since 1961

Baltica

BALTICA Volume 27 Number 2 December 2014 : 151–160
doi: 10.5200/baltica.2014.27.24

Surface drifters experiment in the south-eastern part of the Baltic Sea

Lina Davulienė, Loreta Kelpšaitė, Inga Dailidienė

Davulienė, L., Kelpšaitė, L., Dailidienė, I., 2014. Surface drifters experiment in the south-eastern part of the Baltic Sea. *Baltica, 27 (2), 151–160.* Vilnius. ISSN 0067-3064.

Manuscript submitted 20 September 2014 / Accepted 28 November 2014 / Published online 10 December 2014

Abstract In November 2013, the first short-term surface drifter experiment has been carried out along the Lithuanian coast. Three drifters were deployed from *R/V Vėjūnas* at a location ~6 km offshore and 2.5 km north of Klaipėda. During the period of observation from 22-30 November, the drifting direction has shifted up to five times by more than 90 degrees mainly due to changes in the mean wind direction. After seven days, the drifters have reached the coast approximately 30 km south of Klaipėda. The analysis of the relationships between the mean wind speed and the mean drift speed for the three periods differentiated based on meteorological conditions yielded a regression coefficient of 0.031, with the entire experiment period characterized by a lower value of 0.014.

Keywords *• Lagrangian drifter experiment • drifter pair • spreading rate • near-shore drifting*

✉ *Lina Davulienė (lina.davuliene@ftmc.lt), Center for Physical Sciences and Technology, Savanorių Ave. 231, LT-02300, Vilnius, Lithuania; Virginijus Žąsytis, Loreta Kelpšaitė, Inga Dailidienė, Klaipėda University, Department of Geophysics, Herkaus Manto g. 84, LT-92294, Klaipėda, Lithuania*

INTRODUCTION

In the World Ocean, the satellite-tracked drifters have been widely used to receive the relevant information on water parameters and its movement (Booth, Meldrum 1987; Bograd *et al.* 1999). Relatively long data series with the comparably low cost could be gathered from the places where stationary measurement data or measurements from the ships of occasion are not available.

Due to heavy shipping in the Baltic Sea, the probability of the oil spillage is high (HELCOM 2010). The drifter experiments provide valuable data for the validation of the Lagrangian drift models that are widely used for estimating the fate of oil spills or for pointing out its potential sources (Liungman, Mattsson 2011; Loncar *et al.* 2012). The Lagrangian drift models are also highly relevant for estimating the path of the drifting objects such as polluted water, living organisms or lost goods (Abbott 1990; König, Schrum 1997).

Tracing Lagrangian trajectories is a powerful tool for understanding and diagnosing motion in the ocean. Only a few short-term drift experiments have been performed in the Baltic Sea so far, most of them in the Gulf of Finland. The difficulties of using surface drifters in the Baltic Sea are first due to the heavy traffic and extensive fishing in the Baltic Sea. The second restrictive reason would be a relatively small mean depth of the Baltic Sea, which limits the applicability of the SVP-drifter (Surface Velocity Programme drifter) due to an increased risk of running aground (Lumpkin, Pazos 2006). Therefore, the deployment of the surface SVP drifters measuring currents at the 12–18 m depth is possible in a limited area of the Baltic Sea with a sufficient depth, for example, in the Baltic Proper (Kjellsson, Döös 2012). In some cases, it is more convenient to use drifters submerged in the uppermost 1-2 m water layer. Most of the experiments using such kind of drifters were conducted in the Gulf of Finland in last decades (Gästgifvars *et al.* 2006; Soomere *et al.* 2011).

The movement of water masses in natural water bodies are of different spatial and temporal scales. However, the numerical hydrodynamic models are supposed to reproduce the larger ones, representing the meso-scale dynamics and depending on the horizontal resolution of the model. The sub-grid water motions are matter of parameterization in Eulerian models (Soomere *et al.* 2011). These models have been recently applied for the Lithuanian marine waters (Davulienė, Trinkūnas 2004; Zemlys *et al.* 2013). However, drift simulations by Lagrangian models have to deal with motions on the sub-grid scale with great accuracy, as this might be important for the simulated drifting path. Therefore, the drift experiments are expected to give the required information about the sub-grid hydrodynamic processes.

Although Lagrangian surface drifters are used for scientific purposes in the World Ocean since 1970s, there are no published reports available on any such experiment in the south-eastern part of the Baltic Sea (Niiler 2001). Our first attempt of conducting the Lagrangian drift experiment was useful in gaining the technical experience of dealing with the drifter and in planning the drifting experiment itself. Concerning this, there is a strong willingness to continue the drifting experiments in the Lithuanian marine waters in the future.

The aim of this paper is to analyse the peculiarities of a Lagrangian drift in the south-eastern part of the Baltic Sea at the Lithuanian coast, and to gain understanding, in general, about the processes affecting a path of drifting object and a dispersion characteristics in the upper layer of the sea.

EXPERIMENT

Study site

The study site covers the south-eastern part of the Baltic Sea along the Lithuanian coast. The neighbouring countries at the maritime boundaries are Latvia in the north, Russia (Kaliningrad Oblast) in the south, and Sweden from western site. The area of the exclusive economic zone is 6426.6 km² and extends seawards about 95 km (*http://www.marineregions.org/gazetteer.php?p=details&id=5684*).

The length of the Lithuanian coast is 90.66 km (Žilinskas 1997). The Klaipėda Strait is located nearly in the centre of this length. Here the Nemunas River, the third largest tributary of the Baltic Sea, is flowing into sea through the Curonian Lagoon. The south-eastern part of the Baltic Sea has a wide submarine slope. During the experiment, the drifter reached the distance of about 12 nautical miles from the coast with the maximum depth of about 50 m (Fig. 1). Here locations of the drifters' pick-up are marked by stars, the circles show the location of the drifter on the specified day at 00:00 GMT, and the arrows show the wind direction at the time.

Western and south-western wind directions are dominant at the Lithuanian coast of the Baltic Sea. Analysis of MODIS SST maps over the period of 2000–2011 suggests that the northern direction of transport of the water plume penetrating the sea from the Curonian Lagoon through the Klaipėda Strait is dominating. This corresponds also to the prevailing south and south-westerly winds along the south-eastern Baltic Sea (Kozlov *et al.* 2012). However, during the cold seasons of the year the probability of the northern winds increases (Dailidienė *et al.* 2012). The northern winds induce upwelling at the Lithuanian coast during which the vertical motion of water masses is caused by horizontal divergence in the surface layer of the sea and produces the local decrease in the water temperature in the upper layer of water along the shore (Lepparanta, Myrberg 2009). On contrary, it brings warmer waters from the deep layers to the coastal area during the cold time of the year (Kozlov *et al.* 2012).

Methods

The drifters described in Soomere *et al.* (2011) were used in the experiment. It is a tube-shaped plastic pipe with diameter of 50 mm, which has the 1.8 kg weight and is about 2 m long (the submerged part is of 1.4 m long). Every 15 min. the coordinates of the current drifter's location as a standard SMS message were sent to the local GSM operator. The capacity of eight D-size standard elements (18 Ah) together with the internal Li-ion battery (3.7 V, 18 Ah) ena-

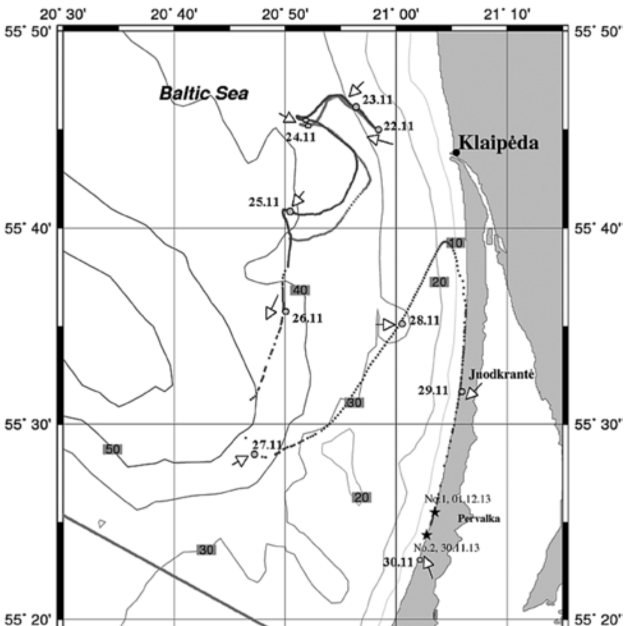

Fig. 1 Paths of drifter's movement on 22–30 November 2013. Compiled by L. Davulienė and V. Žąsytis, 2014.

bled continuous work of the device for 2-3 weeks. The drifter should be able to transmit GSM signal to coastal stations from a distance up to 30 km offshore. However, only the Lithuanian GSM operator could receive the SMS. Therefore, if the drifter would enter the waters of the neighbouring countries the signal is lost. In this case, the probability to recover the drifter would also reduce to minimum.

For the analysis of wind conditions during the experiment the two wind data sets from different sources were used: data measured at the Klaipėda Meteorological Station (Klaipėda MS), operated by the Marine Research Department of the Lithuanian Ministry of Environment, and observation data from the Global Data Assimilation System (GDAS) archive (http://www.ncdc.noaa.gov/data-access/model-data/model-datasets/global-data-assimilation-system-gdas; data source: http://ready.arl.noaa.gov/ READYamet.php).

Comparison of wind data sets showed that, in general, during the period of the experiment the mean difference in wind direction was about 13°±10°. However, the mean difference in the wind speed in the period from 24 to 26 November was about 2.4±0.3 m/s with maximum of 5 m/s on 26 November 3:00 GMT. Both wind data sets have particular disadvantages. The first one is measured in the urban environment far from the field experiment area, and the other is a data set of the global data assimilation model with a comparably course horizontal grid. Therefore, both wind data sets were used in the analysis of the experimental data. The wind parameters at the Klaipėda MS are measured every 3 hours. In the GDAS archive, the meteorological data are also resolved at the 3-hour resolution.

Soomere *et al.* (2011) have estimated the contribution of the wind to the overall drift velocity assuming that wind stress and water friction are dominated by turbulent drag and are compensate each other for the stationary case. According to this analysis, the speed for wind-induced drift of the device and the speed of wind are related by approximate factor of 0.025. This coefficient was calculated for the device with the same geometry used in our experiment.

Description of experiment

The drift experiment began at 17:00 GMT on 22 November 2013. Three drifters were released from the scientific research low draft vessel *Vėjūnas* at the location 55.750 N, 20.972 E that is about 6 km apart from the coast and about 2.5 km to the north from the Klaipėda Strait (see Fig. 1; Table 1). The water column is about 24 m deep in the area. The release point was chosen in close vicinity to the Klaipėda Port and to the shipping way as the ships or the port itself might be a source of drifting objects e.g. waste.

The signal of the drifter No. 1 was lost on 24 November, i.e. approximately after 31 hour from the beginning of the experiment. On 25 November, approximately after 56 hours, the signal of the drifter No. 2 was also lost. The drift experiment ended on 30 November, i.e. approximately after eight days from the start when the last signal of the drifter No. 3 was received.

All drifters were found later on the coast of the Curonian Spit to the south from the start position. However, the full route of drifting was received only from the drifter No. 3 (see Fig. 1). The last signal sent by this drifter was received on 30 November 2013 about 30 km to the south from the Klaipėda Port at the settlement of Preila, and on 4 December this drifter was found at the Nida town, i.e. other 10 km farther to the south. The drifters Nos. 1–2 were picked-up on 1 December and 30 November, respectively, on the coast of the Curonian Spit about 25 km to the south from the Klaipėda Port at the settlement of Pervalka about 1.5 km apart from each other. The drifters moved within reach of the coastal GSM station during the whole time of experiment, therefore, the loss of

Table 1 Course of the experiment: drifter locations at the particular time. Compiled by L. Davulienė, 2014.

Date	Time, GMT	Latitude	Longitude	Comments
22.11.2013	16:54	N 55:44:59	E 20:58:19	Start
23.11.2013	00:09	N 55:46:10	E 20:56:15	Drifter No. 3
24.11.2013	00:09	N 55:45:29	E 20:51:46	Drifter No. 3
25.11.2013	00:09	N 55:40:47	E 20:50:46	Drifter No. 3
26.11.2013	00:09	N 55:35:48	E 20:49:52	Drifter No. 3
27.11.2013	02:39	N 55:28:34	E 20:47:03	Drifter No. 3
28.11.2013	00:09	N 55:35:14	E 21:00:28	Drifter No. 3
29.11.2013	22:09	N 55:31:35	E 21:05:43	Drifter No. 3
30.11.2013	21:54	N 55:23:04	E 21:02:04	Drifter No. 3
01.12.2013	-	N 55:25:07	E 21:03:02	Drifter No. 1 pick-up
30.11.2013	-	N 55:24:13	E 21:03:44	Drifter No. 2 pick-up
04.12.2013	-	N 55:18:10	E 20:58:28	Drifter No. 3 pick-up

signal of the two drifters in the sea could be attributed to other reasons, which have remained undisclosed yet.

During the whole week before the start of the experiment, the southern winds prevailed in the south-eastern part of the Baltic Sea. However, on the day of the start of the experiment the wind direction changed to the opposite. During the period of the experiment, on 22–29 November, the western to northern wind directions prevailed (Fig. 2). It should be noted that the definition of the direction for the water currents and wind are different, therefore, the direction of drifting was recalculated, and e.g. zero° means the northern wind and the drifting direction from the north to the south. The drifter speed is presented as the route length per time interval, where the time interval is 15 min.

The comparison of the wind direction and the drifting direction reveals that the drifting direction was changing from the perpendicular to nearly downwind direction. During the experiment, the course of Lagrangian drifter movement has changed for about five times by more than 90° due to changes in the wind direction.

At the beginning of the experiment, on 22 November, the north north-eastern wind prevailed and the drifters were moving in the north-western direction, i.e. perpendicular to the wind direction, for about 12 hours (Fig. 3). In the second half of 23 November, the direction of drifting path changed and the drifters were moving in the south-western direction nearly downwind for about 16 hours. On 24 November, the wind turned to the western direction for a short period of about 10 hours. This change in the wind direction was also followed by the increase in the wind speed. The direction of drifter movement followed this change in the wind direction very firmly (see Fig. 2). As in the second half of the same day the wind returned to the northern direction and remained stable for the next two days, the direction of drifter movement also turned to the downwind direction parallel to the coast, however, with a delay of about 12 hours. The wind speed increased in the period from the 24 to 26 November compared with the previous period of 22–23 November from about 2.5 m/s to about 7.5 or 5 m/s, according to the GDAS archive or Klaipėda MS, respectively (see Fig. 2).

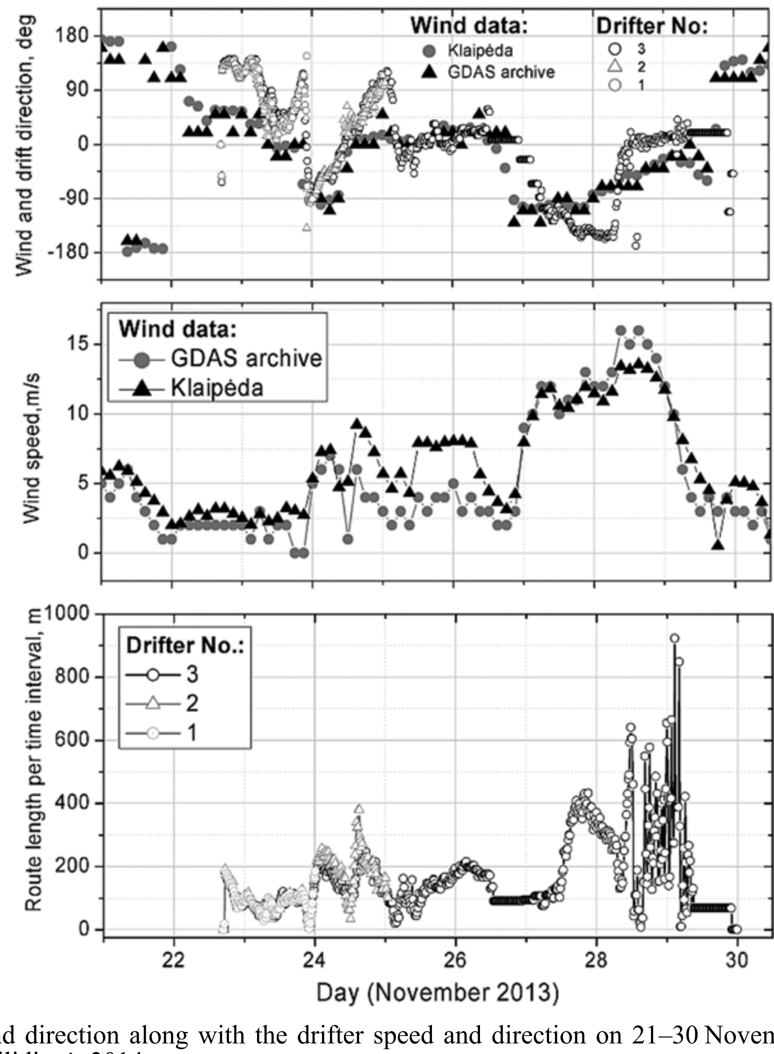

Fig. 2 Wind speed and direction along with the drifter speed and direction on 21–30 November 2013. Compiled by L. Davulienė and I. Dailidienė, 2014.

The wind speed in the subsequent period of 27–28 November increased to 12–13 m/s. On 27 November, the western wind perpendicular to the coast prevailed causing the rise of the sea level towards the coast. Therefore, nearly geostrophic movement of the drifter was observed. The drifter No. 3 was moving almost perpendicularly to the wind direction about 45º to the coastline (Figs. 1 and 3). In the second half of the 28 November, i.e. approximately after 130 hours from the start, the drifter No. 3 came up to the coast of the Curonian Spit about 13 km to the south from the Klaipėda Port. The drifter then moved along the coast to the south up to the place where it was found on 4 December 2013.

The length of the path during the time step (in our case, it is 15 min.) shows that the movement of the drifter No. 3 on 28 November after it came up to the coast became "uneven" or unpredictable. Therefore, these data were excluded from further analysis. Therefore, the time of the end of the experiment is considered the 28 November 8:15 GMT. There were also periods when the measurement data were missing. In case of the drifter No. 3 the longest, 10-hour, data gap occurred on 26 November at about 12:30 GMT, followed by another 4-hour data gap until 2:30 GMT on 27 November. In some cases, these gaps were filled with averaged neighbouring values (see Fig. 2).

The type of the Lagrangian drifter used in the experiment has been proved suitable for the drifting experiments in the south-eastern part of the Baltic Sea, in general. However, in order to avoid the loss of data the causes of technical problems should be found.

RESULTS

The length of the total path of the drifter No. 3 was about 75 km (Fig. 4a). With the mean speed of 0.17 m/s the drifter No. 3 covered the mean distance of about 14.7 km per day (Table 2).The mean speed and standard deviation of other drifters Nos. 1 and 2 were lower compared to that of the drifter No. 3 as the meteorological conditions were rather calm in the first part of the experiment. The drifter No. 3 reached the maximum speed of 0.48 m/s on 27 November at 11:00 GMT when westerly wind of about 13 m/s was prevailing (see Fig. 2).

The simplified analysis of relation between the mean wind speed and the mean drift speed has been carried out. Based on the wind speed data obtained from the GDAS archive, the period of the experiment could be divided into three periods: 22–23, 24–26 and 27–28 November, distinguished by the steady wind direction and the average wind speed of 3 m/s, 8 m/s (5 m/s according to the Klaipėda station) and 12 m/s, respectively (see Fig. 2). During the first period, the mean length of the segment (time interval of 15 min.) was about 100 m (400 m/h). During the second period on 24 November, the wind speed increased to about 8 m/s and the segment length increased to about 180 m (720 m/h) with the maximum for the drifter No. 2 reaching nearly 400 m per time interval. During the third period, on 27 November, the wind speed increased to about 12 m/s and the segment length in the second half of the day reached the mean value of 360 m (1.4 km/h) for a few hours (see Fig. 2). This simplified analysis of relation between the mean wind speed and the mean drift speed evaluated for three selected periods of the experiment with different meteorological conditions gives the regression coefficient of $(31\pm1)\times10^{-3}$. This coefficient gives a first order approximate evaluation of the mean drifter speed when the wind speed is known.

The analysis of the relation between the wind and drifter speed based on overall set of data was also carried out. It showed a similar dependence as discussed above – the segment length or the drifting speed increased along with the increasing wind speed. However, the dispersion of the measurement data points was high and the obtained correlation between the wind speed and the 3-hour averaged drifter speed was rather low – about 0.65 ($p<0.001$) for both wind data sets (Figs. 2–3). Therefore, the regression coefficients evaluated using 3-hour averaged drifter speed data were considerably smaller compared to the former simplified analysis, i.e. $(14.5\pm0.3)\times10^{-3}$ and $(18.9\pm0.4)\times10^{-3}$ for the Klaipėda MS and the GDAS archive wind data sets, respectively (see Fig. 3).

The distance between the drifters was increasing with time (Fig. 4b). The distance between drifters Nos. 1 and 2 increased to 500 m during 16 hours from the start of the experiment (11 m/h). However, after the first turn by about 90 due to changes in the wind direction the distance started to decrease and reached minimum values, i.e. the drifters were moving almost together during the next 12 hours until the signal of

Table 2 Statistics of the drifter and wind speed; SD is Standard Deviation. Compiled by L.Davulienė and V.Žąsytis, 2014.

Drifter	Drifter time on sea, hours	Drifter speed, m/s		Wind speed, m/s			
				Klaipėda MS		GDAS1	
		Mean±SD	min; max	Mean±SD	min; max	Mean±SD	min; max
No. 1	31.25	0.10± 0.04	0.00; 0.21	1.5±1	0; 3	5.4±0.8	4; 6.3
No. 2	56.00	0.15± 0.08	0.01; 0.42	3±2	0; 7	8.8±4.5	4; 17.9
No. 3	116.75	0.17± 0.1	0.02; 0.48	5.8±5	0; 16	7.2±3.5	2.1; 13.5

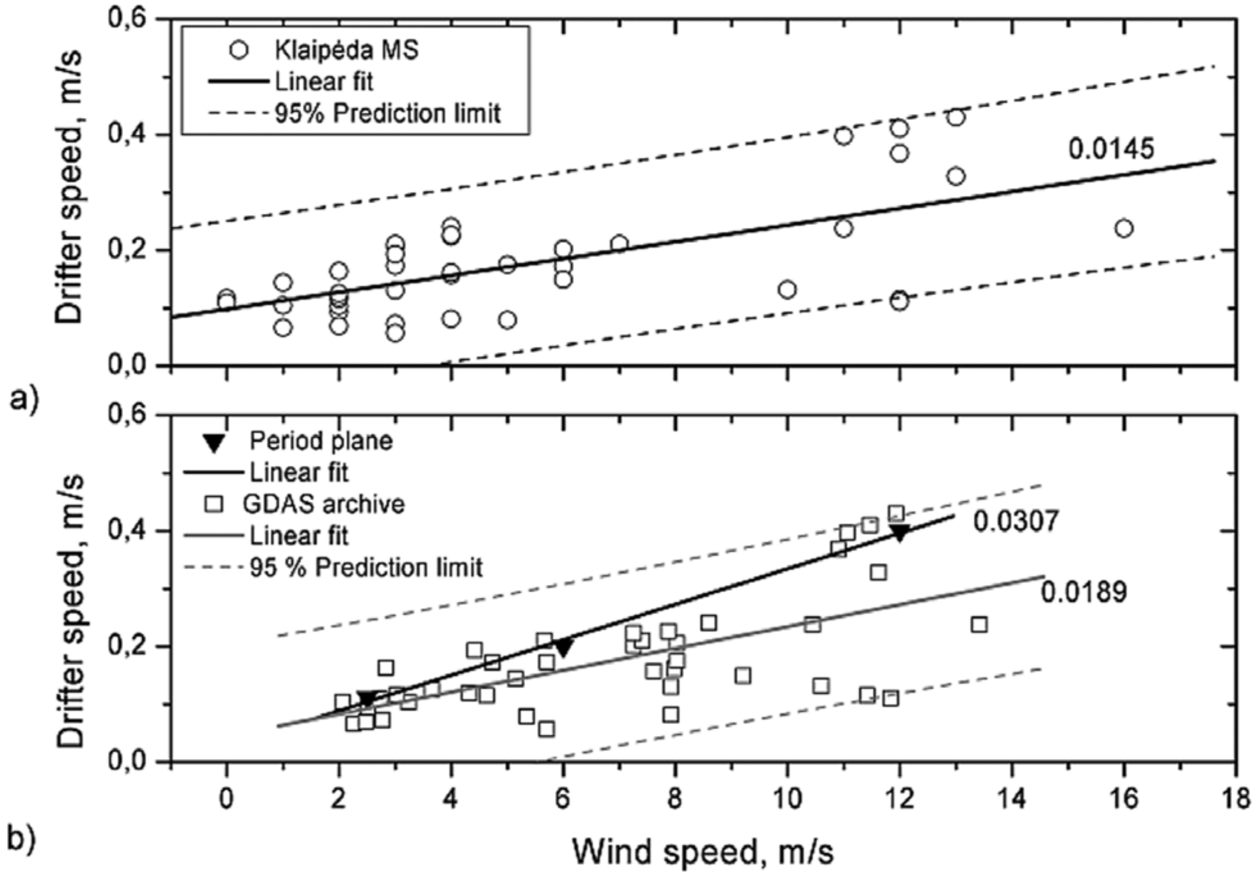

Fig. 3 Correlation between drifter and wind speed for the period of 22–30 November. The source of wind data: ***a)*** Klaipėda MS, ***b)*** GDAS archive. Compiled by L. Davulienė and L. Kelpšaitė.

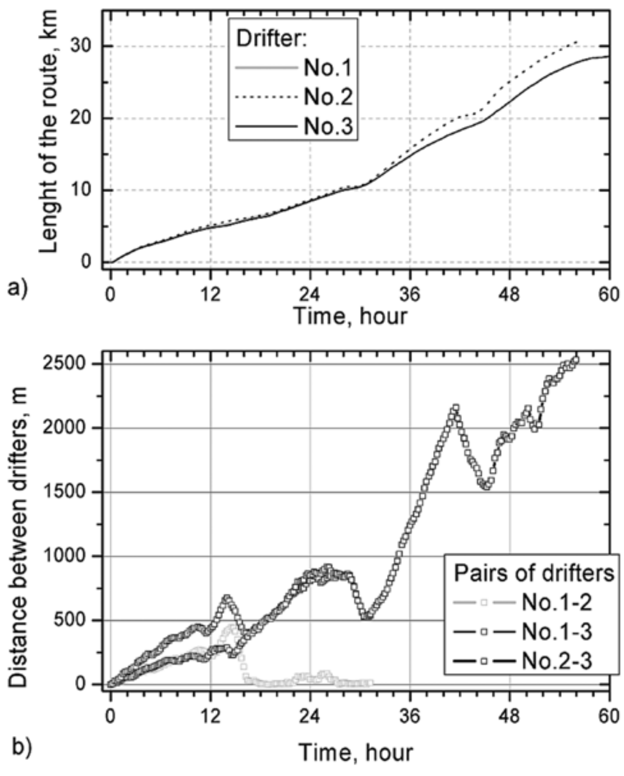

Fig. 4 The lengths of the drifting routes for the first 60 hours: ***a)*** the length in time, ***b)*** the variations of the distance between the pairs of drifters. Compiled by L. Davulienė and V. Žąsytis.

the drifter No. 1 was lost (see Fig. 4b). The distance between drifters Nos. 2 and 3 increased to more than 2500 m in about 56 hours from the start of the experiment, i.e. spreading rate was about 45 m/h. During this time, the drifters covered the distance of about 30 km.

The change in spreading rate with distance between drifters was analysed in more detail for the pair of drifters Nos. 2 and 3. The spreading rate was calculated as a velocity of the change in distance between drifters. In our experiment, the obtained spreading rates were positive as well as negative. Negative values were obtained mostly for the periods where changes in the drifting direction were observed (see Fig. 1). Negative values were excluded from further analysis. Only slight increase of the spreading rate with the distance between drifters was obtained: the correlation coefficient *(R),* was about 0.5 (Fig. 5). The maximum spreading rate value of about 470 m/h was reached for the drifters separated by more than 2 km. In addition, no correlation between spreading velocity and distance between drifters was found for hourly mean spreading rate data set (*R* was about 0.4). However, in general, it could be noticed that the range of the spreading rate values was increasing with the growing distance between drifters.

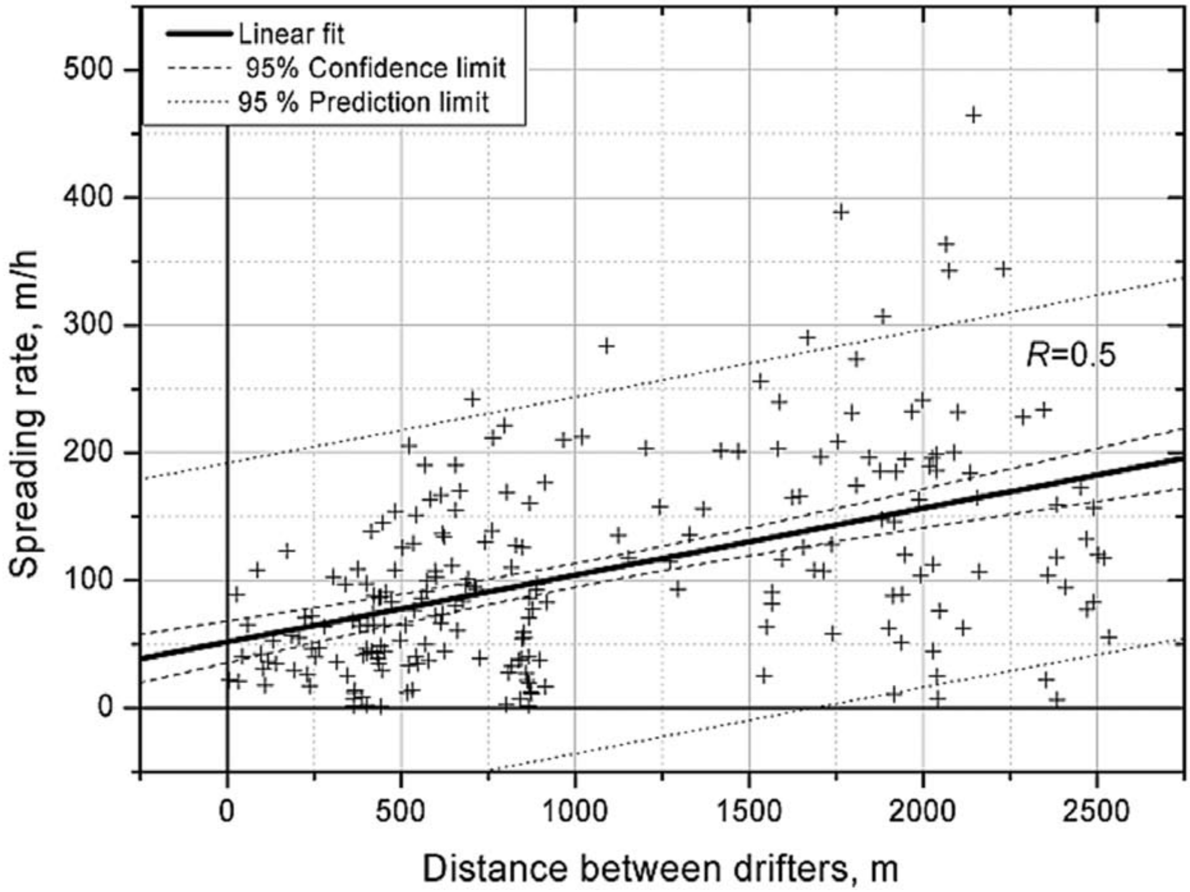

Fig. 5 Spreading rate dependence on the distance between drifters. Compiled by L. Davulienė.

DISCUSSION

The analysis of the relation between wind and drifting speed basing on the experimental data was carried out. The regression coefficient calculated from the whole set of experimental data was about 0.014–0.019 (for the different sources of wind data), and the coefficient calculated from three periods mean data about 0.031. This is due to the inertia of the moving water masses. The direction and speed of the water currents reacts to the changes in the wind direction with a particular delay. Along with the advection and wind drag the drifting path could, in general, also be affected by the Stokes drift, turbulence. The obtained coefficient value of 0.031 is higher than the theoretical value of 0.025 calculated by Soomere *et al.* (2011), however, it might better represent the stationary case when all acting forces are balanced and the drifting speed is relatively stable. On contrary, the lower value of the relation coefficient of 0.014 obtained in the study comprises the whole period of the experiment, i.e. the transient periods are also included. Therefore, this value could hardly be compared with the theoretical value of 0.025.

The drifting experiments where pairs or triplets of drifters are involved enable the drifter dispersion analysis (Kjellsson, Döös 2012; Soomere *et al.* 2011; Vandenbulcke *et al.* 2009). Horizontal spreading is the result of horizontal current shears (on various spatial and temporal scales) (Liungman, Mattsson 2011). The spreading rate represents the velocity of the increase in the distance between the drifters analysed as a pair. This rate is not constant and can be approximated by a power function or an exponential law of the time elapsed from the release of the particles (Richardson 1926; Soomere *et al.* 2011). The analysis revealed weak or no correlation between spreading velocity and distance between drifters was found. However, it also should be noted that in order to characterise the spreading processes in Lithuanian marine waters with greater statistical accuracy more experimental data of drifting pairs should be collected.

The increase in spreading rate for the pairs of drifters was analysed. The dynamics of the distance between drifters represented on a log-log scale could indicate the type of turbulence influencing the motion. The regression coefficient *(b),* has value of 1.5 for the 3D local scale turbulence, according to the Richardson low, and is growing to infinity in case of 2D turbulence characteristic of large-scale motions (Richardson 1926; Lumpkin 2003; Soomere *et al.* 2011). The analysis of the dependence of the distance on the drift

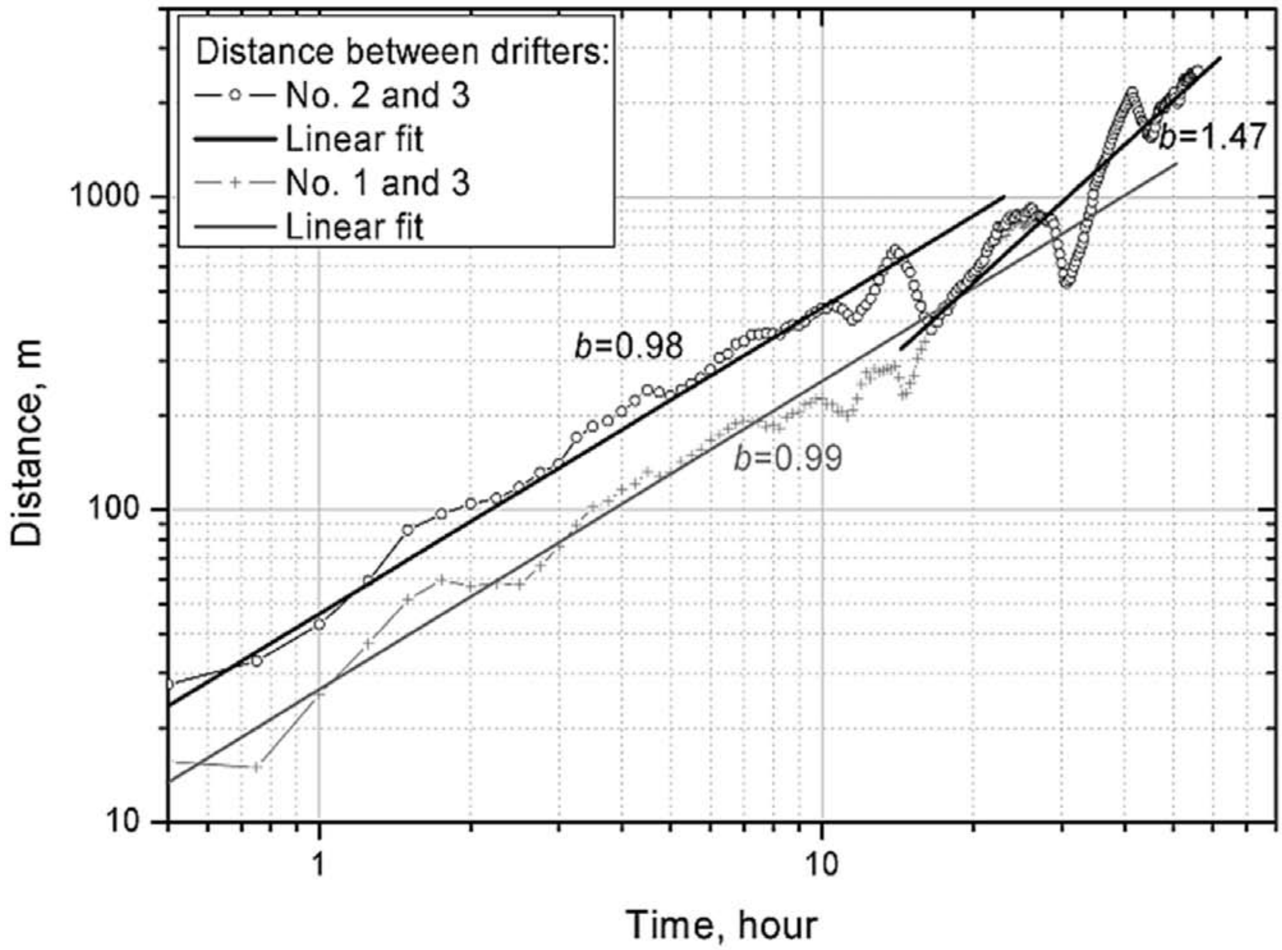

Fig. 6 Time dependence of the distance between pairs of drifters in log-log scale. Compiled by L. Davulienė.

time showed a linear growth with the regression coefficient close to $b \approx 1$ (Fig. 6). However, for relatively large separations, more than 300 m after 15 hours of drifting, the increase in growth of the distance between drifters with time could be indicated. When distance between the drifters reached 400–700 m, i.e. a certain threshold value, the regression coefficient for the time interval of 15–70 hour reached the value of about 1.5 characteristic of 3D turbulent motion.

The analysis of the time dependence of the distance between drifters in log-log scale revealed a certain threshold that is important for the numerical modelling of the hydrodynamic processes. The parameterisation of the sub-grid processes should depend on the size of the horizontal grid of the model, i.e. should depend also on this threshold defining the distance between drifters where transition to 3D turbulence occurs. However, from the available measurement data the exact value of the threshold is hard to define (400–700 m) due to relatively short time series available for analysis of the pair drifting (56 hours) (see Fig. 6). For this type of analysis, the long-time series of measurement are preferred in order to get the larger set of data representing this transition from one type of dispersion to another at the certain threshold value of the distance between the drifters. However, our area of study is close to the coast and the risk for the drifters of running aground is quite high and depends on the length of the period of time the drifter stays in the sea. Therefore, one of the possibilities to shorten the length of the period could be to start the pair drifting experiment from distant starting positions.

CONCLUSIONS

The analysis of the measured wind data available for the period of the experiment revealed the inconsistencies in wind speed data. The quality of wind data is important not only for the analysis of the data of the drift experiment. It is a crucial requirement for the Lagrangian drifting models. Therefore, along with measured wind data other sources of wind data such as local meteorological models should also be considered.

During the period of experiment, 22–30 November 2013, the drifting direction has changed about five times by more than 90º mainly due to changes in the mean wind direction. The direction of drifter movement has fluctuated by about ±90° compared to wind direction. Relatively weak correlation with the correlation coefficient of about 0.65 between the 3-hour mean wind and drifter speed indicates that also other factors, e.g. geostrophic currents, Stockes drift and turbulence, should be taken into consideration.

The analysis of the drifting and wind direction showed that the drift directions during the experiment were changing from parallel to perpendicular and the drifting direction followed the wind direction with the certain delay up to 12 hours. The analysis of relation between the mean wind speed and the mean drift speed for these periods has given the regression coefficient of 0.031. This coefficient enables the approximate evaluation of the mean drift speed when the wind speed is known.

In our experiment, only slight statistically significant increase (correlation coefficient 0.5) in spreading rate with the distance between the drifters was found. Basing on the log-log analysis of the increase in distance between drifters, the threshold of transition to the 3D turbulent motion was found at about 400–700 m distance between drifters.

ACKNOWLEDGMENTS

The authors are grateful to reviewers Dr. Jūratė Kriaučiūnienė (Kaunas) and Dr. Boris Chubarenko (Kaliningrad) for their valuable comments that allowed to improve the quality of the manuscript. Authors would also like to acknowledge Virginijus Žąsytis for the valuable work on the field experiment.

REFERENCES

Abbott, M. R,. Brink, K. H., Booth, C. R., Blasco, D., Codispoti, L. A., Niiler, P. P., Ramp, S. R., 1990. Observations of phytoplankton and nutrients from a Lagrangian drifter off northern California. *Journal of Geophysical Research-Oceans 95 (C6)*, 9393–9409.

Booth, D. A., Meldrum, D. T., 1987. Drifting buoys in the Northeast Atlantic. *ICES Journal of Marine Science 43 (3)*, 261–267.

Bograd, S. J., Thomson, R. E., Rabinovich, A. B., LeBlond, P. H., 1999. Near-surface circulation of the northeast Pacific Ocean derived from WOCE-SVP satellite-tracked drifters. *Deep Sea Research Part II 46 (11–12)*, 2371–2403.

Dailidienė, I., Davulienė, L., Tilickis, B., Stankevičius, A., Myrberg, K., 2006. Sea level variability at the Lithuanian coast of the Baltic Sea. *Boreal Environment Research 11,* 109–121.

Dailidienė, I., Davulienė, L., Kelpšaitė, L., Razinkovas, A., 2012. Analysis of the climate change in Lithuanian coastal areas of the Baltic Sea. *Journal of Coastal Research 28*, 557–569.

Davulienė, L., Trinkūnas, G., 2004. Circulation dynamics in the Curonian Lagoon waters of Lithuania. *Lithuanian Journal of Physics 44*, 67–73.

Gästgifvars, M., Lauri, H., Sarkanen, A. K., Myrberg, K., Andrejev, O., Ambjörn, C., 2006. Modelling surface drifting of buoys during a rapidly-moving weather front in the Gulf of Finland, Baltic Sea. *Estuarine, Coastal and Shelf Science 70*, 567–576.

HELCOM, 2010. Maritime Activities in the Baltic Sea – An integrated thematic assessment on maritime activities and response to pollution at sea in the Baltic Sea Region. *Baltic Sea Environment Proceedings 123. Source: http://www.helcom.fi/Lists/Publications/BSEP123.pdf*

Kjellsson, J., Döös, K., 2012. Surface drifters and model trajectories in the Baltic Sea, *Boreal Environment Research 17*, 447–459.

König, P., Schrum, C., 1997. Hydrodynamic observations and model results from PRISMA drift experiment. *Marine Ecology Progress Series 156*, 225–261.

Kozlov, I. E., Dailidienė, I., Korosov, A., Klemas, V., Mingėlaitė, T., 2012. MODIS-based sea surface temperature of the Baltic Sea Curonian Lagoon. *Journal of Marine Systems 129,* 157–165.

Kozlov, I. E., Kudryavtsev, V. N., Johannessen, J. A., Chapron, B., Dailidienė, I., Myasoedov, A. G., 2012. ASAR imaging for coastal upwelling in the Baltic Sea. *Advances in Space Research 50 (8)*, 1125–1137.

Lepparanta, M., Myrberg, K., 2009. *Physical Oceanography of the Baltic Sea*. Springer, 408 pp.

Liungman, O., Mattsson, J., 2011. Scientific Documentation of Seatrack Web: physical processes, algorithms and references. *Source*: *https://stw-helcom.smhi.se/*

Loncar, G., Leder, N., Paladin, M., 2012. Numerical modelling of an oil spill in the northern Adriatic. *Oceanologia 54 (2)*, 143–173.

Lumpkin, R., 2003. Decomposition of surface drifter observations in the Atlantic Ocean. *Geophysical Research Letters 30 (14)*, 1753–1770.

Lumpkin, R., Elipot S., 2010. Surface drifter pair spreading in the North Atlantic. *Journal of Geophysical Research 115*, C12017.

Lumpkin, R., Pazos, M., 2006: Measuring surface currents with Surface Velocity Program drifters: the instrument, its data, and some recent results. *In* A. Griffa, A. D. Kirwan, A. J. Mariano, T. Ozgokmen, T. Rossby (eds), Lagrangian Analysis and Prediction of Coastal and Ocean Dynamics, 39–67.

Niiler, P. P., 2001. The world ocean surface circulation. *In* Ocean Circulation and Climate, G. Siedler, J. Church, J. Gould (eds), *International Geophysics Series 77*, Academic Press, 193–204.

Richardson, L., 1926. Atmospheric diffusion shown on a distance-neighbour graph. *Proceedings of the Royal Society of London A 110*, 709–737.

Soomere, T., Viidebaum, M., Kalda, J., 2011. On dispersion properties of surfacemotions in the Gulf of Finland. *Proceedings of the Estonian Academy of Sciences 60 (4)*, 269–279.

Vandenbulcke, L., Beckers, J. M., Lenartz, F., Barth, A., Poulain, P. M., Aidonidis, M., Meyrat, J., Ardhuin, F., Tonani, M., Fratianni, C. *et al.,* 2009. Super-ensemble techniques: Application to surface drift prediction. *Progress in Oceanography 82*, 149–167.

Zemlys, P., Dailidienė, I., Zaboras, J., 2013. An operational model for Lithuania's coastal zone. *Baltica 26 (1)*, 115–120.

Žilinskas, G., 1997. Baltijos jūros Lietuvos kranto ilgis bei jo nustatymo problemos [Problems of length test of the Lithuanian shore of the Baltic Sea]. *Geografijos metraštis 30,* 63–71. [In Lithuanian].