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Linking wave loads with the intensity of erosion along the coasts of Latvia

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Abstract. Numerically estimated wave properties and the associated closure depth along the eastern Baltic Sea coast from the Sambian (Samland) Peninsula up to Pärnu Bay in the Gulf of Riga are compared against the existing data about accumulation and erosion. Typical values of the closure depth are about 5–6 m (maximum 6.58 m) at the open Baltic Sea coast, 3–4 m in the Gulf of Riga and 2–2.5 m in semi-sheltered smaller bays. The areas of intense accumulation or erosion (especially the areas of their high variability) generally coincide with the sections, hosting high wave intensity, except for a few locations, dominated by anthropogenic impact. It is shown that the longshore variations in wave intensity (or closure depth) can be used to identify the location of major accumulation and erosion domains. The sections that host the largest change in the wave height along the coast reveal erosion or accumulation features, depending on the predominant wave approach direction.

Key words: coastal processes, wave modelling, erosion, accumulation, longshore transport, Baltic Sea, Gulf of Riga.

1. INTRODUCTION

The coasts of the Baltic Sea develop in relatively rare conditions of this almost non-tidal water body of relatively large dimensions [1], highly intermittent wave regime [2] and complicated patterns of vertical motions of the crust [3]. While large sections of the Baltic Sea coasts are bedrock-based and extremely stable, the southern and eastern coasts of this basin mostly consist of relatively soft and easily erodable sediment. Almost all these coasts suffer from sediment deficit [4–8] and are thus very sensitive to large hydrodynamic loads [7,9] and especially to the sea level rise [10]. Their evolution typically has a step-like manner and episodes of rapid changes take place when high waves occur simultaneously with high water level [7,9].

Several studies have highlighted rapid erosion events at certain locations of the Baltic Sea in the recent past [7–9]. These events are usually associated with changes in the wave climate (potentially caused by the changes in cyclonic activity) [11,12] or with the associated changes to the duration of ice cover [7,8]. Some authors [7,13] even suggest that the increasing storminess (expressed as a statistically significant increasing trend of the number of storm days over the last half-century) and extreme storms in 2001–2005 have already caused extensive erosion and alteration of large sections of depositional coasts in the eastern Baltic Sea. The destruction of beaches owing to the more frequent occurrence of high water levels and intense waves, as well as owing to the lengthening of the ice-free period, may have already overridden the stable development of several sections of Baltic Sea coasts [7]. Another stress factor for the coast is a decrease in the time interval between strong storms. This decrease may destroy the normal recovery cycle of natural beaches: a subsequent storm may impact upon an already vulnerable beach profile [13].

The combination of changing storminess with ever increasing anthropogenic loads and rapid industrial development of several coastal sections has created an acute need for detailed studies into the reaction of the Baltic Sea coasts to the changing driving forces. The primary factor, shaping these almost tideless coasts, is the nearshore wave climate. Recent studies have established the basic properties of the Baltic Sea wave climatology for the open sea areas and for selected coastal sites using instrumental measurements [14], historical wave observations [15,16] and numerical simulations [17–19]. These studies have been linked with the properties of and potential changes to the coastal processes for limited coastal sections [13,20,21].

The existing studies into the evolution and future of the eastern Baltic Sea coasts have been mostly either descriptive [6–8,22] or focused on various scenarios of the water level rise [3,10,23–25] or on the role of combinations of storm surges and rough seas [4,7,8,26–28]. There are very few attempts to predict the long-term impact of wave-driven coastal processes on the evolution of coastal morphology [29]. For the relatively young eastern Baltic Sea coasts, especially for the comparatively straight sections of the Latvian coast, the basic process should be straightening [22]. For sandy coasts its intensity essentially depends on the magnitude of longshore littoral drift and, therefore, on the wave approach direction. In conditions of sediment deficit, its intensity apparently even more strongly depends on the ability of waves to erode partially protected coastal sections (e.g. formations of till or sandstone that frequently occur along the Lithuanian and Latvian coasts).

In this paper, we make an attempt to link the spatial variability in the long-term wave climate (specifically, the numerically estimated overall intensity of wave-driven coastal processes) in selected parts of the eastern Baltic Sea with the

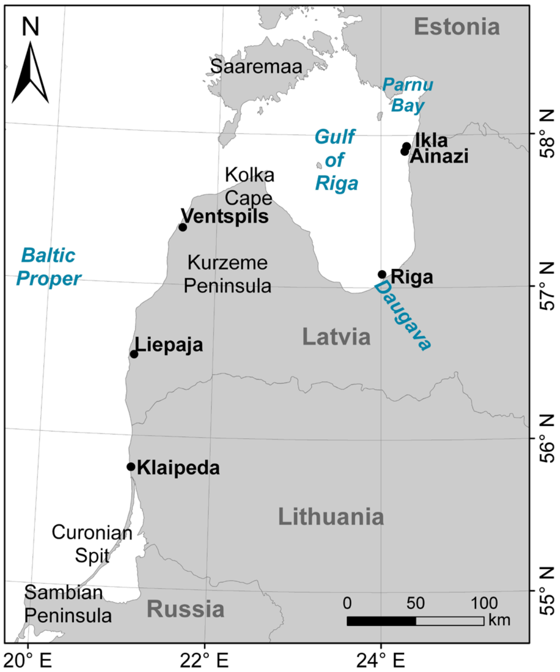

Fig. 1. Scheme of the study area.

existing data about the long-term rate of coastal accumulation and erosion (that are systematically available along the coast of Latvia). For this purpose, we use the threshold for wave heights that are exceeded during 12 h a year and the closure depth (that also accounts for the wave periods). The study area covers the mostly sandy coastal section from the Sambian Peninsula to Kolka Cape and the south-western and eastern coasts of the Gulf of Riga, including a short section of Estonian coast up to Pärnu Bay (Fig. 1).

The paper is structured as follows. We start from a short overview of the wave and coastal data and a description of the method for the calculation of the closure depth from the wave properties in Section 2. Spatial variations in the wave properties and closure depth are discussed in Section 3. Section 4 is dedicated to the analysis of interrelations of closure depth and erosion and accumulation rates. The basic message from the analysis is formulated in Section 5.

2. METHOD AND DATA

The basic characteristic of the intensity of coastal processes is the amount of wave energy that reaches a particular coastal section during a selected time interval [30]. To a first approximation, the long-term average scalar wave energy flux directed to the shore can be used to quantify wave impact on the coast. This quantity (which is decisive in studies into wave energy potential and properly characterizes the intensity of processes on coasts fully consisting of finer sediment), however, only partially and in many cases unsatisfactorily characterizes the processes on the coast. The reason is that the water level along the open parts of the eastern Baltic Sea coasts normally varies insignificantly and waves usually impact on a relatively narrow nearshore band [31]. The processes within this band are in many cases in approximate equilibrium [31] and do not reveal substantial changes to the local sediment budget even in areas of intense sediment transit. As mentioned above, events of rapid coastal evolution occur here infrequently, during events when rough seas are accompanied with high water level and when waves act on unprotected sediment or are powerful enough to erode sections that are partially protected (e.g. by boulders or by a cobble-pebble pavement).

Therefore, it is natural to associate the intensity of the straightening of the coasts (and, therefore, the major erosion and accumulation events) with the impact of the strongest wave storms that usually are accompanied by high water levels. It is not clear beforehand whether one can apply commonly used parameters of wave statistics such as the thresholds for the highest 5% or even 1% of significant wave heights (that are frequently used to estimate long-term changes to extreme wave conditions [18,32]) for this purpose. For example, wave situations that occur with a probability of 1% a year reflect wave storms with a total duration of about 3.5 days a year. Owing to the two-peak structure of the angular distribution of strong winds in the Baltic Proper [33] and large variations in the orientation of the coastal sections in question, a large part of rough seas is not necessarily accompanied with a high water level in the study area.

A more convenient measure to characterize the potential intensity of coastal processes is the threshold $H_{s,0.137}$ for significant wave height that occurs within 12 h a year, equivalently, the threshold for the roughest 0.137% of the wave conditions. The typical duration of the strongest wave storms in the Baltic Sea is close to this time interval. As breaking waves usually contribute to the water level in the nearshore, it is natural to assume that the highest water levels for a particular year generally occur during such storms. Storms, in which this threshold is exceeded, are also thought to maintain the shape of the coastal profile down to so-called closure depth (the largest depth where wind waves effectively keep a fixed-shape profile). This depth not only characterizes the overall intensity of wave impact for a particular coastal section but also serves as a key property of the beach [30,34] and a convenient basis for rapid estimates of sediment loss or gain [19,35,36]. This quantity also implicitly accounts for the wave periods in such storms and thus even better characterizes the impact of storm waves than solely the wave height. Differently from wave properties, the closure depth can be relatively easily measured in field conditions and compared with the theoretical estimates [34].

The data set of coastal monitoring for Latvia, unfortunately, only covers the changes to the shoreline and to the dry coast area. For this reason we employ an alternative estimate for the closure depth h^* based on long-term wave statistics.

The simplest estimates of h^* assume a linear relation between the (annual) average significant wave height H_{sa} and the closure depth (e.g. $h^* \approx 6.75 H_{sa}$ [37]), which is not necessarily true in the complicated geometry of the Baltic Sea [20]. In order to account for this peculiarity, we employ a second-order (quadratic or parabolic) approximation to the closure depth [38] that explicitly accounts for the frequency of occurrence of rough wave conditions and the relevant wave period, and that has led to good results for semi-sheltered beaches in Estonia [20]:

$$h^* = 1.75 H_{s,0.137} - 57.9 \frac{H_{s,0.137}^2}{g T_s^2}. \quad (1)$$

Here g is acceleration due to gravity and T_s is the typical peak period in such wave conditions. In reality, the closure depth gradually increases as in the course of time extremely strong storms (that are averaged out by using Eq. (1)) may shape the coastal profile to even larger depths [39]. As such storms usually cover the entire Baltic Proper and affect quite long sections of the coast, it is reasonable to assume that their impact leads to a more or less homogeneous increase in h^* along the entire study area. The presence of such a bias would affect the particular values of h^* but would not significantly change the pattern of its alongshore variations and, therefore, the link between the local wave intensity and the rate of erosion or accumulation.

The closure depth was calculated for each nearshore grid cell using numerically simulated wave properties along the eastern Baltic Sea coast. The time series of the significant wave height and peak period were extracted from the long-term simulations of wave fields for 1970–2007 with a temporal resolution of 1 h for the entire Baltic Sea using the third-generation spectral wave model WAM [40] driven by properly adjusted geostrophic winds. The regular rectangular model grid with a resolution of about 3 × 3 NM extends from 09°36′ to 30°18′E and from 53°57′ to 65°51′N [17]. The directional wave energy spectrum at each sea point was represented by 24 equally spaced directions. Differently from the standard configuration of the WAM model, an extended frequency range (42 frequencies with an increment of 1.1, up to about 2 Hz or wave periods down to 0.5 s) was used to ensure realistic wave growth rates in low wind conditions after calm situations.

The presence of ice was ignored. Doing so is generally acceptable for the southern part of the coastal section in question but may substantially over-estimate the overall wave intensity in the Gulf of Riga. The estimates for the highest waves and for the closure depth, however, are much less affected by the presence of ice during some months. The windiest months are November–December in the northern Baltic Sea [41]. This is even more clearly evident in terms of wind speeds over 13.9 m/s (over 7 m/s on the Beaufort scale [42]). A shift of the most stormy period to January since about 1990 [42] is accompanied with a similar change in the ice-free period. Therefore, the strongest wave storms (that define the closure depth) occur before the ice formation. For the same reason the highest percentiles of wave conditions and the average wave height over the ice-free period have no correlation with the length of the ice cover even in the Gulf of Finland [43].

The nearshore wave properties (significant wave height H_s and peak period T_s) were commonly extracted for the grid points closest to the shoreline. If, however, the water depth at such points was less than the threshold $H_{s,0.137}$, the next offshore grid point was chosen. Doing so was necessary, for example, for three grid points in the vicinity of the Estonian-Latvian border near Ikla and Ainaži (Fig. 2). In order to account for the potential interannual variability in the wave conditions, we used two methods. Firstly, the closure depth was found as an average of a set of the relevant annual values for each of the 38 years of the simulation period. Secondly, it was estimated directly from the hourly time series of simulated wave heights. The results differed by a few mm.

The intensity of coastal processes is characterized in terms of the long-term rate of coastal erosion or accumulation, extracted from the data obtained from monitoring of coastal geological processes monitoring in Latvia. The monitoring network for this about 497 km long coast was started in 1987–1990, depending

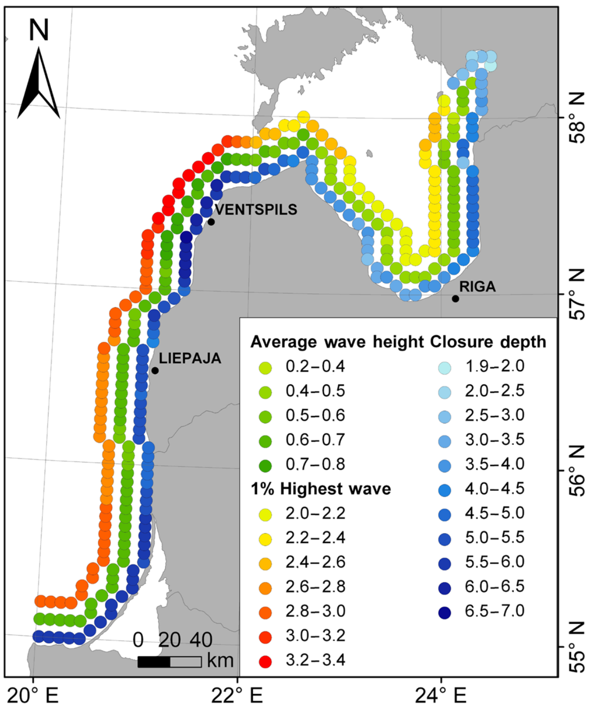

Fig. 2. Longshore variation of the average significant wave height, threshold for the highest 1% of significant wave height and the closure depth (colour scale, m) for wave conditions in 1970–2007. The closure depth is given for the centres of grid cell of the wave model, data from which are used in calculations.

on the particular coastal section. Starting from 1993–1994, the stationary network covers all the coastal area of Latvia [22,44]. The monitoring system consists of two clusters of activities: firstly, the levelling of coastal cross-section profiles (usually from the waterline up to an area well beyond the reach of waves and aeolian transport) and, secondly, regular measurements of the recession of the upper part of the coastal bluff.

The beach and (fore)dune profiles cover the vicinity of the waterline (attached to the long-term mean water level, interpreted here as the zero level in the Baltic height system) and the subaerial transition zone. The latter is interpreted as the part of the shore, which is actively involved in the contemporary coastal processes such as wave- and wind-driven accumulation and erosion, including berms and active aeolian patterns such as foredunes and dunes, if present. The inland border of a profile was determined using the data on the intensity of vertical changes in the coastal terrain. As a rule, the areas in which the vertical changes exceeded 0.01 m/year were included into the data set. The profile length varies between 30 and 200 m, depending on the coastal section. The overall data set – about 400 profiles – is divided into groups of 20–50 that characterize particular coastal districts. The distance between profiles in each group is 200–800 m. The distance between the groups depends on the diversity of the coastal section and is 5–10 km on average. The location of each profile group has been chosen to represent the specific character of the local coastal system, with a goal to characterize as adequately as possible its sediment budget. The levelling is carried out once a year, usually in late summer and autumn when the low summer-season waves have restored the beach that might have been damaged during autumn and winter storms.

The levelling has been used in those coastal sections where the broad beach and the aeolian relief have been developed [44]. In several sections the upper part of the coast consists of a narrow beach and a steep bluff or scarp. The sediment balance for such sections was calculated using about 2000 properly grouped scarp retreat stations, which allowed determining the distance between a fixed point inland and the steep coastal bluff and, consequently, the bluff retreat rate. The mapping of the retreating bluff has been done using partly the methodology for the research of coastal erosion in the rivers of Great Britain and Canada [45,46]. The distance has been measured by a tape-line with a field accuracy of 0.1 m. The distance between the individual stations is about 10–50 m, that is, much shorter than the distance between profiles. In essence, the levelling allows for more detailed estimates of the sediment budget (both erosion and accumulation) in a particular coastal section whereas the measurements of the scarp give a picture of non-invertible processes.

The profiles and the results, characterizing the bluff retreat, were used to calculate the overall change to the sediment volume as follows:

$$V_i = \sum_{i=1}^{N} \frac{Q_i + Q_{i+1}}{2} L_i , \tag{2}$$

where V_i is the total volume in a particular coastal domain between the location of two profiles, $i = 1, \ldots, N$, Q_i is the cross-sectional area of a single profile, L_i is the distance between the profiles or scarp retreat stations and the change to the sediment volume of two profiles is given in cubic metres per annum and per metre of the coastline.

3. SPATIAL VARIATIONS IN THE WAVE INTENSITY

The longshore variation in the simulated closure depth (Fig. 2) largely coincides with similar variations in the average significant wave height and the threshold for the 1% of highest wave conditions [47]. Only at some places (for example, near Kolka) it is much better correlated with the long-term average wave height. As expected, to some extent it follows the spatial variations of the long-term threshold for the 5% of highest wave conditions [47]. The relatively large values of the average closure depth are found along the western coast of the Kurzeme Peninsula (about 5.4 m). On average, the calmest is the western coast of the Gulf of Riga where the average closure depth is 3.5 m. The largest values of h^* for single calculation points, up to 6.58 m, are found along the western coast of the Kurzeme Peninsula between latitudes 57° and 57°30′. To the south of this area the closure depth decreases to some extent and reaches a local minimum (4.35 m) in the neighbourhood of the border between Latvia and Lithuania. It increases again to values around 5.8 m further south along the Curonian Spit and Sambian Peninsula.

The closure depth is substantially smaller, in the range of 2.8–4.9 m along the western and eastern coasts of the Gulf of Riga, and well below 3 m in the interior of Pärnu Bay [36]. The smallness obviously reflects a relatively low wave intensity in this water body that is connected with the rest of the Baltic Sea via quite narrow and shallow straits. Interestingly, the closure depth reveals considerable variations along the Gulf of Riga, with an average of 3.5 m and a minimum of 2.8 m along its western coast, and clearly large values (4.3 m on average) along the eastern coast. This difference evidently reflects the anisotropic nature of wind fields in this region: the angular distribution of strong winds contains two peaks corresponding to SW and N–NW winds, respectively [33]. There is, in general, a good agreement between the longshore variations of the closure depth and the threshold for the 1% of the highest waves whereas the match of the closure depth and the average wave height is worse. A more detailed discussion of this match is presented below.

4. AREAS OF EROSION AND ACCRETION

It is of direct interest for applications and coastal zone management to see whether the numerically simulated estimates for the closure depth match the areas of intense erosion or accumulation. The relevant comparison is made based on the above-described coastal monitoring data.

A comparison of the spatial variations in the closure depth with the existing data about the rates of erosion and accumulation along the Latvian coast [6] shows that there is a certain general consistency between the two characteristics at large scales. Namely, both the erosion and accumulation rates are systematically larger in sections with large closure depths (equivalently, with a relatively large overall wave impact) (Fig. 3). This feature indicates that the coasts in question are, in general, in a rapid development phase. As substantial cross-shore sediment motion is unlikely here, the coasts are characterized by the motion of substantial amounts of sediment along the coast [22]. The length of eroding coastal sections considerably exceeds that for accumulating sections [6,22] (Figs 3, 4). Only very few sections are close to equilibrium (Fig. 5). For some areas (e.g., most of the eastern coast of the Gulf of Riga) no data exists [6,22].

This consistency is almost fully lost on the level of pointwise comparison of the closure depth with the erosion and accumulation rate (Fig. 4). This feature signifies that the key parameters governing this rate are the local properties of the coast (incl. the orientation of the coastline with respect to the predominant wave approach direction) rather than alongshore changes to the wave intensity.

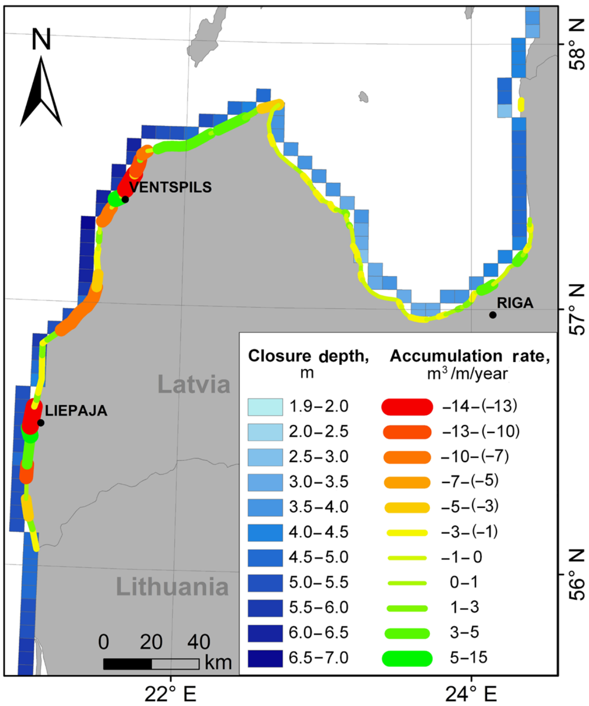

Fig. 3. Comparison of the closure depth for wave conditions in 1970–2007 with the accumulation rate along the Latvian coast for about 1990–2006 [6]. This rate is positive for accumulation areas and negative for erosion areas. There is very little data for the eastern coast of the Gulf of Riga to the north of the latitude 57°20′N.

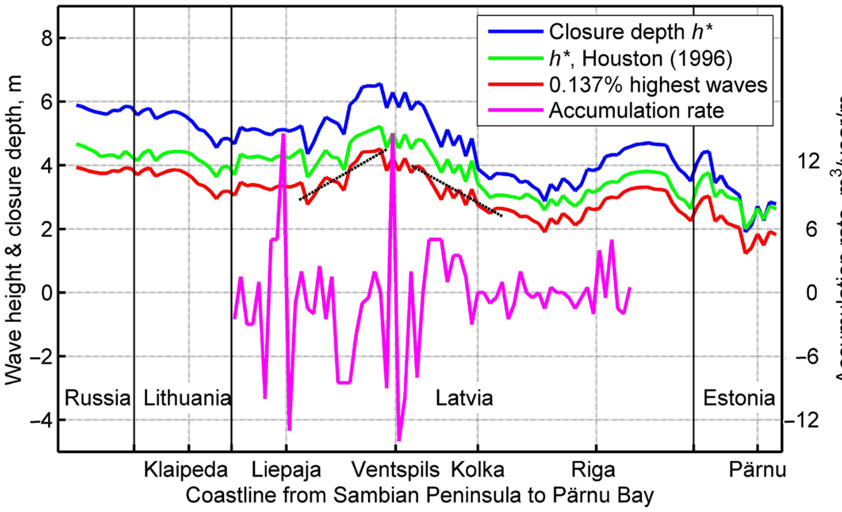

Fig. 4. Spatial variation of the threshold for the highest 0.137% significant wave height, the closure depth calculated from Eq. (1) and from the simplified relation $h^* \approx 6.75H_{sa}$ of Houston (1996) [37] and the erosion (negative values) and accumulation (positive values) rate along the eastern Baltic Sea from 20°E, 55°N on Sambian Peninsula (Fig. 1) up to Pärnu Bay with a step of about 3 NM (5.5 km). Short dashed lines reflect the mean slope of the longshore variation to the highest 0.137% of waves.

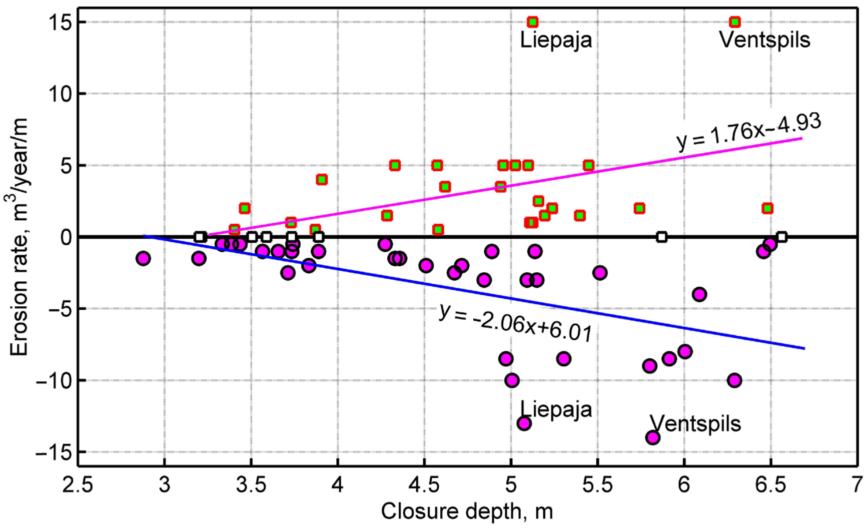

Fig. 5. The dependence of the erosion (magenta circles) and accumulation (green squares) rate on the closure depth along the Latvian coast. White squares correspond to the coastal sections with no changes in the sediment volume. The rates for the vicinity of Liepaja and Ventspils are strongly impacted by the harbour constructions.

The areas with the largest accumulation and erosion rates at calculation points 35–36 and 53–54 (Figs 3, 4) reflect the impact of large harbours at Liepaja and Ventspils. Their quays and breakwaters largely block the natural littoral drift and cause rapid accumulation to the south of these harbours and extensive erosion to the north of the latter. An area of relatively rapid accumulation on the western coast of Kurzeme Peninsula apparently is connected with a considerable change in the orientation of the coastline at 57°35′N and the related change in the approach angle of predominant waves. A similar accumulation to the east of Riga (River Daugava mouth) most likely reflects the river-induced sediment inflow.

There is only one mostly naturally developing longer coastal section in the study area at calculation points 43–51 where erosion predominates. Also, there is only one longer section at points 60–67 along the NW coast of the Kurzeme Peninsula where accumulation predominates. It is remarkable that these sections host the largest average longshore gradients for both the wave height and the closure depth. The section where both these quantities increase over a relatively long distance (between calculation points 44 and 48) is rapidly eroded while there is quite intense accumulation in a section between points 60 and 66. A sensible explanation to this property can be found from a qualitative analysis of the wave approach directions. Namely, waves created by N–NW winds approach the NW coast of the Kurzeme Peninsula almost shore-normal. Therefore, waves approaching from SW mostly govern the longshore transport here and make it move to the NE. As the intensity of waves gradually decreases in the same direction, the littoral flow also decreases. The resulting convergence of littoral flow becomes evident as sediment accumulation. An opposite situation where the wave activity increases along the coast in the direction of the littoral flow occurs at points 43–51. This intensification of wave impact (divergence of the related wave energy flux) becomes evident as a longer eroding section.

The described features are intuitively obvious when the magnitude of the longshore sediment flux is associated with the longshore component of the energy flux model [48]. Remarkably, they become evident here already on the level of longshore variations of the closure depth. In essence, this property means that the location of extensive domains of accumulation and erosion can be extracted already from the nature of longshore changes to the wave heights, provided the predominant wave approach direction is known.

Notice that the linear expression for the closure depth only coincides with the results of Eq. (1) in the interior of Pärnu Bay (Fig. 4). In this region the extreme wave heights are usually damped to some extent due to the joint effect of refraction and wave-bottom interaction, but these factors insignificantly affect the propagation of shorter waves under moderate wind conditions. Generally, the linear expression seems to underestimate the closure depth by about 20%.

There is effectively no correlation between the closure depth and the accumulation or erosion rate along the coastal section in question (Fig. 5). On the other hand, the variability of the erosion or accumulation rate clearly increases with the increase in the closure depth. Analysis of the interrelation of erosion and closure depth separately for accumulation and erosion areas (Fig. 5) reveals an obvious relationship between the development of the coast and wave activity: the intensity of coastal changes (expressed as either the erosion or accumulation rate), clearly increases with the increase in the wave activity. The relevant correlation coefficients are, however, quite small ($r^2 = 0.29$ between the closure depth and erosion rate; $r^2 = 0.13$ between the closure depth and accumulation rate) and, formally, no statistically significant relationship can be identified. The difference between these coefficients is probably associated with the overall sediment deficit in the considered coastal section. In general, the described properties simply reflect the intuitively obvious fact that the overall intensity of coastal processes increases with the increase in the wave impact. It is also consistent with the observation that both the accumulation and erosion rates show greater changes and amplitudes in Baltic Proper than in the western part of the Gulf of Riga (Fig. 3).

5. DISCUSSION AND CONCLUSIONS

The described results not only confirm the intuitively obvious perception – that the overall intensity of coastal processes directly depends on the available wave energy – but also expand it towards better understanding of the spatial variation of the driving forces shaping the eastern Baltic Sea coasts. This variation, as expected, to large extent follows the similar variation in the threshold for 1% of the highest waves. This threshold (that can be easily extracted from contemporary wave reconstructions) eventually can be used as a basic indicator of the wave impact on coastal processes in this water body (although it usually contains several storm events that are not accompanied by high water level and thus have clearly lower impact on coastal processes compared with the strongest storms).

The numerically estimated closure depth for the coasts of the Baltic Proper considerably exceeds its value for the Gulf of Riga. While the largest average closure depth occurs along the western coast of the Kurzeme Peninsula (about 5.4 m), the calmest is the western coast of the Gulf of Riga where the average closure depth is 3.5 m. These values evidently are characteristic for the Baltic Proper and large sub-basins of the Baltic Sea, respectively, while in smaller semi-sheltered bays such as in Pärnu Bay or near Pirita Beach in Tallinn Bay [20] it typically is in the range from 2 to 2.5 m.

The intensity of coastal processes is usually thought to be a function of wave energy flux, a quantity that also depends on the wave period. The typical wave periods vary insignificantly in the Baltic Proper and reveal almost no temporal variation along its eastern coast [18]. It is, therefore, somewhat unexpected that the closure depth (and thus the intensity of coastal processes) shows noticeable deviations from the threshold $H_{s,0.137}$. An obvious source of these deviations is the potential variation in the water depth in the nearshore: a part of wave energy may be redistributed and/or damped before it reaches the surf zone. A more subtle reason is the potential difference in peak wave periods, corresponding to very rough seas in different sea areas. While such a difference naturally exists between the Baltic Proper and the Gulf of Riga, recent research (that will be published elsewhere) has shown evidence about systematic difference in the peak periods in strong storms in southern and northern parts of the Baltic Sea. These deviations, therefore, basically signify the complexity of wave processes and their extensive spatio-temporal variations in the Baltic Sea and along its coasts.

The presented estimates are based exclusively on simulated wave heights and periods, and ignore the dependence of the longshore sediment flux on the wave approach direction. The performed analysis suggests that the longshore variations in wave height may still be useful for the approximate determination of the location of major accumulation and erosion domains. Namely, these coastal sections that host the largest average increase in the (average or extreme) wave height (or closure depth) along the coast in the direction of the littoral flow should reveal erosion features. Contrariwise, accumulation is expected to occur in sections where the wave height decreases along the coast in this direction. In other words, the location of extensive domains of accumulation and erosion can be extracted already from the analysis of the wave heights, provided the predominant wave approach direction is known.

The gradual shift in the directional distribution of winds in this area [49] that apparently is accompanied by similar changes in the wave directions [21] may seriously affect the magnitude of coastal processes in the study area. These potential effects call for more detailed studies of the associated changes in the coastal processes, the identification of major changes in the littoral flow and their consequences to the evolution of the beaches. These aspects may be particularly important for beaches from the Curonian Spit to Kurzeme. Differently from Estonian beaches that are stabilized by the postglacial land uplift to some extent, these beaches of the central Baltic Proper are mostly maintained by littoral drift of sandy sediment from neighbouring coastal sections.

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Lainekoormuse ja rannikuprotsesside intensiivsuse seosest Läänemere idarannikul

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On analüüsitud sulgemissügavuse muutumist ja selle seost ranniku kulutuse ning kuhjumise kohta teadaolevate andmetega piki Läänemere idarannikut Sambia poolsaarest Riia lahe kirdeosani. Pinnalainete parameetrid on leitud WAM-mudeli abil lahutusvõimega 3 meremiili aastate 1970–2007 jaoks. Sulgemissügavus on Läänemere avaosa rannikul tavaliselt 5–6 m (maksimaalselt 6,58 m), Riia lahe rannikul 3–4 m ja Pärnu lahes 2–2,5 m. Kiire kuhjumine ja kulutus toimub üldiselt rannalõikudes, milles lainete intensiivsus ning sulgemissügavus on suhteliselt suured, välja arvatud vähesed inimtegevuse poolt oluliselt mõjutatud piirkonnad. On näidatud, et lainetuse intensiivsuse või sulgemissügavuse pikiranda gradiendi alusel saab määratleda peamisi kulutus- ja kuhjepiirkondi: lainekõrguse kasv piki settevoolu suunda viitab kulutusele ning selle kahanemine kuhjumisele.