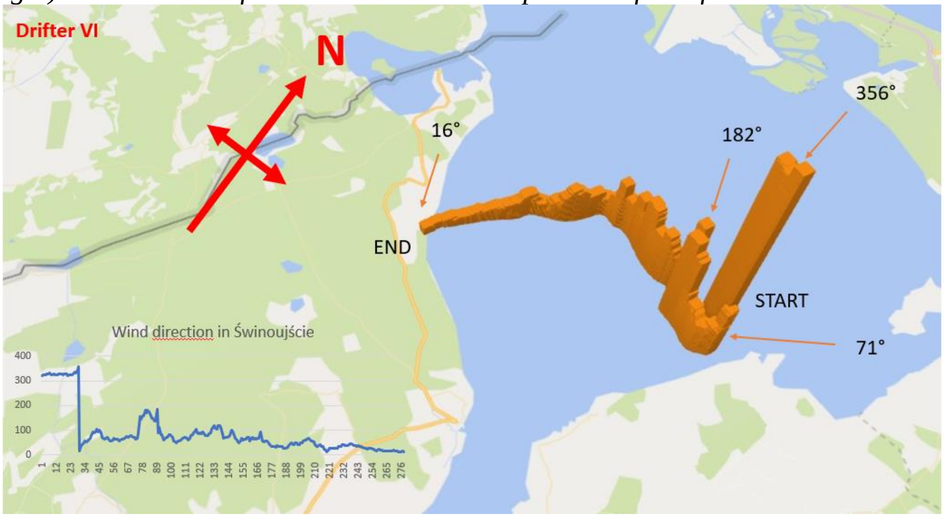
Source: *Own study.*

In contrast, large ranges of wind direction changes go hand in hand with significant changes in the drifter's course. Thus, changing winds cause changing approaches of surface water masses, and their trajectory is affected by the time shift and currently appears challenging to model (Figures 5 and 6).

Figure 5. *Drifter's route from Drift 9 and wind directions (reflected as column height). Some values of the wind direction provided for reference.*

Source: *Own study.*

Figure 6. *Drifter's route from Drift 6 and wind directions (reflected as column height). Some values of the wind direction are provided for reference.*



Source: *Own study.*

In further analysis, 17 fragments were selected from the ten drift trajectories where there was a time shift in the effect of a wind direction on the drifter's change in the direction of travel. For each such shift, the values of the following variables were determined:

- Time of shift
- Weather station, for which the shift was determined
- Average wind speed during the shift
- Average wind direction during the shift
- Distance of the drifter from the selected weather station during the shift
- Value of the wind direction change for the shift
- Value of the wind direction change for the shift per 1 hour
- The absolute value of the wind direction changes for the shift
- The absolute value of the wind direction changes for the shift per 1 hour.

The data for the analysis are summarised in Table 2.

The most important finding is that there were no significant statistical correlations between offset time and the defined variables. Nevertheless, significant correlations were observed between some of the monitored parameters. The correlation relationships are shown in Table 3, where significant correlations are highlighted in red.

Table 2. *Parameters selected for correlation analysis for the 17 most pronounced time shifts*

Shifting time [h]	Station	Wind speed [m/s]	Amount of change in direction [°]	Change of direction per hour [°]	Distance from the station [km]	The initial angle of wind [°]
3	1	6	-30	-7,5	20	240
3	1	7,6	20	5,0	20,5	210
3	1	5,2	35	35,0	24,5	102
4	1	3,5	20	10,0	20	90
1,5	0	3,1	23	23,0	10,4	82
1	0	5,7	-15	-7,5	10,5	105
2,5	1	3,2	110	110,0	16	90
2,5	0	1,5	80	20,0	17	70
1	0	3,5	-70	-46,7	13,6	180
2,5	0	0,9	-180	-180,0	13,5	220
2	1	1,5	-150	-21,4	22,5	200
3	1	1,9	40	40,0	24	50
1	0	2,9	-130	-130,0	13	300
2	0	0,5	-240	-240,0	3,6	360
4	0	2,4	175	58,3	5,8	25
3	0	0,6	-330	-330,0	2,5	350
0	1	2,7	-120	-120,0	17	30

Source: *Own study.*

Table 3. *Correlation values for crucial parameters for the 17 most pronounced time shifts*

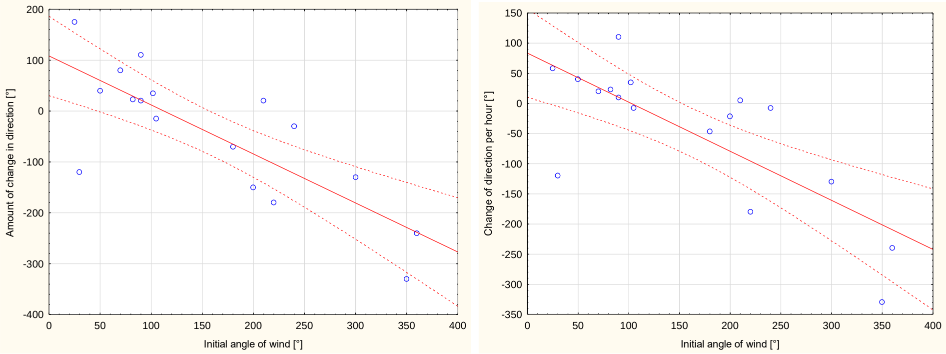
	Shifting time [h]	Wind speed [m/s]	Amount of change in direction [°]	Change of direction per hour [°]	Distance from the station [km]	The initial angle of wind [°]	Absolute wind direction change [°]	Hourly absolute wind direction change [°]
Shifting time [h]	1	0,037815	0,34241	0,241655	0,1269	-0,057072	0,027499	-0,080968
Wind speed [m/s]	0,037815	1	0,443613	0,501234	0,425232	-0,180337	-0,73348	-0,630577
Amount of change in direction [°]	0,34241	0,443613	1	0,936146	0,382292	-0,792146	-0,668836	-0,748468
Change of direction per hour	0,241655	0,501234	0,936146	1	0,578134	-0,75834	-0,769644	-0,862538

[°]								
Distance from the station [km]	0,1269	0,425232	0,382292	0,578134	1	-0,393622	-0,671099	-0,66299
Initial angle of wind [°]	-0,057072	-0,180337	-0,792146	-0,75834	-0,393622	1	0,564674	0,625886
Absolute wind direction change [°]	0,027499	-0,73348	-0,668836	-0,769644	-0,671099	0,564674	1	0,90177
Hourly absolute wind direction change [°]	-0,080968	-0,630577	-0,748468	-0,862538	-0,66299	0,625886	0,90177	1

Source: *Own study.*

It can be seen that the value of the change of wind direction for a shift (r=-0.79) and the value of the evolution of wind direction for a growth per 1 hour, i.e., the rate of change of wind direction (r=-0.76, Figure 7) are most strongly correlated with the initial angle. Thus, winds blowing on the N-S axis are subject to more significant shifts than winds blowing on the W-E axis. Thus, as described in the last part of the analysis, the drift of surface water masses - and thus of survivors or potential contaminants - will be more stable in W-E axis winds than in N-S axis winds.

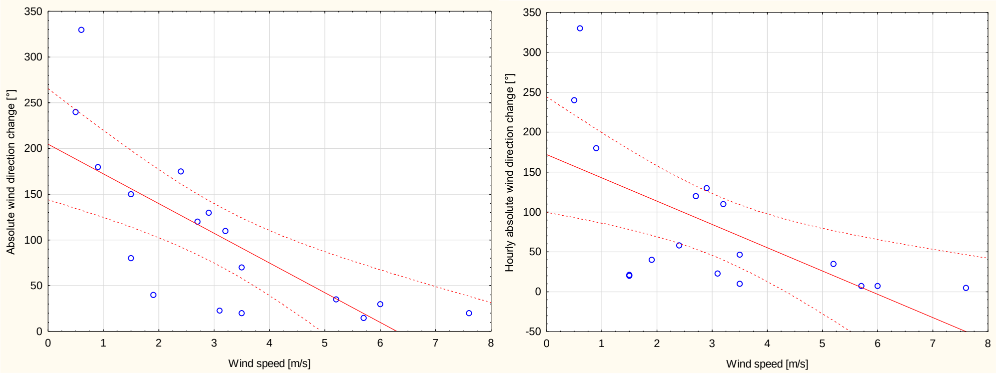
Figure 7. *Scatter plots of wind direction change and hourly wind direction change as a function of initial wind direction*



Source: *Own study.*

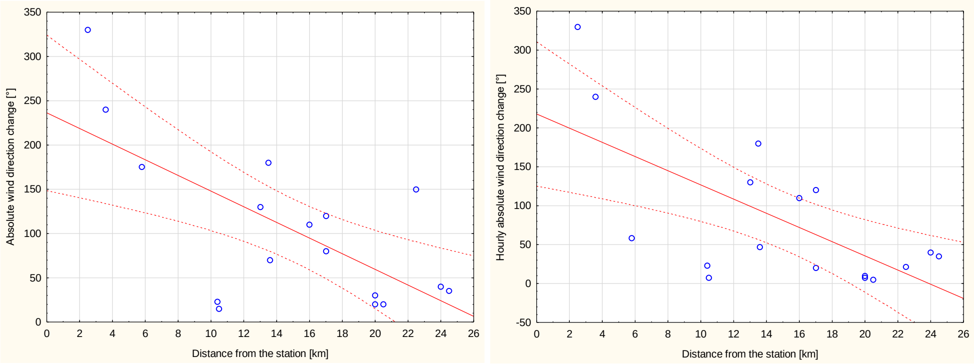
The absolute value of the wind direction change for the displacement is strongly correlated with the wind speed (r=-0.73), the distance from the weather station (r=-0.67), and the initial wind angle (r=0.56). The absolute value of the change in wind direction for a shift of 1 hour is strongly correlated with the wind speed (r=-0.63), the distance from the weather station (r=-0.66), and the initial wind angle (r=0.63). It can be concluded that stronger winds are more stable and subject to fewer changes in direction, so drifting objects or spillways should be subject to more occasional changes in drift course, moving more steadily in stronger winds. Figures 8-10 illustrate these correlations.

Figure 8. *Scatter plots of absolute wind direction change and hourly absolute wind direction change as a function of wind speed*



Source: *Own study.*

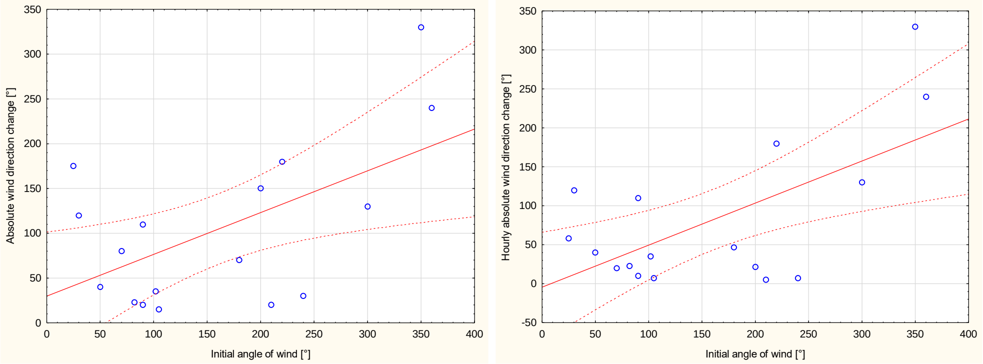
Figure 9. *Scatter plots of absolute wind direction change and hourly absolute wind direction change versus distance from the weather station*



Source: *Own study.*

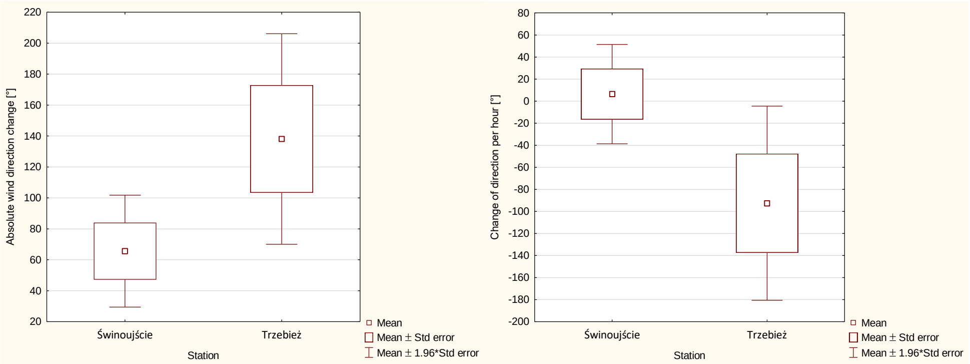
Among the analyzed variables, the absolute value of wind direction change and the importance of wind direction change for shift per 1 hour had statistically significant differences, as shown in Figure 11. These statistically significant differences between critical parameters in the context of the meteorological reference base (absolute value of direction change and shift rate) mean that the quality and location of the meteorological station are crucial. The authors suggest setting up a wind parameter measuring station on one of the new islands in the Szczecin Lagoon to have up-to-date, consistent, and localized data on wind parameters.

Figure 10. *Scatter plots of absolute change in wind direction and absolute hourly change in wind direction versus initial wind direction*



Source: *Own study.*

Figure 11. *Variation of absolute change of direction and hourly wind direction change depending on the weather station*



Source: *Own study.*

5. Discussion and Concluding Remarks

The investigated correlations may support SAR procedures for searching for survivors in the Szczecin Lagoon area or pollution control, even without a general surface water mass movement model. Analysis of the movement of surface water masses can also help to locate better contaminants, such as oil stains or other chemical components and microorganisms. From an ecological point of view, this is a crucial issue.

Providing the action coordinator with more modern tools for fast and correct decision-making in complex situations would be advisable. Such a tool could be an algorithm that, using the available data, would lead to the efficient development of an action plan. Therefore, additional research, data collection, and analysis are needed to improve safety and efficiency.

The research will provide the theoretical basis and subsequent implementation of algorithms to obtain an advanced integrated navigation system combining ECDIS with hydrometeorological data available through GMDSS and the positioning systems. The proposed solution would be a tool combining different information sources into one. The result should be an optimal scheme to control the movement of surface water layers.

The system to be developed should be universal, and it can be used for all types of services directly by the SAR service, its branches, and the police and fire brigades operating in the Szczecin Lagoon area. Deployment to a vessel should be simple due to the requirements for compulsory vessel equipment.

High safety culture is associated with a high value placed on human health and life and maintaining the boundary between the necessary risks inherent in life and development and the provision of safety and protection against hazards.

Emerging systems should integrate already existing and operating components. Inputs and outputs should be understandable to operators and convincingly provide arguments for taking specific actions. Combining several elements into one should translate directly into shorter assessment times of the situation and thus directly into increased effectiveness of the action.

Moreover, the research can provide data for defining relations between the surface water mass movement of the Szczecin Lagoon and air mass movement in the region. Such data have not been available so far. Unfortunately, considering the drift parameters, the area of the Szczecin Lagoon has not been sufficiently covered by any of the existing hydrodynamic models. This poses a challenge for further research.

The presented relationships between some fundamental processes in the energy transfer between wind and water surface and water surface can facilitate the understanding of wind-water interaction because a wave forecast is only as accurate as the wind estimate is correct.

References:

Aksamit, N.O., et al. 2019. Machine-learning mesoscale and sub mesoscale surface dynamics from Lagrange ocean drifter trajectories. Journal of Physical Oceanography 50 (5), 1179-1196.

Abascal, A., et al. 2012. Backtracking drifting objects using surface currents from high-frequency (HF) radar technology.

Chang, C. 2012. The Philippines–Taiwan Oscillation: Monsoon-like Interannual Oscillation of the Subtropical–Tropical Western North Pacific Wind System and Its Impact on the Ocean.

Delpeche-Ellmann, E., et al. 2016. A comparison of the motions of surface drifters with offshore wind properties in the Gulf of Finland, the Baltic Sea.

Fitzenreiter, K. et al. 2022. Characteristics of Surface Currents in a Shallow Lagoon–Inlet–Coastal Ocean System Revealed by Surface Drifter Observations, Estuaries, and Coasts.

Gough, M.K., et al. 2019. Persistent Lagrange transport patterns in the northwestern Gulf of Mexico. Journal of Physical Oceanography, 49(2), 353-367.

Jupp, P., Mardia, K. 2016. Directional Statistics. Wiley Series on Probability and Statistics.

Locja Bałtyku 502 wybrzeże Polskie, BHMW. 2016.

Kasyk, L., et al. 2018. Comparative Analysis of the Data on the Surface Currents and Wind Parameters Generated by Numerical Models on the Szczecin Lagoon Area. TransNav - The International Journal on Marine Navigation and Safety of Sea Transportation.

Kasyk, L., et al. 2019a. Statistical Analysis of the Real Surface Currents and Wind Parameters for the Szczecin Lagoon. Advances in Maritime Navigation and Safety of Sea Transportation.

Kasyk, L., et al. 2019b. Analiza ruchu powierzchniowych mas wody w centralnej części Zalewu Szczecińskiego. Problematyka z zakresu nauk o środowisku - przegląd i badania.

Kijewska and Pleskacz. 2017. Niepewność prognoz parametrów wiatru dla Zalewu Szczecińskiego i Zatoki Pomorskiej jako jedno ze źródeł błędów predykcji trasy dryfu rozbitka.

Kjellsson and Döös. 2011. Surface drifters and model trajectories in the Baltic Sea.

Liu, Y., et al. 2011. Evaluation of trajectory modeling in different dynamic regions using normalized cumulative Lagrange separation. Journal of Geophysical Research: Oceans, 116, C09013.

Nesterov. 2018. Consideration of various aspects in a drift study of MH370 debris.

Ozeren and Wreng. 2009. Predicting Wind driven Waves in Small Reservoirs. American Society.

Pidgeon 1991. Safety Culture and Risk Management in Organizations.

Poulain, et al. 2009. Wind Effects on Drogue and Unrouged Drifters in the Eastern Mediterranean.

Schiewer. 2008. Ecology of Baltic Coastal Waters.

Vandenbulcke, et al. 2009. Super-ensemble techniques: Application to surface drift prediction.

Zhang, et al. 2011. Analysis of 50-year wind data of the southern Baltic Sea for modeling coastal morphological evolution – a case study from the Darss-Zingst Peninsula.