# CHAPTER 338

# Wind- and Sea Level-Induced Shore Evolution in Poland

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Abstract

The effect of climate change factors on Polish shoreline is investigated in mesoscales of decades and tens of kilometres along the entire Baltic coast, with emphasis on the selected segment from Ustka to Łeba. Intensification of westerly wind circulation and sea level rise (SLR) are quantified as an input in computations of shoreline change by a one-line model. Joint probability distributions of wind and sea level derived under an extensive programme employing field data are used to produce input for computations of shoreline change due to rare events. The computations prove that the effects of both wind change and SLR can be perceptible in mesoscales, although it is difficult to clearly single out one from the other. In general, the westerly intensification of wind climate along the Polish coast seems to be slightly less important than SLR. A separate qualitative analysis of the acceleration of Polish shore retreat noted in recent years points to wind change as one of the possible causes.

## 1. Introduction: Coastal Climate Change (CCC)

The present coastal climate in the Baltic area, including Poland, is believed to undergo perceptible change due to global warming. The sea level rise, an increase in storminess and annual sea level maxima, and the changing patterns of wind circulation are the most pronounced change features affecting the coastal processes. The potential changes in precipitation, evaporation, transpiration, and their various outcomes over the Baltic coast and its drainage area, are also investigated although they are not easy to predict reliably and accurately.

An analysis of the variation of the zonal and meridional components of the geostrophic wind vector allows one to draw conclusions on the change of both components in the 40-year period from 1951 to 1990. For the more pronounced zonal component, this appears to be a trend of 0.0125 m/yr having a 95-% confidence level. By and large, one may note an intensification of the westerly air flow over the Polish coast, reflected in a shift of predominant wind directions towards W and NW, at the expense of the SW-W sector. A schematic change in the wind direction rose postulated for 50 years from 1995 to 2045 is

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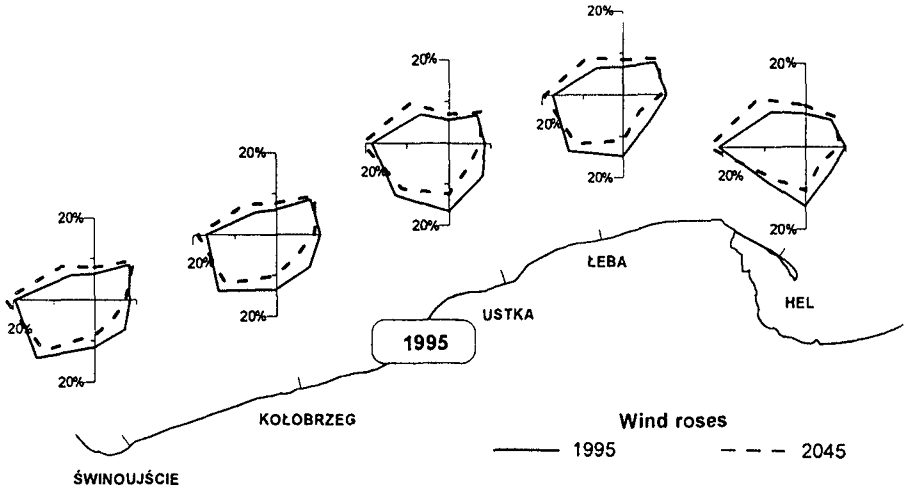



Figure 1. Frequencies of wind along the Polish coastline in 1995 (solid line) and postulated for the year 2045 (dash line).

depicted in Figure 1. In seasonal terms, the intensification of the westerly sector is particularly conspicuous in the winter season from October to March.

The mean sea level (SL) rise in Poland is presently estimated below 30 cm per century but its acceleration due to the greenhouse effect is taken into consideration (Zeidler 1995).

Another factor of climate change, i.e. storm intensity or 'storminess' can be analysed in terms of the annual sea level maximum (occurring once per year). One can prove that such storminess clealy increases over recent decades (Zeidler 1995). The growth trend of annual sea level maxima (ASLM) along the Polish coast is estimated about 10 cm per century.

It is also worthwhile to recollect that sea level increments $\Delta h$ (four- or six-hourly at the Polish stations) display a certain long-term trend (Zeidler 1995). Moreover, they have been found to be correlated with high sea levels.

The present practice identifies as storm surges the events at which high sea levels alone occur, which brings about ambiguities. In order to determine the linkage between high sea levels and significant sea level increments, an analysis of the two quantities has been carried out (Wróblewski et al. 1996), with the primary objective as the derivation of statistical and probabilistic characteristics for both datasets and subsequent identification of their common features. Taken as a criterion of similarity was the condition that the numbers of occurrences of both quantities (SL and SL increments) are nearly equal. Such similarity has been concluded for 4-hourly SL increments greater than 21 cm at Ustka and Gdańsk (Nowy Port) or 26 cm at Swinoujscie, versus $h \geq 563$ cm at Swinoujscie and Gdańsk and $h \geq 560$ cm at Ustka (mean sea level being 500 cm). Within the above approach, regressional relationships between the time series for SL and their increments have been established.

Further on, the trend of storm winds could have been determined on the basis of the sea level increments measured at Swinoujscie, Ustka and Gdańsk (Wróblewski et al. 1996). This was done by relying on relationships between $\Delta h$ and storm winds in selected areas; a detailed analysis of statistical characteristics of storm winds and identification of their trend would have required processing of thousands of synoptic maps (e.g. above 100,000 maps taken every 4 hours in the investigated time span of 1955-1990).

The two major factors of CCC, i.e. wind and sea level in Poland are dealt with in this study while other CCC effects (primarily temperature, precipitation and groundwater changes) are incorporated in a coastal management programme led by the first author, where they contribute to changes in land-use patterns, flooding of coastal lowlands, cliff stability and other phenomena.

The basic objective of this study is to determine the effects of wind change and sea level change on the evolution of the Polish coastline.

It is interesting to note that the intensification of the westerly circulation has also been noted along the Danish coast. Figure 2 provides evidence for a time span of 100 years, showing increasing frequency of high wind speeds of the westerlies. The atmospheric circulation in Denmark has been shown to change by enhancement of the westerly winds and the clockwise turning of the predominant winds (from W to NW along the Jutland Peninsula coast investigated by Christiansen and Bowman, 1990). The wind change is accompanied by a more severe wave attack and retreat of the more exposed coastline segments.

In this paper, description of the climate change precedes shore evolution computations, from which conclusions can be drawn as to the evolution of the Polish coast in decadal scales, and these findings can be compared with the prototype data available.

The entire Polish coast measures five hundred kilometers between the mouth of the Oder (Odra) River and Poland's eastern border with Russia across the Vistula Spit. All over the Polish coast one encounters coastal lakes/lagoons of glacial origin. The same origin is assigned to the Hel Peninsula, a spectacular yet vulnerable to storms and climate change 30-km barrier separating the Gulf of Gdańsk from the open sea. Although the large-scale evolution of the Hel Peninsula is also investigated, this paper describes only some results obtained for the coastal stretch from Ustka to Łeba, belonging in part to the former category (lagoonal barrier).

The primary objectives of the study discussed in this paper consist in assessing the effects of climate change on the evolution of Polish coastline. The two basic effects tested are sea level change and wind change, treated both separately and jointly.

## 2. Joint Characteristics of Coastal Phenomena

In an investigation of shore evolution due to climate change one faces the necessity of focusing on joint characteristics of coastal phenomena, such as waves, sea level and wind. Also, extreme cases of coast evolution should be looked at. The selection and definition of extreme cases brings one to the problem of joint probability distributions for coastal quantities (such as sea level, wave parameter(s), wind etc.). By using the software produced for this programme one is able to compute shoreline changes or coastal evolution for every situation (sea level, wind speed and direction and at the same time the respective wave climate and other derivatives) but the open question remains how wave parameters are correlated with wind and sea level, and which combinations thereof are representative for extreme cases.

Hence four-dimensional probability distributions of wind (speed and di-

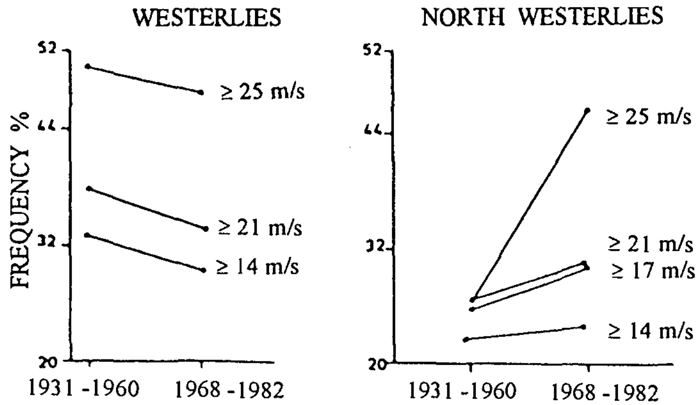



Figure 2. Change in wind direction along a latitudinal segment of NW Jutland (Klitmoller to Blokhus) shown by Christiansen and Bowman (1990).

rection), wave height and sea level have been investigated by the use of a large database for the Polish coastal weather stations, covering the years 1955–1990. At the beginning of the investigations it was realised that the probability of higher sea levels (exceeding 60 cm above the multiyearly mean value) might depend on wind direction. This would mean *inter alia* that the local growth of the mean sea level along the Polish coast due to the expected changes in wind circulation patterns could be quite pronounced by the year 2050.

As the study proceeded, wind-wave parameters were found to be correlated with wind direction as well, which is linked to the effect of fetch. At the same time, the correlation of wave height and sea level is low (about 0.2 for the stations of Hel and Gdynia) for all wind directions lumped, but a clear dependence on particular wind directions is displayed in some classes of water levels.

Figure 3 illustrates the cumulative joint probability of wind speed and sea level for N and NW winds at Hel, while Figure 4 shows the counterparts for Gdańsk (North Harbour). The two graphs stem from different datasets, not only for their locations but also because of the concept by which they were selected. The data for Hel in Figure 3 were taken for all events, i.e. at regular time steps, every three hours over nearly 5 years from 1976 to 1981 (11,500 events). The data for Gdańsk were purposefully biased to represent the impact of storm events (defined as those with significant wave height above 1 m); they also cover a shorter time lapse (1991 to 1992 and some months of 1995; about 4,500 events).

The correlations between sea level and wind speed were tested in eight principal classes of wind directions. Sea levels were arranged in sets exceeding the numbers indicated in the top lines of the tables in Figures 3 and 4. In order to examine the dependence on wind strength, the datasets were truncated in the sense that all events with wind speed below 6 or 8 m/s were rejected.

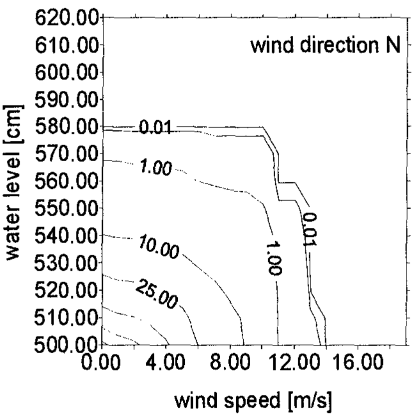
The correlations at Hel have been found very low in general; they seldom exceed 0.6 (the rightmost figures in the tables are not conclusive because of the low counts of data in those classes). The findings are certainly affected by the

**Hel**. Correlations sea level (L) - wind speed (v), truncated at v=6m/s

| | **500** | **510** | **520** | **530** | **540** | **550** | **560** | **570** | **580** |
|---|---|---|---|---|---|---|---|---|---|
| **N** | 0,253 | 0,177 | 0,146 | 0,016 | -0,03 | -0,23 | -0,03 | 0,408 | x |
| **NE** | 0,271 | 0,326 | 0,123 | 0,021 | 0,017 | 0,288 | 0,444 | x | x |
| **E** | 0,131 | 0,12 | 0,248 | 0,071 | 0,228 | 0,375 | 0,431 | x | x |
| **SE** | -0,02 | 0,04 | 0,249 | 0,041 | x | x | x | x | x |
| **S.** | 0,017 | 0,087 | 0,093 | 0,156 | 0,478 | 0,424 | x | x | x |
| **SW** | 0,073 | 0,104 | 0,155 | 0,141 | 0,232 | 0,262 | -0,06 | x | x |
| **W** | 0,277 | 0,293 | 0,306 | 0,266 | 0,321 | 0,335 | 0,326 | 0,408 | 0,116 |
| **NW** | 0,301 | 0,301 | 0,281 | 0,269 | 0,268 | 0,267 | 0,259 | 0,146 | 0,319 |
| | | | | | | | | | |
| | **N** | **NE** | **E** | **SE** | **S** | **SW** | **W** | **NW** | |
| **L - V** | 0,287 | 0,199 | -0,13 | -0,24 | -0,11 | 0,051 | 0,244 | 0,246 | |

**Hel**. Correlations sea level (L) - wind speed (v), truncated at v=8m/s.

| | **500** | **510** | **520** | **530** | **540** | **550** | **560** | **570** | **580** |
|---|---|---|---|---|---|---|---|---|---|
| **N** | 0,222 | 0,137 | 0,097 | 0,057 | 0,13 | -0,11 | 0,422 | x | x |
| **NE** | 0,095 | 0,146 | 0,062 | -0,08 | 0,163 | -0,53 | -0,4 | x | x |
| **E** | 0,13 | 0,06 | 0,237 | 0,034 | 0,251 | 0,424 | 0,41 | x | x |
| **SE** | 0,308 | 0,187 | 0,622 | 0,614 | x | x | x | x | x |
| **S.** | 0,069 | 0,097 | 0,266 | 0,264 | 0,702 | x | x | x | x |
| **SW** | 0,088 | 0,143 | 0,195 | 0,308 | 0,329 | 0,29 | 0,918 | x | x |
| **W** | 0,298 | 0,316 | 0,367 | 0,18 | 0,359 | 0,453 | 0,417 | 0,225 | 0,116 |
| **NW** | 0,35 | 0,333 | 0,276 | 0,278 | 0,301 | 0,322 | 0,253 | 0,041 | 0,687 |
| | | | | | | | | | |
| | **N** | **NE** | **E** | **SE** | **S** | **SW** | **W** | **NW** | |
| **L - V** | 0,238 | -0,05 | -0,15 | -0,18 | -0,05 | 0,049 | 0,254 | 0,218 | |



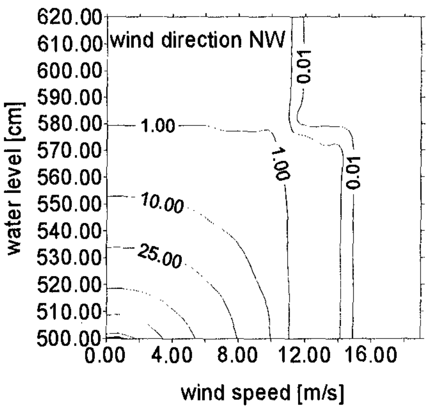




Figure 3. Correlation tables and cumulative exceedance graph for sea level and wind speed at the station of Hel, 1976-1981.

**North Harbour**. Correlations sea level (L) - wind speed (v), truncated at v=6m/s

| | 500 | 510 | 520 | 530 | 540 | 550 | 560 | 570 | 580 |
|---|---|---|---|---|---|---|---|---|---|
| N | x | 0,27 | 0,13 | 0,17 | 0,20 | -0,20 | -0,31 | -0,35 | x |
| NE | 0,35 | 0,35 | 0,35 | 0,17 | 0,64 | 0,41 | 0,44 | -0,24 | x |
| E | 0,47 | 0,39 | 0,34 | 0,54 | 0,54 | 0,50 | -0,57 | x | x |
| SE | -0,05 | x | x | x | x | x | x | x | x |
| S. | -0,05 | -0,23 | 0,45 | x | x | x | x | x | x |
| SW | 0,03 | -0,27 | -0,76 | x | x | x | x | x | x |
| W | 0,21 | 0,47 | 0,41 | 0,34 | 0,06 | -0,37 | x | x | x |
| NW | 0,29 | 0,26 | 0,20 | 0,07 | -0,15 | -0,05 | x | x | x |
| | | | | | | | | | |
| | N | NE | E | SE | S | SW | W | NW | |
| L - V | 0,66 | 0,52 | 0,31 | 0,01 | 0,13 | 0,15 | 0,23 | 0,31 | |

**North Harbour**. Correlations sea level (L) - wind speed (v), truncated at v=8m/s.

| | 500 | 510 | 520 | 530 | 540 | 550 | 560 | 570 | 580 |
|---|---|---|---|---|---|---|---|---|---|
| N | x | 0,18 | 0,07 | 0,10 | 0,04 | -0,20 | -0,31 | -0,35 | x |
| NE | -0,09 | -0,09 | -0,09 | 0,03 | 0,03 | 0,61 | 0,55 | -0,24 | x |
| E | 0,39 | 0,19 | 0,17 | 0,54 | 0,54 | 0,50 | -0,57 | x | x |
| SE | x | x | x | x | x | x | x | x | x |
| S. | -0,17 | -0,05 | x | x | x | x | x | x | x |
| SW | 0,22 | 0,12 | -0,52 | x | x | x | x | x | x |
| W | -0,07 | 0,21 | 0,19 | -0,07 | -0,24 | -0,37 | x | x | x |
| NW | 0,21 | 0,20 | 0,17 | 0,05 | -0,11 | -0,05 | x | x | x |
| | | | | | | | | | |
| | N | NE | E | SE | S | SW | W | NW | |
| L - V | 0,66 | 0,54 | 0,33 | -0,07 | -0,13 | 0,21 | 0,13 | 0,25 | |

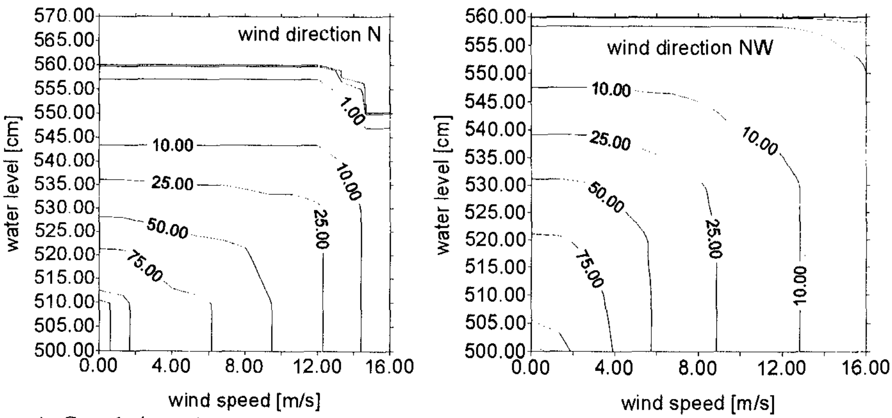



Figure 4. Correlation tables and cumulative exceedance graph for sea level and wind speed at the station of Gdańsk (North Harbour, 1991-1992..1995).

very specific location of the station and the complex nature of the controlling hydrodynamic phenomena.

For the North Harbour, the correlations become significant for NE winds. The relatively high marginal correlations with both N and NE winds (given at the bottom of table) are linked to the fact that all sea levels were taken into account there (also those below 500, i.e. below MSL).

In representation of some characteristic rare events in the subsequent shoreline evolution computations, reference should be made to the exceedance graphs of the type shown in Figures 3 and 4. The following couples of wind and sea level were chosen for the selected isolines of the exceedance probability $F$:

(a1) wind N 9 m/s + SL 545 ($F$=2%);
(a2) wind N 16 m/s + SL 500 ($F$=0.01%);
(b1) wind NW 9 m/s + SL 555 ($F$=2%);
(b2) wind NW 17 m/s + SL 500 ($F$=0.01%);
(c1) wind E 7 m/s + SL 535 ($F$=2%);
(c2) wind E 12 m/s + SL 500 ($F$=0.01%).

## 3. Shore Evolution Computations

The wind change trends alone have been taken for granted by Zeidler (1995), who computed the respective sediment transport along the Polish coast in the 50-year time span, and drew conclusions on shoreline evolution. Despite a sharp change in wind direction (but not speed) the alteration of sediment transport rate and the subsequent shoreline evolution was not found dramatic, due to the wind change alone. Yet it was concluded that shoreline change might become quite conspicuous if the wind change is added to the accompanying storm surge or a sea level rise.

The shoreline computations in this study are founded on the one-line theory, which ends up with the diffusion-type equation

$$\frac{dy}{dt} = A\frac{d^2y}{dx^2} - B \tag{1}$$

in which

$A = \frac{2}{(1-p)h_c}\frac{\partial Q_l}{\partial \varphi}$

$B = \frac{2}{(1-p)h_c}(\frac{\partial Q_l}{\partial x} + q_c)$

$h_c$ = depth of closure,

$p$ = porosity of bed sediment,

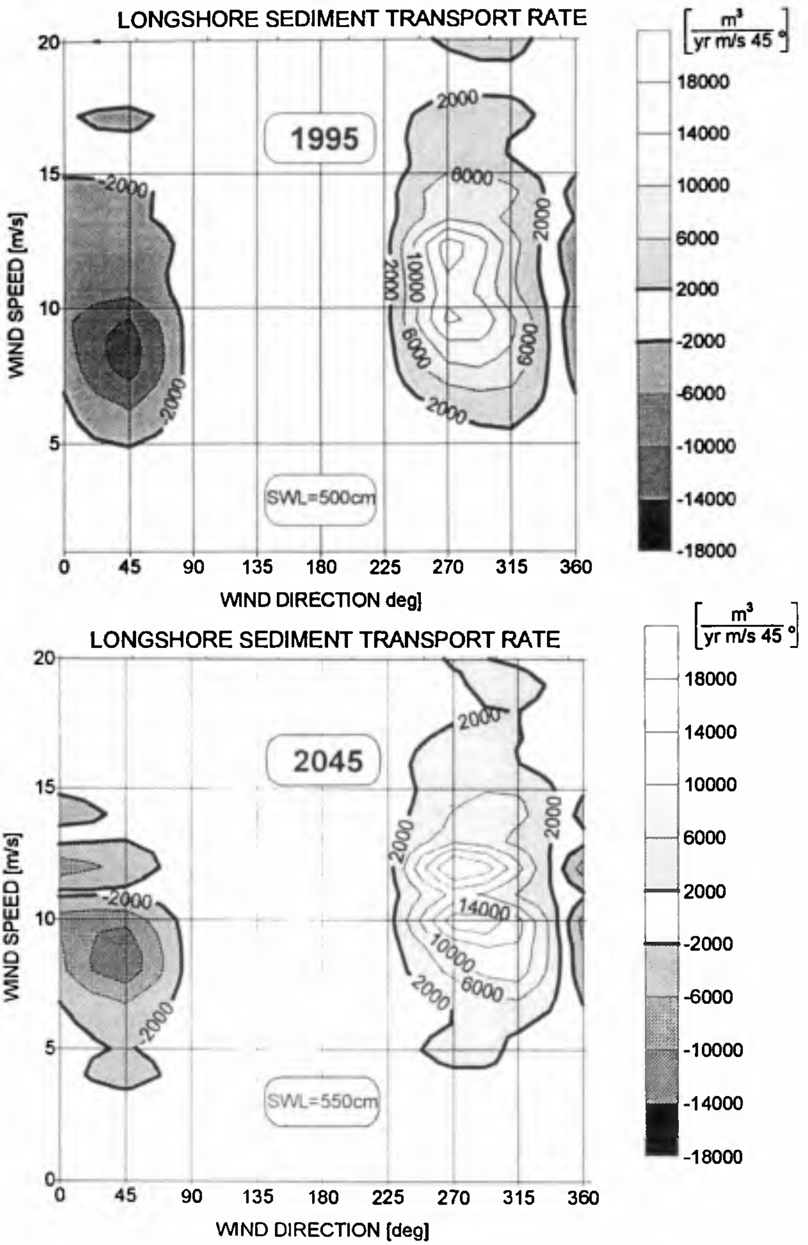
$Q_l$ = longshore sediment transport rate,

$q_c$ = cross-shore transport rate per unit length along shore,

$t$ = time,

$x$, $y$ = longshore and cross-shore coordinate of shoreline.

In order to determine the long-term shore evolution due to changes in wind, waves and sea level, by the above one-line scheme, an extensive computational procedure had to be employed. It encompasses five major subroutines: (1) preparation of input data with CCC quantities (wind, wind-induced waves and sea level); (2) arrangement of probability distributions for wave height and sea level in the format accepting CCC; (3) computations of sediment transport for the whole domain of wave height and sea level occurrence; (4) integration of sediment transport rate over representative time spans, with their probability distributions; (5) one-line type assessment of shore evolution over the time span of CCC.




**SEDIMENT TRANSPORT VS. WIND,ŁEBA**

Figure 5. Longshore sediment transport rate as a function of wind speed and direction at Łeba, for the years 1995 (SWL datum 500, top) and 2045 (SL rising by 50 cm to SWL datum 550, bottom).

Waves are computed routinely by Krylov's 'spectral' method calibrated against field data. A Battjes/Jansen-type algorithm for irregular wave transformation is used as an input of the IBW PAN program for wave-induced currents, and the sediment transport formulae are Bijker-type for longshore movement and IBW PAN modified Bailard-type for cross-shore transport. Sea level controls the shore evolution at the places where shoaling and the closure depth intervene but is not included in nonlinear interactions with waves.

Hence in our routine, the input wind change leads to wave climate change, waves producing currents and then sediment transport. On the basis of that input, together with sea level rise, shore evolution patterns are produced.

The results of our computations of the longshore transport are depicted in Figure 5. For every cell of particular wind speed and direction one has the sediment transport rate computed for the present situation (1995) and for the future (2045). It should be noted that the future situation can arise in two versions — wind change only and wind change plus sea level rise. Hence at present one has the status shown at the top of the drawing, while in the future one may face two different situations with sediment transport for sea level change and for wind climate change.

The coefficients $A$ and $B$ in the one-line equation are functions of longshore sediment transport rate (partial derivatives) and cross-shore rates as well (per unit length along the shore). Those coefficients were assessed separately for every location of the study area, with respective closure depths, wave incidence angles, breaking parameters etc.

The study area was confined to the coastal stretch between Ustka and Łeba. Various climate input situations were tested. In addition to the rare cases selected from the joint probability graphs as described in Section 2 (situations a1–c2), the average year was also simulated. The latter encompassed aggregated westerly winds and aggregated easterly winds, for which one obviously had different sediment transport rates, different angles of wave attack etc.

The program USTLEB was compiled for computations of shoreline change in accordance with the one-line model, and was validated against the known analytical solutions (i.a. Larson et al. 1996). It is based on an explicit finite-difference scheme, where instablity problems do not arise in practice. Some peculiarities emerge at points of discontinuity (of sediment transport rate, shoreline position) but the difficulties are overcome by locally decreasing space steps and iterative finding of shoreline derivatives. Estimates of the partial derivatives of the longshore transport rate must also be reasonably derived in a practical way.

In the computations by USTLEB for the 45-km segment Ustka-Łeba, the following conditions were adopted:

(i) the time span 1995–2045 divided in 25 time steps 2 years each;
(ii) two basic versions of climate change: (a) wind climate change only, (b) wind change + sea level change, 50 cm per 50 years;
(iii) 'average year' and 'rare cases' a1–c2 as specified above for the wind ... sediment transport input.

Some results of the shoreline change computations are illustrated in Figure 6. Only the aggregated annual effects are shown to highlight the basic differences resulting from the impacts of the two major directional sectors of wind action along the Polish coast — from west to east (top) and east to west (bottom). The two annual components of shoreline change are strikingly different. The wind change effect is negligible vs. the sea level rise effect for the westerlies, and becomes of the same magnitude for the easterlies. The absolute magnitude of shoreline change is greater for the westerlies than for the winds

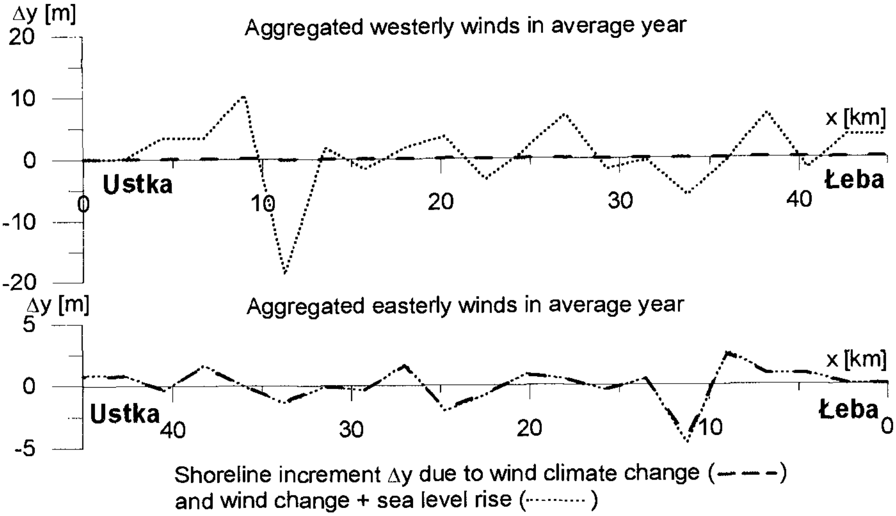



Figure 6. Results of one-line computations for the Polish coast segment from Ustka to Łeba, showing the 50-yr climate change effects — wind change only and wind change + SL change.

blowing from the eastern sector. If one takes into account that the former are more frequent than the latter, then one may venture the conclusion that the effect of wind change on the shoreline change is generally weaker than the impact of sea level rise.

Yet it is appropriate to note that the above conclusion is not so straightforward for the individual 'rare events' (a1–c2) tested in this study. Moreover, the contribution of the cross-shore transport to results of the computations by USTLEB also remains unclear so far. Attempts with various predictors of the cross-shore transport integrated along the shore transects (26 from Ustka to Łeba) have been inconlusive, and therefore are not reflected in Figure 6. More complementary research is required to shed light on the cross-shore effects. Needless to say, the latter may turn out fairly diversified along the Polish coast, if the research is extended far beyond the segment from Ustka to Łeba.

## 4. Prototype Data and Comparison with Computations

In preparation for the extended research on the entire Polish coast, as signalled at the end of Section 3, one may turn to the prototype evidence collected to date. On the basis of this data one can then venture some general observations and hypotheses relating to the evolution of the Polish coast in large scales of decades and hundreds of kilometres. Similarly, postulates can be formulated for the effects on shoreline of sea level rise and wind climate change.

For a period of slightly above one hundred years, Zawadzka-Kahlau (1994) retrieved the data on the position of Polish beach and shore features. The basic core of that collection consists of a vast database for shoreline ('waterline')and cliff/dune toe stemming from cartographic mapping dating back to

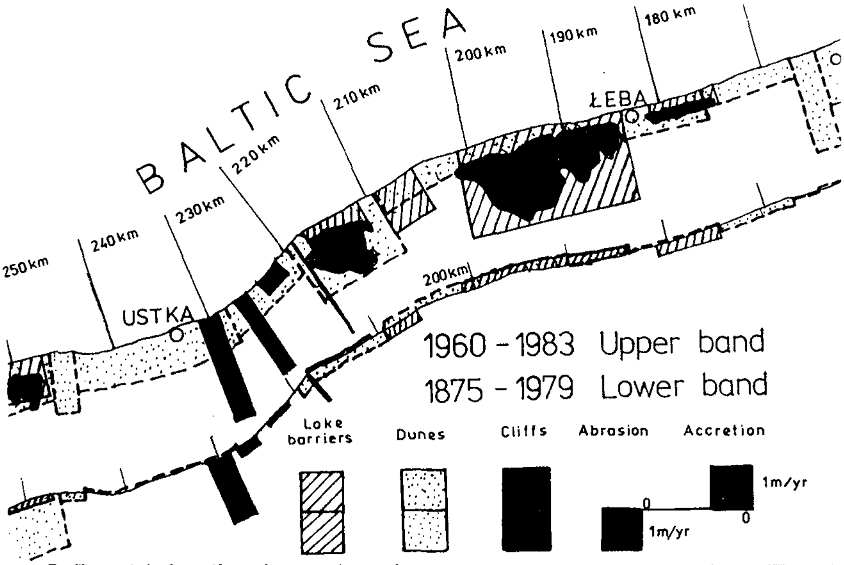



Figure 7. Decadal shoreline change along the coast segment from Ustka to Łeba (Zawadzka-Kahlau 1994).

the 19th century and extending over most of the Polish coastline. The statistical estimates obtained by processing of that database provide an opportunity of verifying the quantities resulting from our computations.

Under this study the database has been re-arranged graphically in the form illustrated in Figure 7 for the area Ustka-Łeba (although the same format was applied to the entire coast). Hence the shoreline change undergone in the years from 1875 till 1979 is shown in the lower band, while that in the more recent 20 years (1960-1983) is presented in the upper band. The purpose of such rearrangement is to provide insight into the general trends and to determine whether one faces some more conspicuous, dramatic shoreline changes in the recent years and if these changes are somehow linked to the change in wind circulation patterns and sea level change.

Consider the intensification of westerly winds, i.e. decadal increase in the frequency of W and NW winds depicted in Figure 1. More pronounced abrasion of concave shore segments could be expected, although to a different degree, depending on the coast type i.e. lake/lagoon barriers, dunes and cliffs. Indeed, such a trend is visible on many Polish coast segments. For majority of concave shore segments it can be concluded that more erosion is encountered in the recent years. There are a number of locations on concave segments where this can be claimed and where dramatic shift from accretion to erosion is noted. As a sound hypothesis, such behaviour can be assigned to the intensification of the westerly circulation. Unfortunately, this qualitative finding suffers i.a. from being embedded in the effect of sea level change. Unless differentiated more clearly, the two effects should be considered equally probable.

Figure 7 has been drawn for the stretch from Ustka to Łeba only. Accretion and erosion have been marked for three different shore types, accretion lines progressing towards the sea and erosion being marked as lines of landward retreat. One very conspicuous feature visible in the drawing is the clear growth of the erosion rate in the years 1960–1983. Identification of the nature and cause of that accelerated growth remains a task of future investigations — the combined effects of the westerly intensification and SL change are slightly more likely than decadal cyclicity of shore evolution change.

## 5. Summary and Conclusions

The effect of climate change factors (wind and sea level) on Polish shoreline has been investigated in mesoscales of decades and tens of kilometres along the entire Baltic coast. Emphasis has been placed on the selected segment from Ustka to Łeba. Intensification of westerly wind circulation and sea level rise (SLR) have been quantified as an input in computations of shoreline change by a one-line model. Joint probability distributions of wind and sea level derived under an extensive programme employing field data have been used to produce input for computations of shoreline change due to rare events.

The computations carried out in this study prove that the effects of both wind change and SLR can be perceptible in mesoscales, although it is difficult to clearly single out one from the other, and/or from other natural and man-induced effects. In general, the westerly intensification of wind climate along the Polish coast seems to be less important than SLR alone, in terms of decadal and centurial coast evolution patterns. Simple one-line computations of Polish coast evolution confirm the potential effects of wind change and SLR in both interannual coast evolution and extreme events (SLR + Wind Change). Both effects are also equally probable in the light of field data for Polish shore covering the period of more than one century.

The software routine worked out in this study provides a useful tool of long-term coastal planning facing coastal climate change. The data input (wind, wave, sea level, bathymetry) and the software itself pave way for more complex investigations of coast evolution, including the modelling of joint wind, wave and sea level input and chronology effects.

## ACKNOWLEDGEMENTS

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## REFERENCES

Christiansen Ch. & D. Bowman 1990. Long-term beach and shoreface changes in NW Jutland, Denmark: effects of change in wind direction. *Expected effects of climatic change on marine coastal ecosystems* (J.J. Beukema, ed), 113-122. Kluwer Acad. Publ.

Larson M., H. Hanson & N.C. Kraus 1996. Analytical solutions of the one-line model for shoreline change near coastal structures. *Jour. Waterway, Port, Coastal and Ocean Eng.* (in press).

Wróblewski A., R.B. Zeidler & J. Kaczmarek 1996. Analysis of storm surges, sea level and atmospheric pressure for the Polish Baltic coast. *Arch. Hydr. Envir. Engng* Gdańsk (in press).

Zawadzka-Kahlau E. 1994. *Coast evolution trends on the Polish Baltic* (in Polish). Ph.D. Thesis. Gdańsk University.

Zeidler R.B. 1995. Sea level rise and coast evolution in Poland. *Proceedings 24th Intern. Conf. Coastal Eng.* 3462–3475. ASCE, New York.