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Baltica

BALTICA Volume 30 Number 2 December 2017: 75–85
http://dx.doi.org/10.5200/baltica.2017.30.09

Sea surface temperature variations in the south-eastern BalticSea in 1960–2015

Viktorija Rukšėnienė, Inga Dailidienė, Loreta Kelpšaitė-Rimkienė, Tarmo Soomere

Rukšėnienė, V., Dailidienė, I., Kelpšaitė-Rimkienė, L., Soomere, T., 2017. Sea surface temperature variations in the south-eastern Baltic Sea in 1960–2015. *Baltica, Vol. 30 (2),* 75–85. Vilnius. ISSN 0067-3064.
Manuscript submitted 24 October 2017 / Accepted 28 November 2017 / Published online 11 December 2017

Abstract. This study focuses on time scales and spatial variations of interrelations between average weather conditions and sea surface temperature (SST), and long-term changes in the SST in south-eastern Baltic Sea. The analysis relies on SST samples measured in situ four times a year in up to 17 open sea monitoring stations in Lithuanian waters in 1960–2015. A joint application of non-metric multi-dimensional scaling and cluster analysis reveals four distinct SST regimes and associated sub-regions in the study area. The increase in SST has occurred during both winter and summer seasons in 1960–2015 whereas the switch from relatively warm summer to colder autumn temperatures has been shifted by 4–6 weeks over this time in all sub-regions. The annual average air temperature and SST have increased by 0.03°C yr^{-1} and 0.02°C yr^{-1}, respectively, from 1960 till 2015. These data are compared with air temperatures measured in coastal meteorological stations and averaged over time intervals from 1 to 9 weeks. Statistically significant positive correlation exists between the SST and the average air temperature. This correlation is strongest for the averaging interval of 35 days.

Keywords *• sea monitoring • sea sub-regions • sea surface temperature • sea-air interactions • climate change*

✉ *Viktorija Rukšėnienė (viktorija.rukseniene@gmail.com), Inga Dailidienė, Loreta Kelpšaitė-Rimkienė, Faculty of Marine Technologies and Natural Sciences Klaipeda University, Herkaus Manto str. 84, 92294 Klaipeda, Lithuania; Tarmo Soomere, Tallinn University of Technology, Akadeemia tee 21, 12618 Tallinn, Estonia*

INTRODUCTION

The Baltic Sea is one of the most sensitive areas of the World Ocean with respect to the climate change, and one of the most polluted marine regions. Many environmental problems are here particularly acute because of specific features of the Baltic Sea such as its relatively small size and depth, large catchment area compared to the basin size, limited water exchange through the narrow straits that connect it with the North Sea, and extremely intensive human activities in the entire catchment (BACC I Author Team, 2008; BACC II Author Team, 2015; Leppäranta and Myrberg, 2009).

The combination of its relatively small size and the vulnerability of its ecosystem makes the Baltic Sea particularly sensitive to both gradual climate change and regime shifts. The associated challenges for the Baltic Sea unique ecosystem are known for a long time. To support the necessary mitigation actions by scientific evidence, all nine Baltic Sea states carry out intensive marine monitoring. As climate change at times is highly inhomogeneous in neighbouring regions, decisions on the mitigation of the climate change impact in the European Water Framework Directive require comprehensive regional investigation (HELCOM, 2017).

The major environmental impacts of anthropogenic influence are well documented and their main consequences (such as eutrophication, invasion of alien species, or environmental pollution) have been commonly recognised. In many occasions the impact of these phenomena is amplified by climate change and specifically by changes in the water temperature (BACC II Author Team, 2015; HELCOM, 2017).

Sea surface temperature (SST) is one of the key variables that can be used for climate change detection and calculations of associated changes in air-sea fluxes (Høyer and Karagali, 2016). It is also one of the most explored parameters in physical oceanography. The measurements of SST in the Baltic Sea have been reported already since the 1700s (Fonselius and Valderrama, 2003). Regular measurements of SST and other hydro physical parameters of this water body started at end of the 19th century. The waters of the Baltic Sea are generally cold, with the northern areas freezing over every winter, but the surface waters heat up in summer, in warm years to over 20°C (Elmgren et al., 2015). These spatio-temporal gradients cause large differences in ecological conditions in different regions of the sea.

The gradually increasing availability of SST and meteorological data has inspired many efforts to understand past and present changes in the climate of the Baltic Sea region. The possibility of merging data from different sources made it possible to demonstrate, for example, that during the past century the increased frequency of both cyclonic circulation and westerly winds has resulted in a warmer climate with reduced sea-ice cover and significant increase in surface air and water temperatures in the Baltic Sea region (BACC II Author Team, 2015; Omstedt et al., 2014). The Baltic Sea is one of the marine areas with the highest recorded near-surface air temperature increase during the past century, and this increase is almost certain to continue (Rutgersson et al., 2014). Specific warming started in the Baltic Sea region from the 1970s–1980s (BACC II Author Team, 2015) like in many regions all over the globe.

A similar warming trend has been observed in the annual variation of SST of the Baltic Sea (BACC I Author Team, 2008; Lehmann et al., 2011). Despite some regional differences, a positive trend in the yearly mean SST with an average increase of 0.8°C during 15 years has been indicated from the beginning of the 20th century (Siegel et al., 2006). Both global and regional climate models generally agree that the Baltic region is likely to warm up by about 2–4°C by the end of the 21st century (Elmgren et al., 2015). The rise of water temperature in all the Baltic Sea regions is a natural consequence of changes in the air temperature and atmospheric circulation over north-eastern Europe. This increase is accompanied by a dramatic increase in the variability of the annual mean water temperature and temperature extremes since the end of the 20th century, when the winter NAO (Hurrell North Atlantic Oscillation) index was mostly in the positive phase (Dailidienė et al., 2006; Lehmann et al., 2011). This index reflects the status of the leading pattern of weather and climate variability over the Northern Hemisphere, and the leading mode of atmospheric circulation variability over the Atlantic/European sector on winter (December–March) surface air temperature (Deser et al., 2017; Hurrell and Deser, 2010). The NAO index refers to the redistribution of atmospheric masses between the Arctic and the subtropical Atlantic. Major fluctuations in the values of this index are associated with large changes in surface air temperature, winds, storminess and precipitation over the Atlantic as well as the adjacent continents (Hurrell and Deser, 2010).

The complexity of physics and dynamics of the Baltic Sea extends far beyond the typical features of many other water bodies of comparable size (BACC I Author Team, 2008; Wulff et al., 2001). In particular, it often exhibits substantially different climatic changes in its different parts (Soomere et al., 2015), whereas spatial scales of changes with different signs are sometimes just a few tens of kilometres (BACC II Author Team, 2015). On the one hand, this feature together with the vulnerability of its ecosystem makes this region particularly sensitive to climate changes. On the other hand, this feature calls for more detailed zonation of regions with possibly different drivers of hydro-physical properties as well as for the development of express methods for rapid evaluation of changes of various properties of water masses based on available data sources. These considerations stress the need for comprehensive analysis of spatial-temporal variability of existing marine data. In this paper we make use of the data gathered in the framework of the Lithuanian Baltic marine environment monitoring program that is targeted to the determining the current environmental status, climatic trends and relevant forecasts based on the requirements of EU Marine Strategy Framework Directive.

The purpose of this work is twofold. Firstly, we show that even such a small area as the Lithuanian exclusive economic zone and Lithuanian territorial waters (about 100×120 km) in the south-eastern (SE) open part of the Baltic Sea reveals several significantly different regions in terms of temporal course of SST. Secondly, we analyse interrelations between the offshore SST in these regions (measured in standard open sea monitoring stations) with average values of several common meteorological parameters (air temperature, solar radiation observed in coastal meteorological stations. The focus of this research is on the reaction time and memory of sea surface temperature with respect to its main driving factors. The presented analysis reconfirms the extensive variability of processes of formation of different Baltic Sea water masses whereas the (changes in the) SST could serve as a convenient indicator of the magnitude of pressure on the marine environment and its ecological balance.

MATERIAL AND METHODS

We explore possibilities of identification of different surface water masses based on the simplest quantity that characterises the properties of surface waters at a single monitoring station, namely, the annual mean SST. The analysis relies on SST measured *in situ* four times a year (once at season) at 17 marine monitoring stations in the Lithuanian sector of the Baltic Sea (Fig. 1, Table 1). The measurements were performed during expeditions organised by the Department of Marine Research of the Lithuanian Environmental Protection Agency.

As the number of visited stations greatly varies in different years, we use two data sets of the SST in the analysis. For the clustering analysis and estimation of the reaction time and memory of SST we used time series covering the years 1994–2009 when all 17 stations were regularly visited. The data set contains about 60 measurements in each monitoring station (Table 1). Long-term changes in the SST were evaluated using data from one monitoring station from each more or less homogeneous cluster sampled during much longer time interval of 56 years (1960–2015).

To identify possible systematic differences in the properties of surface waters in the Lithuanian sea monitoring zone we applied clustering and non-metric multi-dimensional scaling (nMDS) analysis. Clustering analysis takes the similarity matrix as the starting point and successively fuses the samples into groups and the groups into larger clusters, starting with the highest mutual similarities and then gradually lowering the similarity level at which groups are formed (Clarke and Warwick, 2001). The nMDS technique has been used to ordinate the similarity data. This scaling approach uses an algorithm, which successively refines the positions of the points until they satisfy, as closely as possible, the dissimilarity between samples. The result is a two-dimensional ordination plot where points that are close to each other represent stations that are very similar in terms of the temporal course of SST. Points that are far apart correspond to stations with a different SST regime. Using these methods, the monitored region has been divided into subareas, which are distinguished by similar average values and a certain similarity in the variation in the SST.

The further analysis focuses on the reaction time and memory of sea surface temperature with respect to its main driving factors, quantified in terms of correlations of single SST values and averages of meteorological parameters. The SST data in 17 marine monitoring stations in the Lithuanian sector of the Baltic Sea (Fig. 1) in 1994–2009 are compared with a set of average values of meteorological parameters (air temperature, duration of solar radiation from onshore coastal meteorological stations: Palanga, Klaipėda and Nida (Fig. 1).

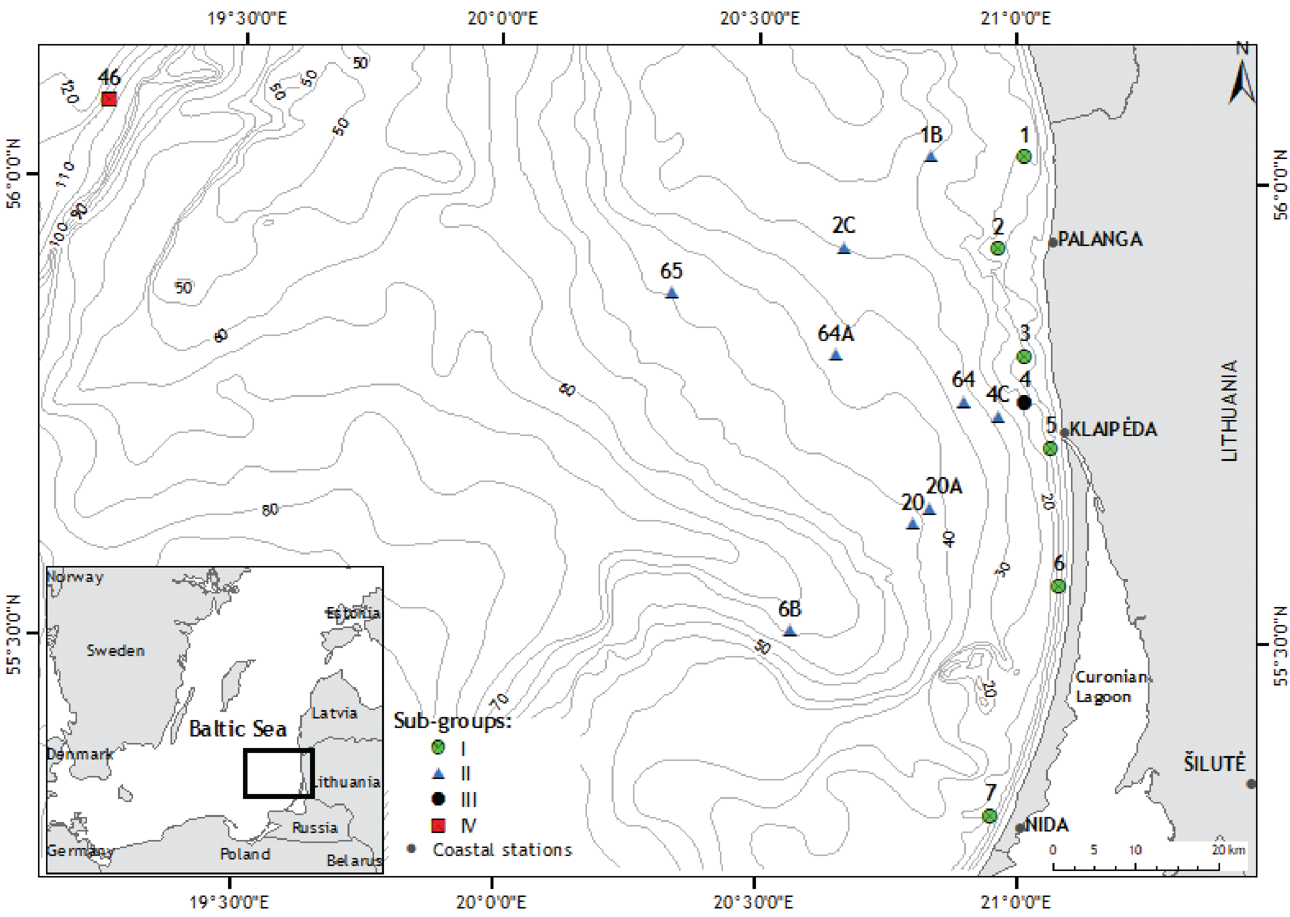

Fig. 1 Research area: South-eastern Baltic monitoring stations selected for the survey scheme. (V. Rukšėnienė)

The data of all meteorological stations on the coast are averaged to assess the general meteorological conditions prevailing in the SE Baltic Sea during the monitoring activities. For comparisons, we used the mean values evaluated for different time intervals for each coastal station. The goal is to identify the strongest relationships (in terms of formal correlations and their statistical significance) between single values of SST in individual monitoring stations and the set of average values of the listed meteorological parameters in the coastal measurement sites. The average values in question were evaluated for each offshore site for the time intervals with the length of 7, 14, 21, 28, 35, 42, 49, 56 and 63 days (1–9 weeks). Each such time interval is chosen just before the particular offshore SST measurement. The idea is to define the typical duration of the time interval (days, weeks, months), for which the average air temperature has the largest correlation with the SST. Spatial geoinformation (GIS) maps have been created to identify the potential sub-regional differences in the interrelations of the properties of surface waters and meteorological conditions over different averaging intervals.

For the analysis of long-term changes in the SST we used data from monitoring stations No. 4, No. 64, No. 65 and No 46 for a much longer time interval of 56 years (1960–2015). For the detailed regression analysis, we chose the data from station No. 46 (Fig. 1). As will be shown below, this station represents open waters of the Baltic Sea proper. It is thus likely that this sampling location at best reflects long-term changes in the water properties and their potential impact on the marine ecosystem whereas changes in the nearshore sampling stations are modulated by the impact of land and waters from the Curonian Lagoon. To recover missing values in the SST and air temperature time series, we employed (following Zorita and von Storch, 2005) a linear regression analysis for the entire research period 1960–2015.

RESULTS

The results of the nMDS analysis indicate that the SE Baltic Sea monitoring stations in Figure 1 can be grouped into nine clusters. Based on 95% Bray-Curtis similarity index, these stations were further divided into four groups (Fig. 2). The two larger groups contain nine and five stations, respectively, whereas each of the two smaller groups represents only one station. It is likely that these groups represent different natural physical conditions of the SST variation in the SE Baltic Sea in four sub-regions.

The joint applications of the nMDS (Fig. 2) and cluster analysis (Fig. 3) show similar results. The cluster analysis also reveals the presence of four different SST regimes and associated sub-regions in the study area. The results of clustering analysis according to the SST variation in the SE Baltic Sea indicate that the majority of stations have high levels (>95%) of similarity of the course of SST within each cluster (Fig. 3)

Two stations (No. 4 and No. 46) exhibit markedly different properties of the SST course compared to the rest of stations. This difference becomes evident as clearly lower similarity (92–94%) with other stations and also with respect to each other.

The properties of surface waters in marine monitoring station No. 46 (Fig. 1) differ considerably from those in other stations. This monitoring site is located at distance of 80 km from other stations. It represents

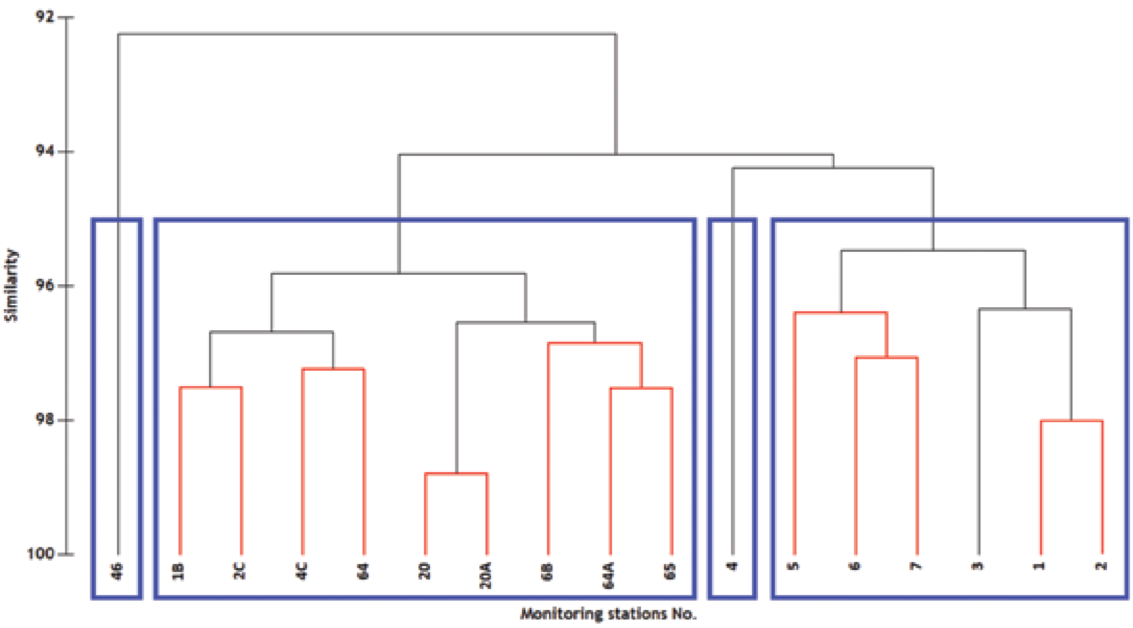

Fig. 2 Sea surface temperature similarity dendrogram plot of the SE Baltic Sea monitoring stations. Blue squares indicate 95% similarity. (V. Rukšėnienė)

water properties in the deepest part of the Lithuanian marine monitoring zone on the south-eastern slope of the Gotland Deep (Leppäranta and Myrberg, 2009). This area is relatively strongly affected by the most persistent features of the general circulation scheme of the Baltic Proper (Meier, 2007) and measurements in this station apparently reflect the properties of water masses in the central part of the Baltic Sea.

The variation of the SST in station No. 4 (Fig. 2 and Fig. 3) is clearly different from that in other stations. This station is located at only ~2 km off the sea coast from the entrance to Klaipėda Strait (Fig. 1). Therefore, most likely the changes in water properties at this location are often substantially affected by water balance in the sea-lagoon interaction system. The properties of waters in the lagoon and to a large extent also the water exchange between the lagoon and the open Baltic Sea are largely governed by the voluminous discharge (about 23 km^3 per year) of the Nemunas River (one of the biggest rivers in the Baltic Sea basin) and other rivers of the Curonian Lagoon

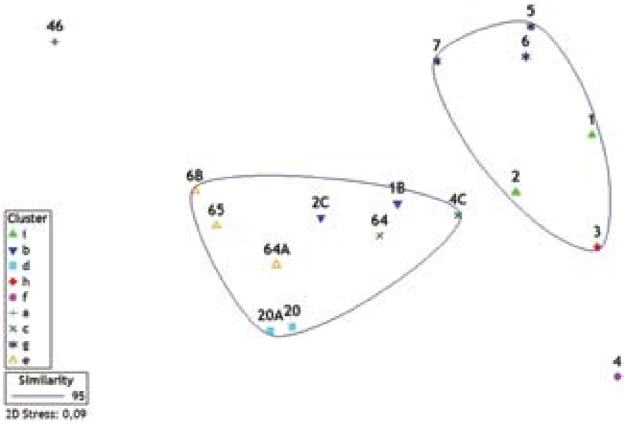

Fig. 3 Ordination plot of the results of an application of nMDS to the monitoring stations. Lines indicate the 95% similarity level and distinguish four groups of the monitoring stations according to the measured sea surface temperature data. (V. Rukšėnienė)

catchment. This feature suggests that water properties in this station largely describe the transit waters of the sea-lagoon zone rather than properties of sea waters in the SE Baltic Sea region.

The presented analysis thus displays a clear grouping of the monitoring stations into four clusters. These clusters cover the following sea areas (ordered here according to the distance from the Lithuanian shore): (I) the impact area of Klaipėda Strait and the Curonian Lagoon on waters in the Baltic Sea proper, (II) the coastal area dominated by the effects of shallow nearshore waters and processes, (III) the open Baltic Sea sub-region, and (IV) sub-region of the Gotland Basin in the deepest monitored part of the SE Baltic Sea

The presented results show that the current scheme of monitoring of properties of offshore waters could be optimised by reducing the number of monitoring stations in those sub-regions that exhibit a similar variation in the physical conditions and contain a large amount of stations. This suggestion is supported by the analysis of the effects of changes in the tropospheric temperature variation on the SST over different periods.

The correlations between the SST of the sea monitoring stations and average air temperature of the coastal meteorological stations (Fig. 4 and Fig. 5) over different time intervals are statistically significant at a 90% or higher ($p < 0.1$) level. The correlation is relatively weak for averages over 1–2 weeks. The relationship is the strongest for the averaging length of 42 days (6 weeks or 1.5 month), and is decreasing for most of stations and for even longer averaging intervals. In other words, a SST sample serves as a good proxy of average atmospheric conditions over the last 6 weeks.

The pattern of correlations for station 4 is different from similar correlations for all other stations. The correlation coefficient shows the strongest relationship between the SST in this station and the average air temperature for averages over 1–2 weeks. The values of this coefficient rapidly decrease for longer

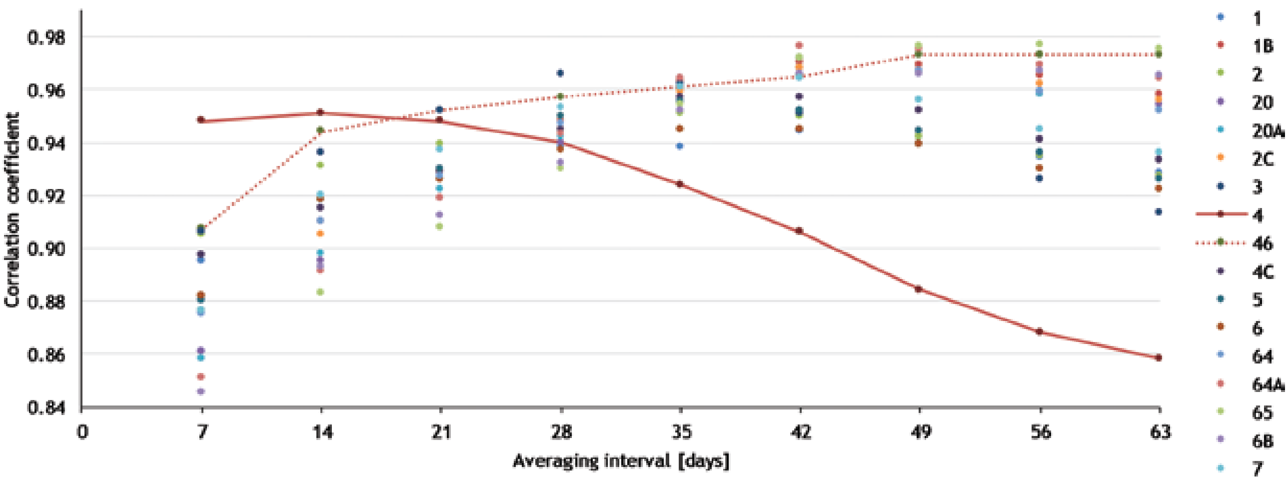

Fig. 4 Correlations between the sea surface temperature and the air temperature for different intervals (of days) of the sea monitoring stations. (V. Rukšėnienė)

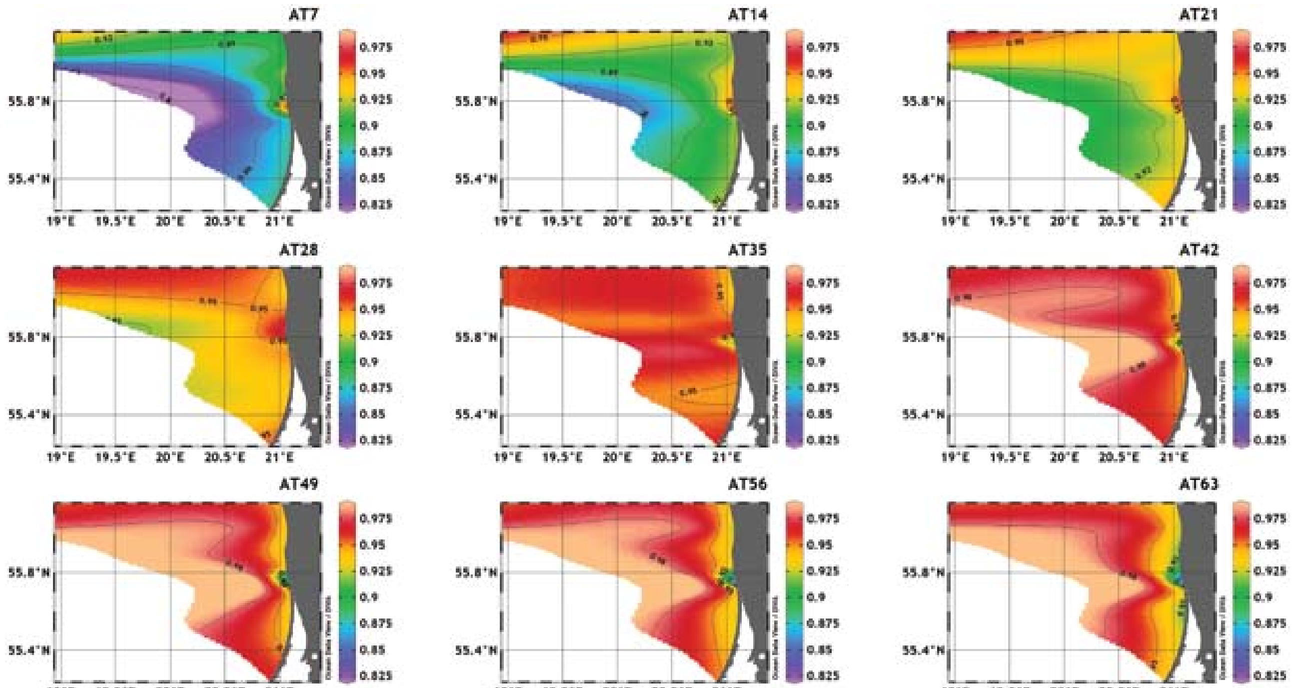

Fig. 5 Spatial maps of correlation coefficients *R* between the sea surface temperature (SST) in different monitoring stations and the average air temperature (AT) for different averaging periods (7,14,21,28,35,42,49,56,63 days). (V. Rukšėnienė)

averaging intervals. This station represents processes in the area that is strongly influenced by the outflow from the Curonian Lagoon. Therefore, this result, not unexpectedly, signals that waters in this shallow basin relatively rapidly react to short-term changes in the atmospheric conditions.

The correlations in question are among the strongest values for station No. 46 for all averaging intervals (Fig. 4). This station is the farthest from the shore in a deep area and largely reflects the properties of waters in the central Baltic Sea. It is not obvious why the correlation in question is relatively large for short averaging intervals. However, it is natural that properties of water masses in this location correlate well with the long-term course of air temperature.

Regression analysis of interrelations of the average air temperature and the SST provides further information about the reaction of water masses to changes in the air temperature on different time scales (Fig. 5). The linear regression equations were calculated for SST in sub-regions I–IV for all analysed averaging intervals of air temperature. The relevant squared correlation coefficients R^2 vary from 0.83 to 0.93 in sub-region I, from 0.79 to 0.95 in sub-region II, from 0.78 to 0.92 in sub-region III and from 0.73 to 0.90 in sub-region IV. The highest values of R^2 in groups II and III reach 0.9 for the averaging lengths over 21 days.

The best correlation of SST with the air temperature is in station No. 4 (sub-region I) for averaging intervals of 1–4 weeks. As explained above, waters in this sub-region are markedly impacted by the outflow from Klaipėda Strait. This outflow is greatly influenced by both global (variations in the water level of the entire Baltic Sea) and local land-sea interaction processes (e.g. sea breeze, effect of sea-lagoon transitional waters). It is therefore natural that for longer averaging intervals the correlation between the air temperature and SST is lost.

The correlations between the SST and the duration of solar radiation, albeit all statistically significant at a 95% or higher level, are clearly weaker than similar correlations for the average air temperature. The correlation coefficient between the SST and the average duration of solar radiation almost monotonously increases with the lengthening of the averaging interval (Fig. 6). The associated correlation coefficients exceed 0.8 starting from the 49-day (7 weeks) averaging interval in all offshore monitoring stations. This kind of correlation has basically the same origin as the relationship between the SST and air temperature. The maximum values of correlation coefficient variation are in sub-regions II and III, and lower R^2 values are observed in sub-regions I and IV.

LONG-TERM CHANGES IN AIR AND SEA SURFACE TEMPERATURES

The above analysis has shown that the course of SST is very similar within each of the established sub-regions I–IV. For this reason, it is, to a first approxima-

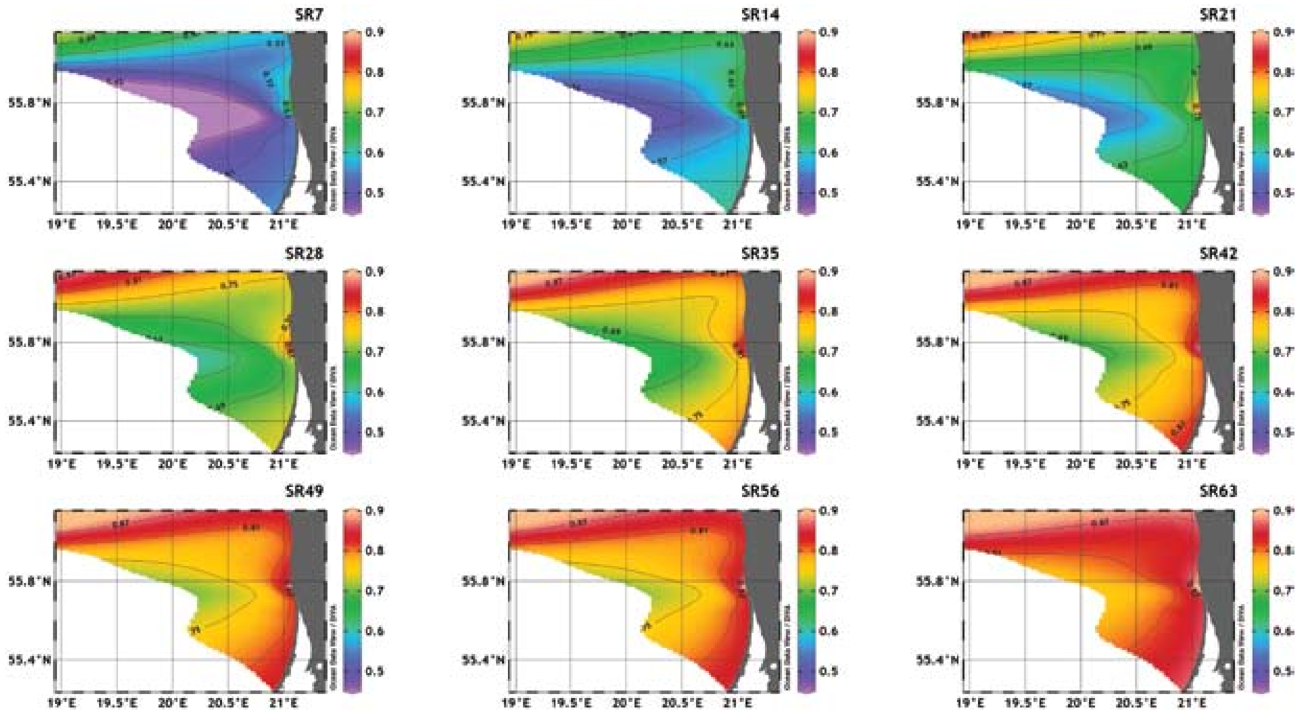

Fig. 6 Distribution of correlation (coefficients *R*) between the average sea surface temperature (SST) and the average duration of the solar radiation (SR) for different intervals (7,14,21,28,35,42,49,56,63 days). (V. Rukšėnienė)

tion, acceptable to consider in more detail the long-term evolution of SST in single stations that (i) represent well these sub-regions and (ii) have much longer time series of SST samples. For this purpose, we chose stations No. 4, No. 64, No. 65 and No 46 (Fig. 1), samples in which cover the years 1960–2015.

Air temperatures in the Baltic Sea region have already risen over the past century. The increase has been about 1.0°C in the northern Baltic Sea and by about 0.7°C in the southern areas of this basin (BACC I Author Team, 2008; BACC II Author Team, 2015). Water temperatures generally follow air temperatures but have smaller fluctuations and gentler trends. Earlier studies have shown that the average increase in the mean air temperature and the mean SST near the SE coast of the Baltic Sea was about 0.06°C yr^{-1} and 0.04°C yr^{-1}, respectively, from 1991 onward (Dailidienė et al., 2012). Our analysis shows that similar (albeit gentler) trends existed before 1991 and continue until today in the study area. The annual average air temperature and the annual average SST in the offshore station No. 46 increased by 0.03°C yr^{-1} and 0.02°C yr^{-1}, respectively, from 1960 till 2015 (Fig. 7). This result is in agreement with the outcome of studies of multiyear trends in and the variability of the Baltic Sea SST using the satellite data of 1982–2013 (Stramska and Białogrodzka, 2015). They identified a statistically significant increase by 0.03 to 0.06°C yr^{-1} in the SST in the entire Baltic Sea.

Importantly, the increase in the air temperature on the sea coast of the study area has been observed in

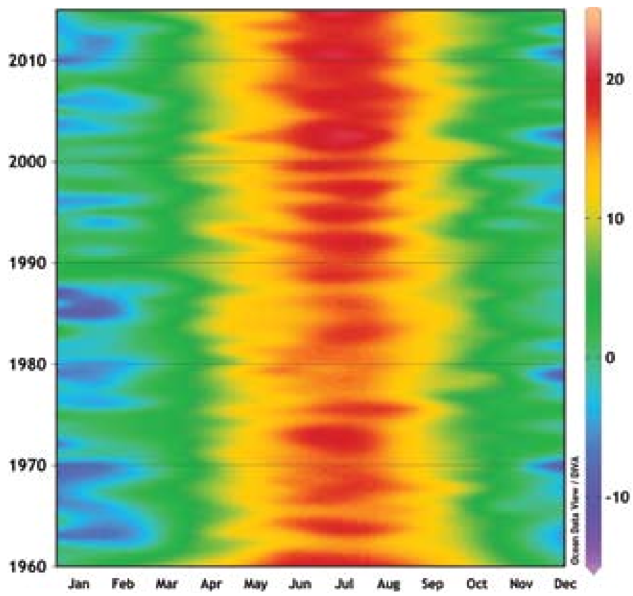

Fig. 7 Annual and seasonal variation of air temperature at the SE Baltic Sea coast in 1960-2015. (I. Dailidienė, V. Rukšėnienė)

1960–2015 during both winter and summer seasons (Fig. 8). This tendency becomes evident, for example, as longer warm periods (with the air temperatures above 20°C) in summer since the 1990s accompanied with a gradual shortening of the time with freezing air temperatures in March–April (Fig. 8).

As expected, climatic changes in the annual and seasonal conditions are more clearly indicated by changes in the SST (Fig. 9). An even more pro-

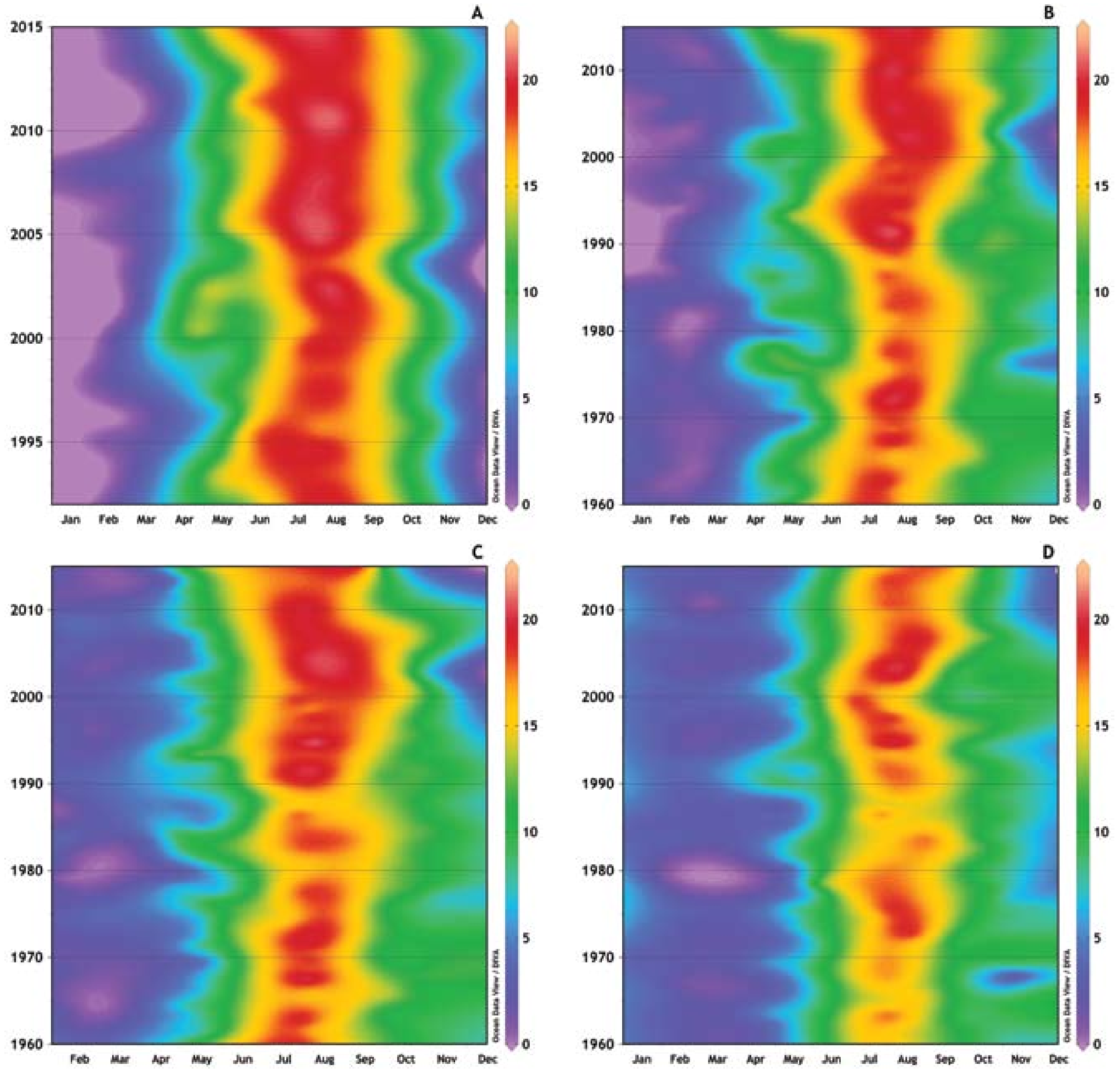

Fig. 8 Long-term annual and seasonal the sea surface temperature changes in the SE Baltic Sea at the marine monitoring stations: (A) No. 4 (1992-2015); (B) No. 64 (1960-2015); (C) No. 65 (1960-2015) and (D) No. 46 (1960-2015). (V. Rukšėnienė, I. Dailidienė)

nounced rise in SST compared to the air temperature has occurred in the summer season in all sub-regions of the study area in 1960–2015. This tendency is particularly pronounced since the end of the 20th century (Fig. 9) in sub-regions II and III. Summer months host relatively steep SST trends in these sub-regions whereas similar trends are not statistically significant in the winter months. The summers since the 1980s–1990s contain a notably longer relatively warm period during which the sampled SST rises above 20°C.

Another interesting feature is a gradual shift of the time with maximum SST toward autumn (Fig. 9). This autumn-winter shift (from 2 weeks to one month) in the temporal course of SST exists in all sub-regions of the SE Baltic Sea. A possible reason for this tendency is that warm summers have become gradually longer and more heat has been accumulated in the water. The release of this partially compensates the falling air temperature and in this way prolongs the presence of comfortable temperatures on the coast at the beginning of autumn. This effect is a probable reason for the decreasing difference between the average annual air and sea surface temperatures from the end of the 20th century (Fig. 7). It is likely that the joint increase in the air temperatures and the length in the warm summer periods leads to an increase in the probability of the occurrence of extreme sea surface temperatures in future in the Baltic Sea (An and Haapala, 2014) (Fig. 8)..

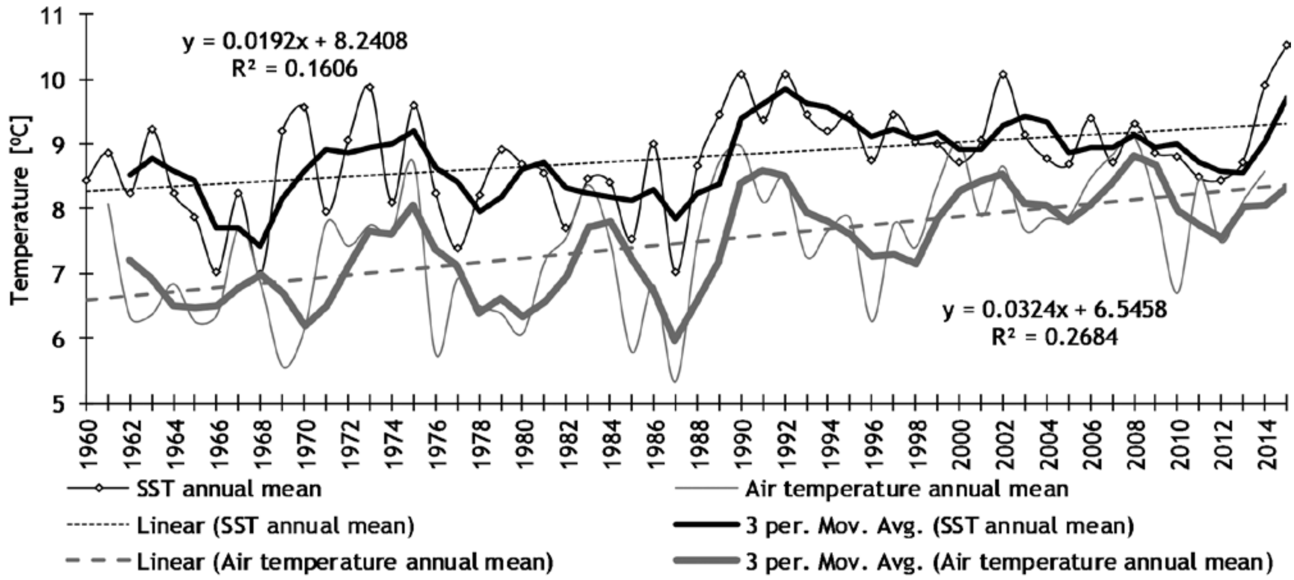

Fig. 9 Long-term annual mean SST (No. 46 station) and annual mean air temperature (Klaipeda) variation and trends in the 1960-2015 period. (I. Dailidienė, V. Rukšėnienė)

DISCUSSION

The changes in the sea water temperature in the south-eastern Baltic Sea are obviously related to the changes in the air temperature and, more generally, the changes in the atmospheric circulation, air-flow and wave patterns, and changes in the course of coastal processes identified in the recent years (Dailidienė et al., 2011; Lehmann et al., 2011; Soomere et al., 2015). The presented analysis, first of all, reconfirms the well-known extensive variability of processes of the formation of different Baltic Sea water masses (Leppäranta and Myrberg, 2009). It is however interesting that different segments of such a relatively small section of the Baltic Sea possess substantially different courses of seasonal variations in SST. The applied analysis (a combination of clustering analysis and non-metric multi-dimensional scaling) demonstrates, based on patterns of temporal dynamics of the STT, that this region contains four distinct areas with different properties and eventually with certain peculiarities of the formation of surface waters: waters of the central Baltic Sea (the Gotland Basin), an intermediate region between these waters and coastal waters, the nearshore domain and an area impacted by the outflow from Klaipėda Strait.

While it is natural that coastal areas have their own course of SST because of frequent presence of persistent alongshore currents, a separation of areas at a moderate distance from the coast from those located at the south-eastern margin of the Gotland Deep is a nontrivial feature. Its occurrence suggests the presence of different circulation and mesoscale patterns in these two areas and signals that the large-scale transport patterns in the Baltic Sea proper do not enter deep into the Lithuanian sector of the sea. The appearance of the fourth, relatively small section near Klaipėda is evidently caused by the impact of the discharge from the Curonian lagoon on SST in the vicinity of Klaipėda Strait. It is natural to expect that ecological research in these areas can also indicate different biogeochemical and bio-optical properties (Šiaulys and Bučas, 2015; Vaičiūtė et al., 2012) and thus provide different background environmental conditions for the local ecosystem.

This conjecture has direct implications for the planning of marine monitoring activities. HELCOM has taken such regional differences into account. A natural step forward is to implement this approach into the relevant policies that today commonly apply a single classification to the whole Baltic Sea area (Elmgren et al., 2015). A better knowledge of the Baltic Sea and continuous improvement of marine monitoring, including optimisation, would be helpful for the implementation of the Marine Strategy Framework Directive, Water Framework Directive, Habitats Directive, and HELCOM Baltic Sea Action Plan, as well as national strategies of marine policies.

Our results also confirm an intuitively comprehensible perception that strong positive correlations exist between the average SST and the air temperature averaged during a time interval just before the SST sampling instant. This relationship varies depending on the length of the averaging interval and is greatly different for certain sub-regions. The strongest correlation generally exists when the air temperature is averaged over the half-length of a season (about 6 weeks).

Not surprisingly, the analysis also reconfirms the well-known gradual increase in the average air and water temperatures in the entire Baltic Sea basin.

The established long-term trends (0.03°C yr^{-1} and 0.02°C yr^{-1}, respectively, in 1960–2015) are gentler than similar trends since the turn of the century. This feature once more signals an acceleration of the climate change in the Baltic Sea region. Interestingly, the analysis reveals a certain seasonal differences and shifts in the changes in the SST in the SE Baltic Sea in 1960–2015. The results in the recent past claimed that the main warming occurred during the cold period (Dailidiene et al. 2012). This feature mostly influenced the course of SST in the spring and in the summer. We identified that the biggest long-term rise of the SST occurred during the summer time. The summer conditions with SST ≥20°C generally last much longer since the end of the 20th century. This is apparently associated with an increase in the summer SST values and the frequency of hot summers. Most importantly, the identified shift of the warm period towards autumn by approximately half month may greatly impact marine biological and hydrochemical processes, conditions of spreading of marine pollution, the formation of algal blooms and seasonal eutrophication.

Climate change imposes strong selective pressures on species and populations (Poloczanska et al., 2016). The Baltic Sea is not rich in species diversity, compared to the shelf seas and oceans, as well as with freshwater basins. Rising water temperatures might also increase the stress levels of the entire ecosystem, affect the reproduction and juvenile stages of fish, and also influence fish migration and fish stock in general. The results of this work will be helpful for oceanographers, ecologists and environmentalists to evaluate processes following natural seasons and to accordingly improve mathematical models.

CONCLUSIONS

The entire Lithuanian marine monitoring area can be naturally divided into four sub-regions based on the seasonal and interannual course of sampled sea surface temperatures. Consequently, marine monitoring and the necessary in situ measurements could be optimised by selecting a few stations from the larger clusters of stations in sub-regions with fairly homogeneous hydrophysical regime. Statistically significant positive correlation exists between the annual average sea surface temperature and the average air temperature in coastal stations. This correlation is strongest for the averaging interval of 35 days.

A comparison of the derived estimates of the long-term increase in average air and water temperatures (0.03°C yr^{-1} and 0.02°C yr^{-1}, respectively, in 1960–2015) with similar trends in the recent past suggests that the response of the Baltic Sea water masses to the climate change is gradually accelerating. A substantial part of the long-term rise of the SST occurred during the summer time. This process is accompanied with a gradual of the lengthening of the summer conditions and a shift of the switch from relatively summer water temperatures to colder autumn conditions from mid-August to mid-September.

ACKNOWLEDGMENTS

The research has been partially financed by the Lithuanian national grant „*Lithuanian Maritime Sectors' Technologies and Environmental Research Development*“ (VP1-3.1-ŠMM-08-K-01-019), COST Action ES1402 „*Evaluation of Ocean Syntheses*“, and institutional support of the Estonian Ministry of Education and Research (IUT33-3). The autors are grateful to the Lithuanian Hydrometeorological Service under the Ministry of Environment for providing the meteorological data and kind support, and to the Department of Marine Research of the Lithuanian Environment Agency for providing the marine monitoring data. The authors are deeply grateful to reviewers Prof. Dr. Egidijus Rimkus (Vilnius) and Dr. Irina Chubarenko (Kaliningrad) for critical reading of the manuscript and helpful comments.

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