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THE INFLUENCE OF CURRENTS ON POSSIBLE DISPERSION OF OIL PRODUCTS IN THE SOUTH-EAST BALTIC

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Abstract. Frequent spills of oil products represent one of the most urgent ecological problems of the Baltic Sea. Oil products are most widespread and rather dangerous pollutants of seas and oceans. Oil pollutants are especially dangerous to the Baltic Sea ecosystem where processes of self-cleaning are slower than in warmer waters. The aim of the present work was to analyse possible dispersion patterns of oil products in the South-East Baltic near the Lithuanian coastline based on the measurement data on currents in the Baltic Sea. Data on the direction of currents and wind, as well as on water surface and air temperatures, provided by oceanographic and hydrometeorological stations were used in this work.
Key words: Baltic Sea, oil pollutants, ecological problems, marine currents

Introduction

The Lithuanian economic zone of the Baltic Sea is surrounded by economic objects, the activity of which is related to oil products as potential pollutants of the marine environment. The Būtingė Oil Terminal is situated in its northern part, the specialized terminal for liquid oil products of Klaipėda Port is located in the central part and oil platform D-6 is in Russian territorial waters (Kravtsovskoje) 6 km from the Russian–Lithuanian border (Fig. 1).

Frequent spills of oil products represent one of the most urgent ecological problems of the Baltic Sea. Oil products are most widespread and rather dangerous pollutants of seas and oceans. They get into water basins with river water, rainwater flows, industrial and domestic waste or during accidents related to oil recovery and transportation (oil tankers or platforms extracting oil in the sea shelf).

Accidents during oil transportation, extraction or pumping may inflict considerable damage to marine ecosystems. Oil pollutants are especially dangerous to the Baltic Sea ecosystem where processes of self-cleaning are slower than in warmer waters. Laboratory and field investigations showed that oil products on the bottom and water surface are very unfriendly to vegetation, fish, small fry, wildfowl and animals (Wirdheim 1992; Bubinas & Vaitonis 2003; Kazlauskienė *et al*. 2003; Zolubas 2003). Due to polluted seawater, bottom and beaches, fauna representatives migrate from their habitats or are threatened to become extinct. Dispersion and migration of oil products in water and their effects on marine ecosystems are urgent problems in many coastal countries (Nelson-Smith 1972; Pustelnikov & Nesterova 1984; Orlenok *et al*. 2004; COS 2003). Recently, these problems have also become relevant to Lithuania due to the intentions of the Russian oil company ‘Lukoil’ to start exploitation of oil deposit D-6 and due to increasing oil export and import through the Klaipėda and Būtingė Oil Terminals. One can mention the accidental oil spill of 16,493 tons of the tanker ‘Globe Asimi’ near Klaipėda Port in 1981, while smaller oil spills are reported at the Būtingė Oil Terminal every year. In order to avoid ecological disasters, it is necessary to be ready to combat the consequences of possible oil spills. In the case of ecological disaster, we must know possible patterns of oil dispersion in the waters of the Lithuanian economic zone.

The aim of the present work was to analyse possible dispersion patterns of oil products in the South-East Baltic near the Lithuanian coastline based on the measurement data on currents in the Baltic Sea.

Material and methods

The work was based on the measurement data on the direction of currents and wind, as well as on water and air temperatures, provided by oceanographic and hydrometeorological stations (Fig. 1). Current direc-

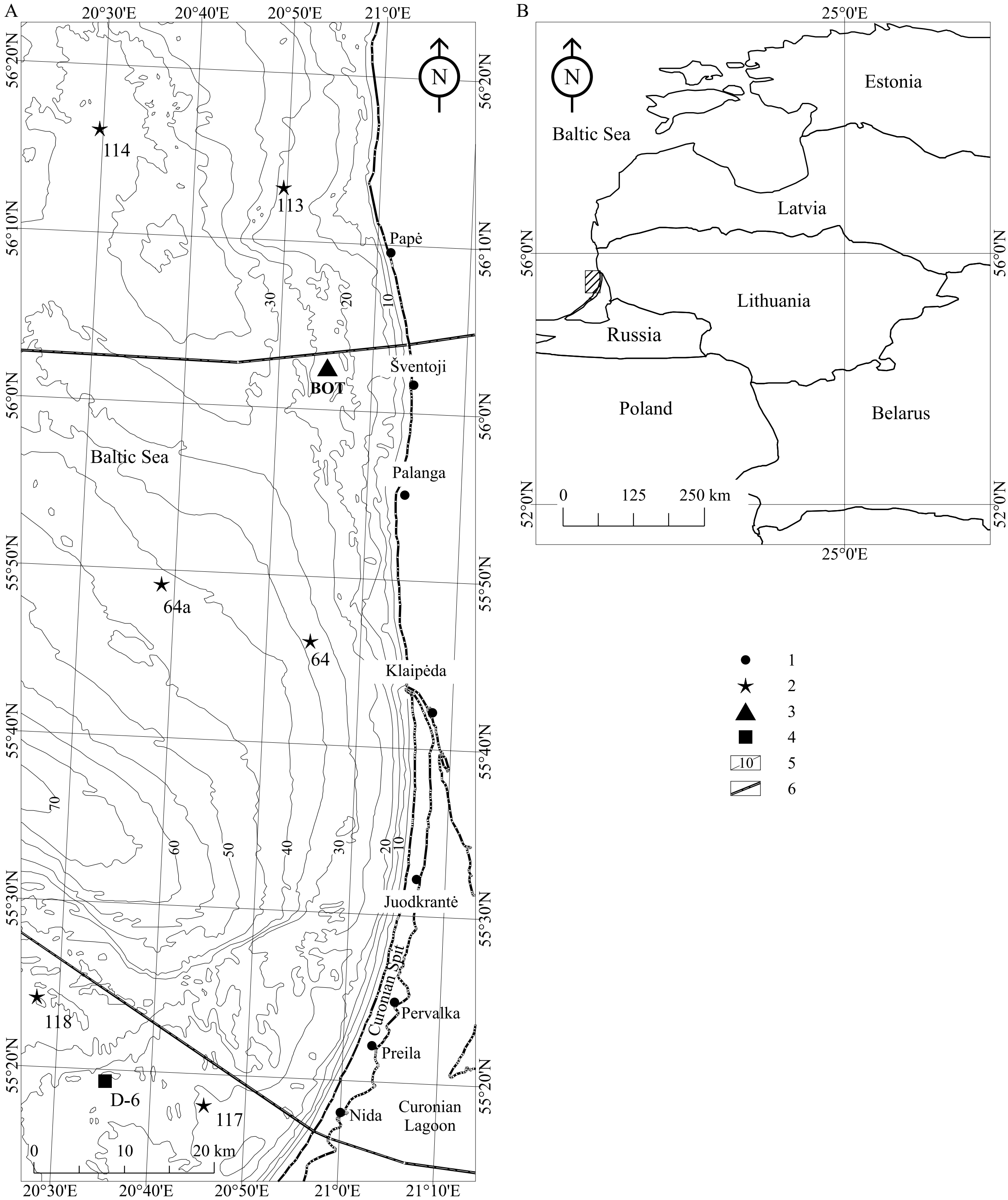

Figure 1. The map of the study area: 1 – settlement, 2 – oceanographic station, 3 – Būtingė Oil Terminal (BOT), 4 – Kravtsovskoje oil platform (D-6), 5 – isobaths, 6 – national border.

tions were measured at the 40-m isobath in six oceanographic stations: two of the stations are located in Lithuanian (64 and 64a), two in Latvian (113 and 114) and two in Russian Exclusive Economic Zone (EEZ) (117 and 118). Measurements were carried out in 1950–1970 by the Leningrad Department of the State Institute of the USSR and the Klaipėda Hydrometeorological Observatory (at present Centre of Marine

Research of Klaipėda). The measurements at all oceanographic stations were performed using automatic Aleksejev's mills BPV-2 and marine modernised mills VMM. All investigations were carried out following the methods of oceanographic measuring (Morozov 1971). More information about the studies of currents in the Baltic Sea can be found in the works published by Lithuanian and Russian authors (Dubra 1970, 2003; Dubra & Dubra 1994, 1998; Galkus 2003; Žaromskis & Pupienis 2003).

Data on the Baltic Sea surface temperature (SST) were obtained from the International Council for the Exploration of the Sea (ICES), whereas data on air temperature at the Klaipėda Coastal Meteorological Station were taken from the archive of the Lithuanian Hydrometeorological Service for the periods 1950–1970 and 1990–2005. Long-term atmospheric circulation was evaluated using data on the atmospheric pressure at sea level in 1950–1970 and 1990–2005 obtained from the reanalysis database (at latitude 2.5° and longitude 2.5°) of the NOAA-CIRES (National Oceanic & Atmospheric Administration – Cooperative Institute for Research in Environmental Sciences) Climate Diagnostic Centre (CDC).

In order to compare different time periods and to identify the contemporariness of data sets, correlation analysis was performed between the Baltic SST and air temperature at the Klaipėda Station for the periods 1950–1970 and 1990–2005 (Fig. 2). Furthermore, monthly means of the Baltic SST and Klaipėda air temperature during the two periods were compared to identify cold and warm seasons (Fig. 3). The mean sea level pressure (SLP) over Europe during cold (November–April) and warm (May–October) seasons of the two periods was analysed to determine changes in meteorological properties of the Baltic region. The Baltic SST falls below 10°C from November (December) to April (May) and rises above 10°C during the rest of the year (Vyšniauskas & Lesys 1998). A more detailed study on the Baltic SST was carried out at the Centre of Marine Research (Vyšniauskas 2003).

Taking into account that water and air temperatures vary beyond the limit of 10°C twice a year (in May and October), the variation pattern of currents was defined for the warm (May–October) and cold (November–April) season. Oil products are classified into heavy (crude oil) and light (naphtha, petrol and fuel oil) ones. Oil in water can be present in different forms: a slick on the water surface, granules of a different size, water-oil emulsions (water-in-oil or oil-in-water) and colloidal solutions (Pustelnikov & Nesterova 1984; COS 2003). Based on previously reported data, it was determined that the state and dispersion of oil depend on water and air temperatures. When water and air temperatures are above 10°C, the dispersion rates of oil spills on the water surface are higher, whereas at temperatures below 10°C the physical and chemical properties of oil begin to change (Lehtinen 1981; COS 2003).

Results

Comparison of mean SLP patterns during cold and warm seasons of the periods 1950–1970 and 1990–2005 showed only small changes in the SLP field over the Baltic region (Figs 4, 5). Similar changes were also observed in the wind field (not shown). This indicated more or less identical meteorological conditions of the compared periods.

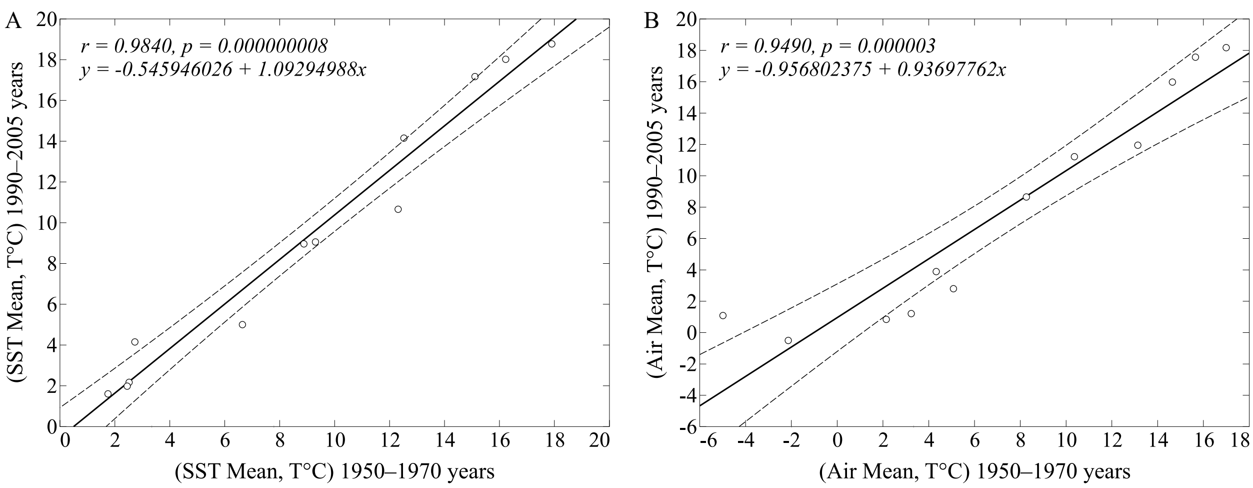

Figure 2. Relation between the periods 1950–1970 and 1990–2005: A) SST, B) air temperature.

During the warm season (May–October), the circulation pattern of the Euro-Atlantic domain is mostly generated by the ridge of the anticyclone extending east of the Azores. It forms a low-gradient field of atmospheric pressure (Fig. 4) and dominant westerly winds in the Lithuanian coastal zone. According to the data of the Klaipėda Coastal Meteorological Station, westerly and north-westerly winds (19.0% and 17.2% of cases, respectively) dominate during the warm season. This creates favourable conditions for the formation of the cyclonic system of surface currents near the Lithuanian coast (Žaromskis 1996).

One of the main indicators for the determination of wind direction and speed is SLP, which is often used in the climate research activities (Bukantis 1994). During the cold season (November–April), when westerly and south-westerly winds (Fig. 3) are dominant over the larger part of the Euro-Atlantic domain and the continental part of the Lithuanian territory (Fig. 5), local south-easterly winds blowing from the cooler land to the warmer sea are dominant in the coastal zone (LHMS 1996). South-easterly winds account for 22.7% and easterly winds for 14% of the total of winds recorded at the Klaipėda Meteorological Station.

Based on measurement results, current directions were classified into eight groups. Frequency of currents was calculated for each station distinguishing warm (Table 1) and cold (Table 2) seasons and three horizons (surface, 5 m and near-bottom). Uneven seasonal distribution was observed in the frequency pattern of currents and horizons. This means that under different hydrometeorological conditions the migra-

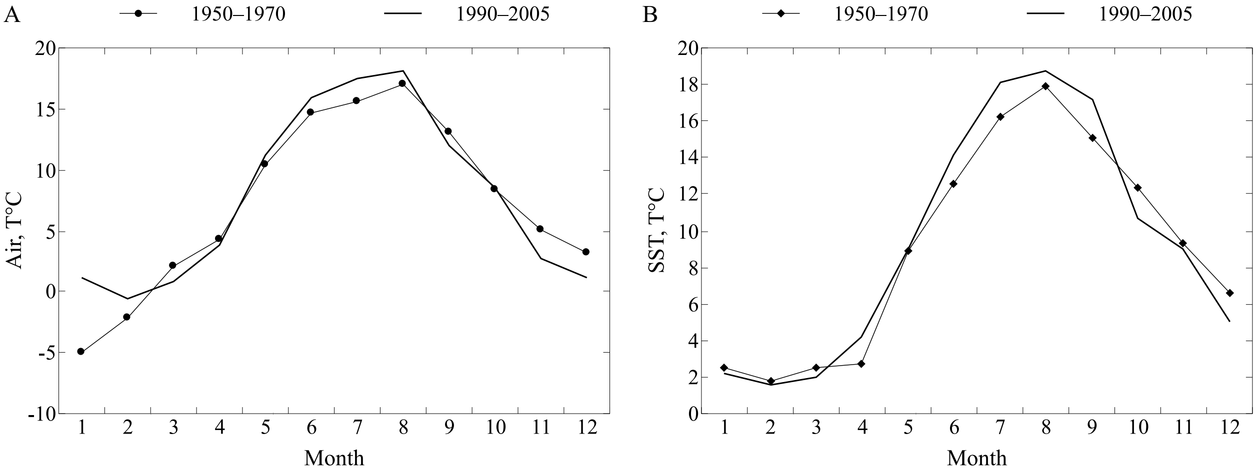

Figure 3. Time series of the periods 1950–1970 and 1990–2005: A) air temperature, B) SST.

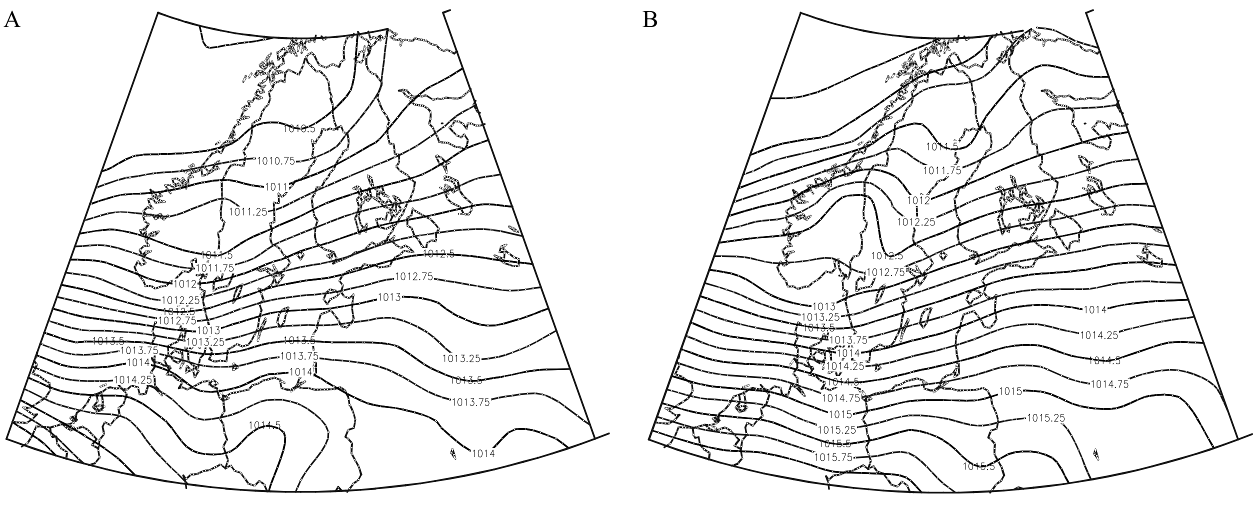

Figure 4. The mean sea level pressure during the warm season: A) 1950–1970, B) 1990–2005 (NOAA/CIRES Climate Diagnostic Centre).

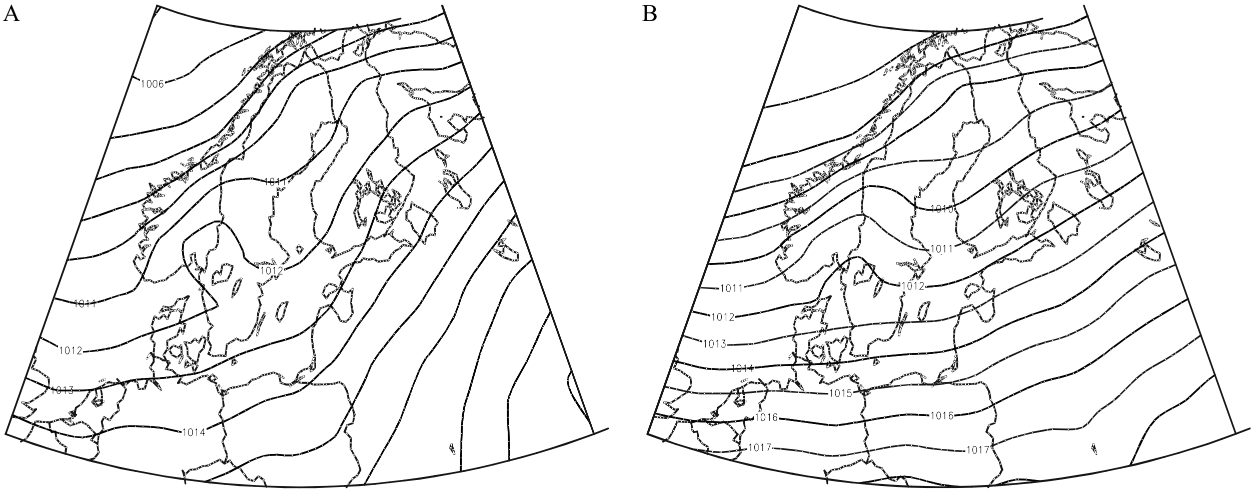

Figure 5. The mean sea level pressure during the cold season: A) 1950–1970, B) 1990–2005 (NOAA/CIRES Climate Diagnostic Centre).

Table 1. The frequency of the Baltic Sea current directions during the warm season.

Layer	Station	Current direction frequency, %							
		N	NE	E	SE	S	SW	W	NW
Surface	113	33.3	27.8	5.6	5.6	5.6	5.6	5.6	11.1
	114	14.3	28.6	7.1	28.6	7.1	0.0	0.0	14.3
	64	10.6	9.1	18.2	15.2	16.7	9.1	13.6	7.6
	64a	17.2	3.4	24.1	13.8	10.3	10.3	13.8	6.9
	117	14.3	28.6	7.1	14.3	14.3	7.1	7.1	7.1
	118	12.1	21.2	15.2	9.1	15.2	12.1	0.0	15.2
5 m	113	13.3	33.3	6.7	6.7	13.3	6.7	0.0	20.0
	114	20.0	6.7	26.7	6.7	6.7	13.3	13.3	6.7
	64	11.8	10.3	2.9	25.0	20.6	13.2	5.9	10.3
	64a	19.4	9.7	0.0	0.0	25.8	16.1	19.4	9.7
	117	0.0	6.3	12.5	12.5	12.5	18.8	12.5	25.0
	118	22.2	16.7	5.6	22.2	11.1	11.1	5.6	5.6
Near-bottom	113	23.5	5.9	0.0	11.8	5.9	11.8	29.4	11.8
	114	20.0	13.3	13.3	0.0	13.3	13.3	6.7	20.0
	64	18.9	9.4	3.8	11.3	18.9	11.3	9.4	17.0
	64a	16.1	9.7	3.2	12.9	19.4	6.5	9.7	22.6
	117	21.4	7.1	14.3	7.1	0.0	35.7	0.0	14.3
	118	16.7	22.2	11.1	11.1	5.6	5.6	16.7	11.1

tion of oil products in the Baltic Sea may follow a specific pattern.

In the warm season, current systems of different directions form in the water surface layer of the studied area (Fig. 6B). Closer to the shore, in the northern part, currents up to the 15-m isobath are directed N (33.3%), whereas dominant currents between the 15- and 30-m isobaths are directed NE and SE (28.6% each). Currents up to the 37-m isobath in the central part of the area near the Klaipėda Strait (st. 64 and 64a) are directed E. The frequency of the currents in these stations varies from 18.2 to 24.1%. Up to the 38-m isobath, in the southern part of the area, where measuring stations are located at oil platform D-6, currents are directed NE. The frequency of NE currents varies from 21.2 to 28.6% in stations 117 and 118, respectively.

In the cold season, the distribution pattern of current

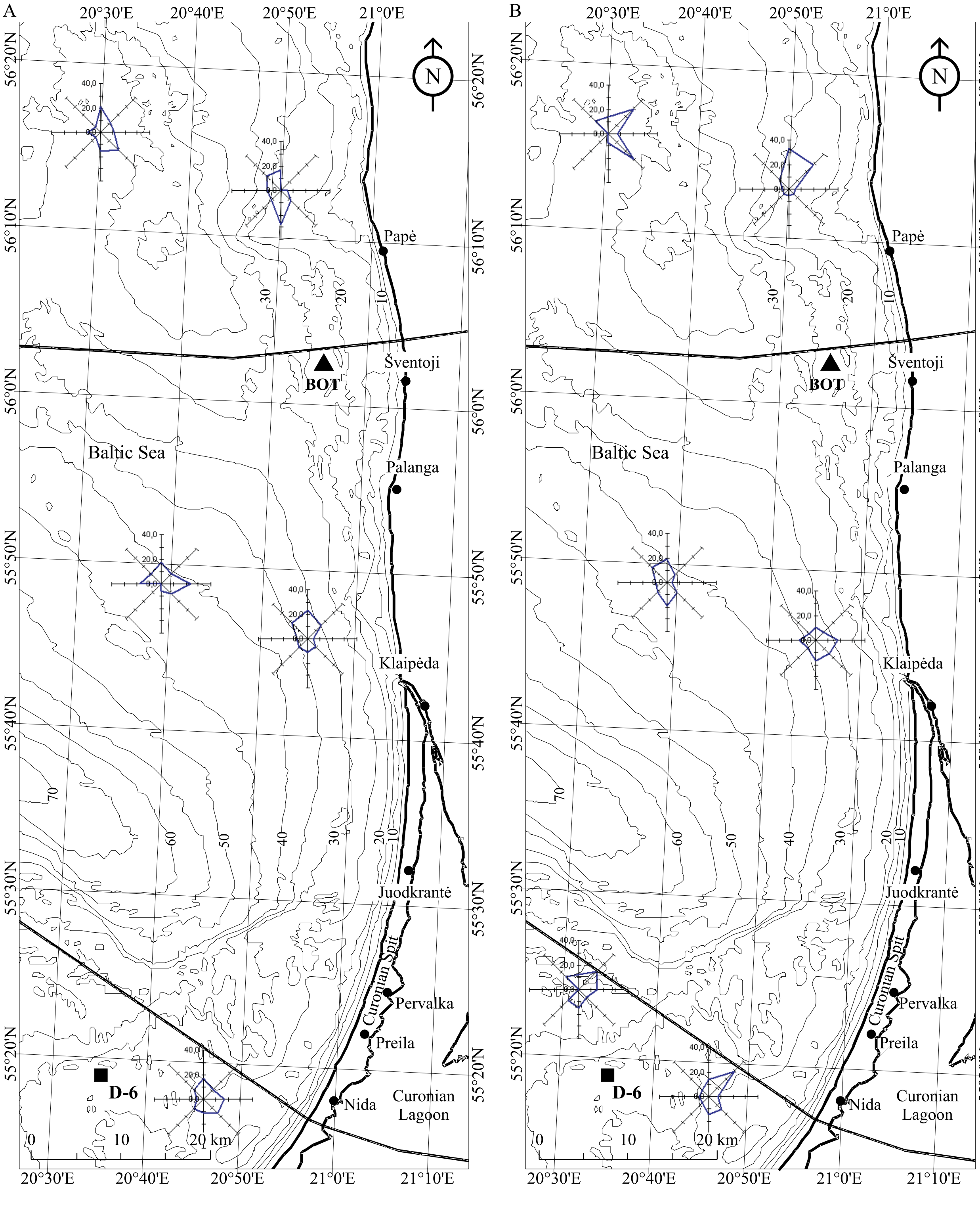

Figure 6. Surface current direction frequency (%) for the Baltic Sea: A) warm season, B) cold season.

directions becomes even more complicated. This can be explained by a more frequent recurrence of storms. The probability of ecological disasters becomes greater. In the northern part of the area (Būtingė Oil Terminal), currents are directed S (27.8%) and SE (21.1%) (st. 113 and 114) (Fig. 6A), whereas in the central part, near the Klaipėda Strait, N (23.7%) and E (23.5%) currents are dominant (st. 64 and 64a). The dominant direction

Table 2. The frequency of the Baltic Sea current directions during the cold season.

Layer	Station	Current direction frequency, %							
		N	NE	E	SE	S	SW	W	NW
Surface	113	16.7	0.0	5.6	11.1	27.8	11.1	11.1	16.7
	114	21.1	10.5	10.5	21.1	15.8	5.3	10.5	5.3
	64	23.7	16.1	4.3	8.6	10.8	9.7	8.6	18.3
	64a	17.6	11.8	23.5	11.8	5.9	0.0	17.6	11.8
	117	16.7	11.1	16.7	16.7	11.1	11.1	5.6	11.1
	118	11.1	22.2	11.1	11.1	11.1	16.7	0.0	16.7
5 m	113	31.6	0.0	5.3	5.3	31.6	5.3	15.8	5.3
	114	27.8	0.0	11.1	16.7	22.2	5.6	5.6	11.1
	64	24.7	9.0	15.7	12.4	12.4	11.2	4.5	10.1
	64a	13.3	13.3	13.3	20.0	6.7	6.7	6.7	20.0
	117	20.0	13.3	6.7	20.0	6.7	13.3	0.0	20.0
	118	26.7	6.7	26.7	20.0	0.0	0.0	6.7	13.3
Near-bottom	113	20.0	5.0	0.0	15.0	30.0	15.0	10.0	5.0
	114	10.0	5.0	15.0	15.0	20.0	10.0	10.0	15.0
	64	20.7	14.1	9.8	20.7	8.7	4.3	5.4	16.3
	64a	20.0	6.7	6.7	20.0	26.7	6.7	6.7	6.7
	117	31.3	6.3	12.5	6.3	12.5	0.0	6.3	25.0
	118	0.0	20.0	13.3	6.7	0.0	6.7	33.3	20.0

of N currents in this zone was caused by the wreck of the tanker ‘Globe Assimi’ on 21 November 1981, when spilled oil spread in the area between Klaipėda and Šventoji (Pustelnikov & Nesterova 1984; Dubra & Dubra 1998). In the southern part of the area (platform D-6), surface currents are directed NE (22.2%), and N and E (16.7%) in warm and cold seasons.

Comparison of data revealed that at a depth of 5 m the direction of currents in many stations was different from that in the surface horizon in cold (Fig. 7A) and warm seasons (Fig. 7B). Dominant currents in the surface layer were directed N, NE, E, SE and S, whereas at a depth of 5 m a westward flow formed, which is rather rare in the surface layer.

In the warm season, currents in the near-bottom water horizon (st. 113 and 114) are directed W (29.4%), and N and NW (20.0%) (Fig. 8B). This means that the water flow in this horizon is affected by relief properties rather than by wind strength and direction. The uneven distribution and great variety of current directions may be partly determined by the sophisticated relief of the Klaipėda–Ventspils plateau. The dependence of current directions on the bottom relief is demonstrated by N, S (18.9%) and N, SW (19.4%) currents at Klaipėda (st. 64 and 64a), where they are parallel to isobaths. In the northern part of the area, current directions are influenced by the complicated relief of the Sambian-Curonian plateau. Up to a depth of 25 m, in station 117, currents are directed SW (35.7%), whereas between the 25- and 38-m isobaths, they flow in the opposite NE (22.2%) direction (st. 118).

In the cold season, southerly currents are dominant in the near-bottom horizon in the northern part of the area (30.0 and 20.0% in stations 113 and 114, respectively). Near Klaipėda, the dominant currents are directed N, SE (20.0%) and S (26.7%) (st. 64 and 64a) (Fig. 8A). In the southern part, the dominant currents are directed N (31.3%) and W (33.3%) (st. 117 and 118). The results show that oil products settled on the bottom in most cases are transported into the open sea.

Discussion

Atmospheric circulation, particularly in mid-latitudes, is the main control behind regional changes in temperature, precipitation and other climatic variables (Parker *et al.* 1994; Hurrell & van Loon, 1997; Slonosky 1999; Slonosky *et al.* 2000). Wind, depending on the general pattern of atmospheric circulation and local features of the water surface area and the adjacent land, is one of the main factors determining oil migration in the sea. The atmospheric circulation pattern in the Euro-Atlantic sector is formed by three

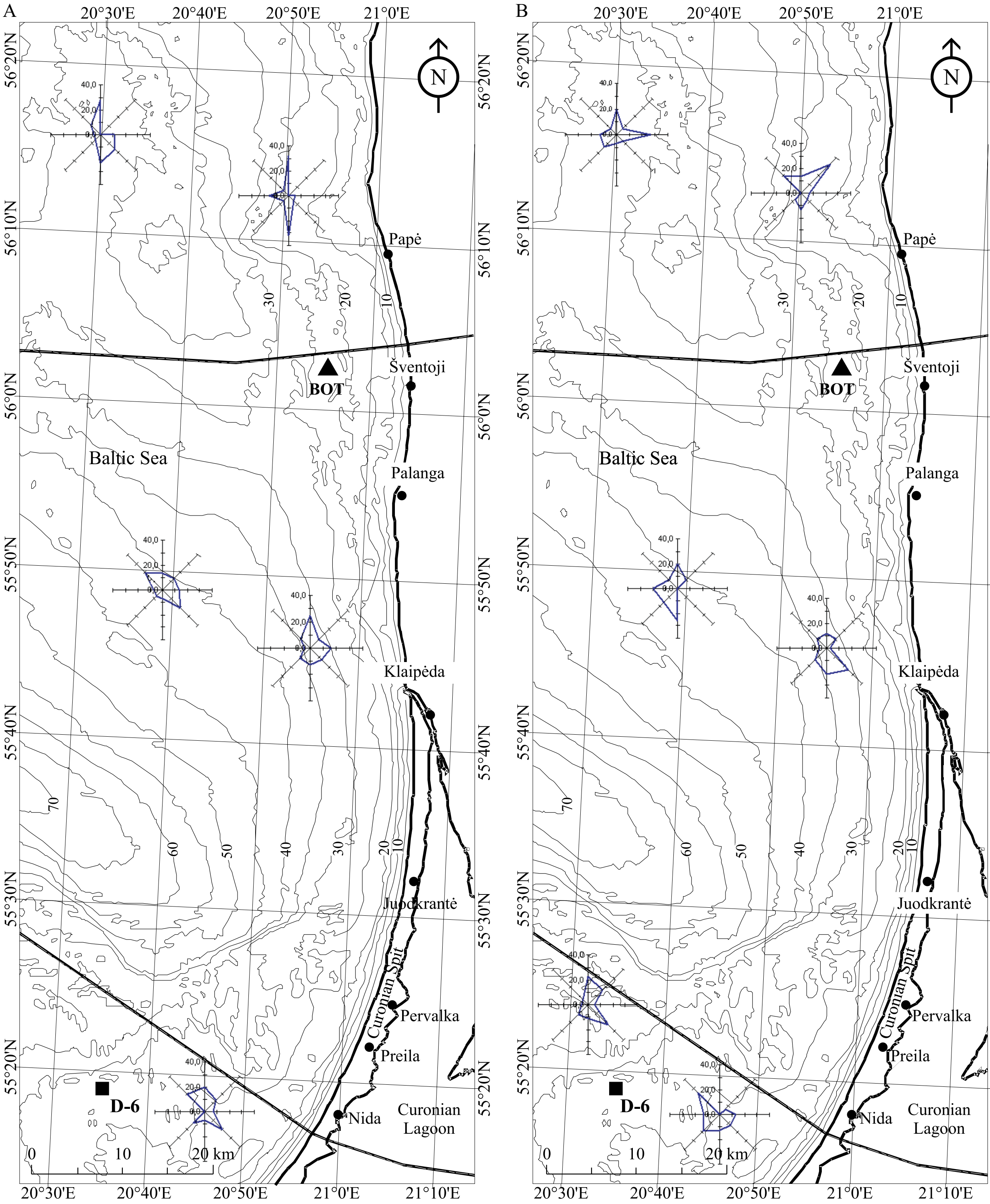

Figure 7. 5 m-layer current direction frequency (%) for the Baltic Sea: A) warm season, B) cold season.

climatic pressure centres: low-pressure North Atlantic (Iceland) domain, Azorean anticyclones and the western ridge of the Asian anticyclone (Bukantis 1994). The distribution and activity variations of these formations influence the wind regime in the studied aquatic area. Scientists distinguish a few types of atmospheric circulation, of which the most important are: 1) central tendency with the activity cen-

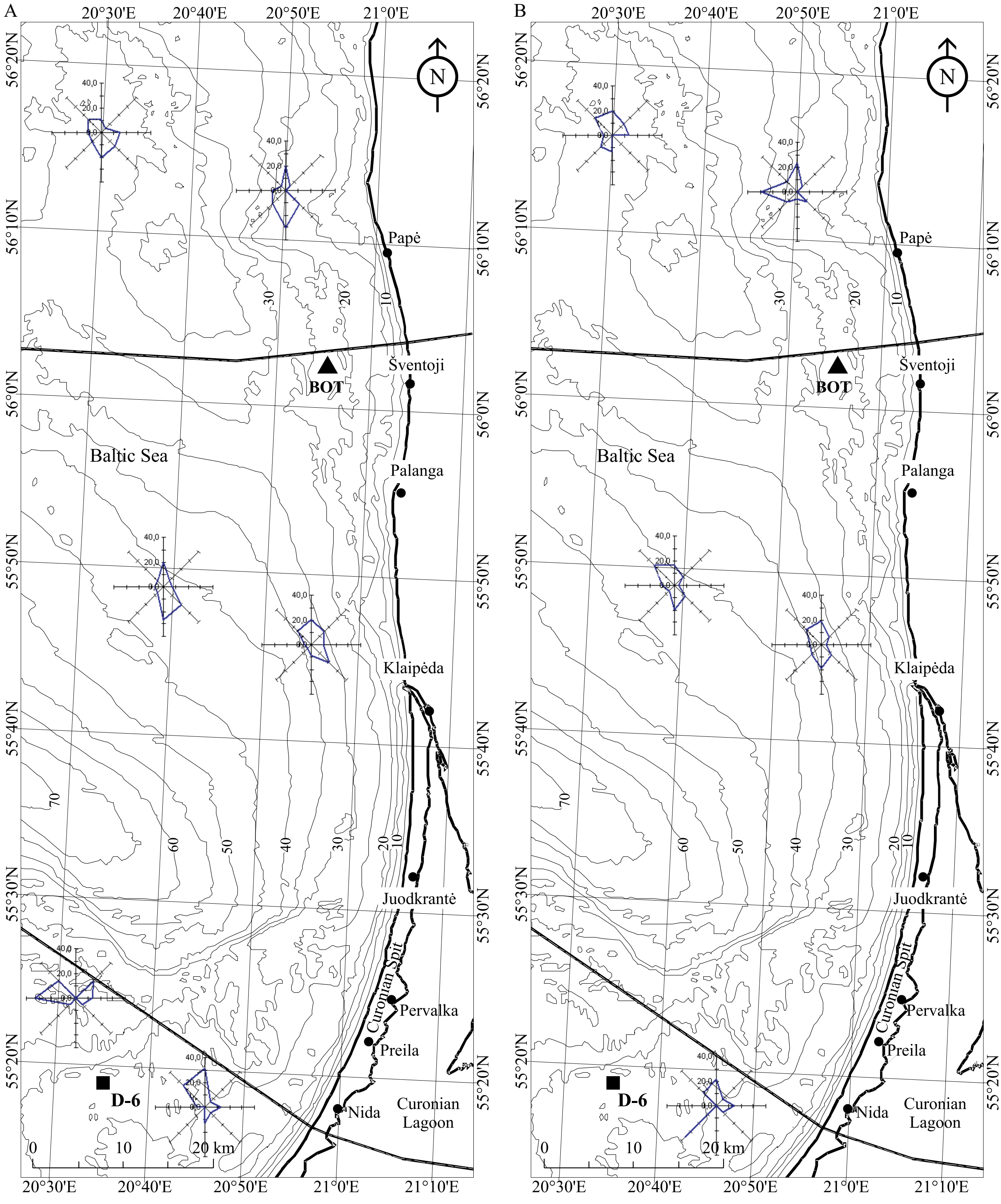

Figure 8. Near-bottom current direction frequency (%) for the Baltic Sea: A) warm season, B) cold season.

tre above central Europe (characterized by a low-pressure gradient), 2) zone circulation and 3) blocking ridge or low-pressure formation above the North-East Atlantic (Slonosky *et al*. 2000).

The results on the current distribution pattern and meteorological analysis allow to assume that oil spills at platform D-6 would be transported by prevailing W and NW currents (Fig. 8A) towards the Curonian

Spit in the warm season and by dominant W and SW currents (Fig. 8A) in the cold season. Bearing in mind temperature variations during the cold season, we may expect that oil products would not reach the shore, because as a result of changes in their physical state they may settle on the bottom. In such cases they would be transported into the open sea in W and NW directions (Table 2) (Fig. 8A). In the case of ecological disaster at the Klaipėda Strait during cold and warm seasons, oil products would be drifted to the mainland and marine coasts. In the case of ecological disaster at the Būtingė Terminal, oil spills would be transported toward Latvia in the warm season (Fig. 8B) or southward in the cold season (Fig. 8A). About half a million of waterfowl and fish species (including many species from the Red Data Book of Lithuania) would be endangered in the risk zone (Švažas & Vaitkus 1994).

Analysis of surface currents questions Russian researchers' claims that oil products detected in the Russian part of the Curonian Spit in May of 2003 and 2004 were transported from the Lithuanian Būtingė Terminal (Orlenok *et al*. 2004). Water mass circulation in warm and cold seasons is mostly directed N and NE (Figs 6A, B).

Changes in current direction at a depth of 5 m (Figs 7A, B) offer an explanation why in some cases oil patches do not move in wind direction. At this depth, the effect of wind action is reduced and other factors gain weight (water density, etc.). This in turn also explains why oil patches sometimes appear in other zones than predicted by hydrodynamic modelling. After getting into water, oil products in water may decompose into several forms. Oil can form a slick on the water surface or can remain under water in other forms (water-oil emulsions: water-in-oil or oil-in-water). A slick may move in one direction, whereas emulsions drift in other direction as it happened after the oil spill at Būtingė in 2001 (Dailydienė 2003). Every spill of oil products is unique and depends on many factors: the physical state of oil products, hydrological and meteorological conditions, and other factors.

Conclusions

Based on the measurement results of currents, we assume that in the warm season spilled oil products would be transported by surface currents northward and north-eastward. In the cold season, oil spilled at platform D-6 and near Klaipėda would migrate northward and oil spilled at Būtingė would migrate southward. Water mass movement at a depth of 5 m may be opposite to surface water mass movement (most probably clockwise). In the near-bottom water horizon, migration of oil products in the majority of cases would be opposite to migration in the surface horizon. In this horizon, water mass moves along isobaths or crosses them perpendicularly to the bottom surface.

The present study revealed only general dispersion trends of oil pollutants and their dependence on atmospheric circulation and dominant winds. Processes on the synoptic scale sometimes become decisive factors in oil spill dispersion. Reliability of meteorological and marine/hydrological observations is another important factor. Wind observations at the Nida Meteorological Station are of paramount importance (especially in the case of D-6 accident). Unfortunately, they do not represent the marine coast of the Curonian Spit, but only a part of the eastern dune ridge.

Even small-scale oil spills in the Baltic Sea or near the Lithuanian coastline would inflict damage first of all to flora and fauna and would pollute seawater and beaches. This would be a great anthropogenic load to the sensitive Baltic Sea ecosystem.

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Jūrinių srovių įtaka naftos produktų sklaidai Pietryčių Baltijoje

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Santrauka

Viena iš opiausių ir pagrindinių Baltijos jūros ekologinių problemų yra padažnėję naftos ir naftos produktų išsiliejimai. Nafta ir naftos produktai yra labiausiai paplitę ir ganėtinai pavojingi teršalai jūrose ir vandenynuose. Naftos teršalai itin pavojingi Baltijos jūrai, kur biologiniai savaiminio apsivalymo procesai yra lėtesni nei šiltesniuose vandenyse. Šio straipsnio tikslas – remiantis jūrinių srovių matavimais, atliktais Baltijos jūroje, išanalizuoti galimą naftos ir naftos produktų sklaidą Pietryčių Baltijoje ties Lietuvos priekrante. Darbo pagrindą sudaro srovių krypties, vandens paviršiaus bei oro temperatūros ir vėjo krypties matavimai atlikti okeanografinėse bei hidrometeorologinėse stotyse.

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