Archives of Hydro-Engineering and Environmental Mechanics
Vol. 48 (2001), No. 2, pp. 55–72

Specific Features of Sea Waves in the Pomeranian Bay

Barbara Paplińska

Institute of Hydro-Engineering of the Polish Academy of Sciences,
ul. Kościerska 7, 80-953 Gdańsk, Poland

Abstract

The paper concerns investigations of regional variability of the wave climate in the Pomeranian Bay. Analysis is based on the wave measurements taken during a period of four months and numerical wave model WAM4 results. The calculations covered period of 3 months in 1997 (Oct., Nov., Dec.) and two years: 1998, 1999. Analysis of wave modelling results shows that wave fields are not homogeneous in the whole area. The gradual increase (up to 50%) of yearly mean values of selected wave parameters can be observed going from the south-westerly of the Bay to north-easterly direction. Directional distribution of significant wave height is determined by wind climate and shape of the basin and prevails in easterly, south-easterly, south-westerly directions.

Introduction

In Polish literature there are only a few papers regarding the wave climate along the Polish coastline. These works are mostly based on the calculations made for stationary and uniform wind fields (Paszkiewicz 1988, Zeidler et al. 1995). 30 years visual observations of wave height in Baltic region can be also found in the report released by World Meteorology Organisation (WMO) in 1998. In 1997 the extensive works were carried out aiming at an implementation of third generation numerical wave model WAM4 for the Baltic Sea conditions (Paplińska 1998). At the same time the Interdisciplinary Centre for Mathematical and Computer Modelling (ICM) of Warsaw University has released operationally mesoscale atmospheric model UMPL. Close co-operation between ICM and the Institute of Hydroengineering (IBW PAN) enableded the utilisation of the results produced by the atmospheric model for sea waves modelling. The calculation results of the numerical wave model WAM4 were next compared to wave measurements which were simultaneously carried out for two locations along the Polish coast i.e. near Niechorze and Lubiatowo. The comparison revealed good conformity between predicted and measured values. This suggests that the wave model can reproduce real wave conditions for the Polish Baltic coast with sufficient accuracy. The analysis of the one-year WAM4 model results, concerning change in space and time of wave parameters, showed that the Polish Baltic coast can be divided into four regions with different wave conditions (Paplińska, Reda 1999). One of the selected regions is the Pomeranian Bay. Wave calculations for that region have been elongated. An analysis of the results concerning wave climate in the Pomeranian Bay is presented in the paper.

The paper has been divided onto three chapters. The first chapter is devoted to the presentation and analysis of wave measurements. Methodology of calculations of waves and the comparison between measured and calculated values are presented in Chapter 2 whereas Chapter 3 concerns mainly the analysis of hindcast results.

1. Offshore Waves in the Pomeranian Bay – Measurement Results

Wave measurements were carried out in the Pomeranian Bay using Directional Waverider buoy located in the vicinity of Niechorze village. This being shown in Fig. 1. Water depth at that point was 18 m. Measurements were conducted over a period of four months: October, November, December 1997 and January 1998.

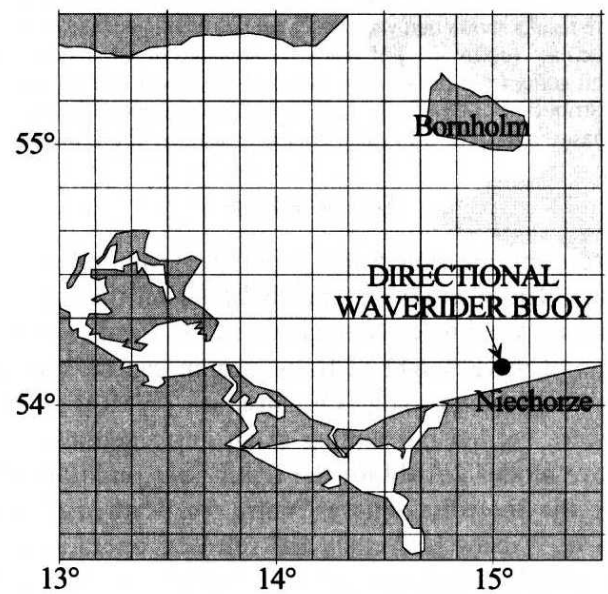

Fig. 1. Location of Directional Waverider buoy

Maximum and mean values, over the whole period of measurements, of the following wave parameters are given in Table 1:

H_{max} – highest wave in the record,

T_{max} – period of H_{max},
H_s – significant wave height (average height of the 1/3 highest waves),
T_s – significant wave period (the average period time of the 1/3 highest waves),
H_m – mean wave height (average height of the 1/2 highest waves),
T_m – mean wave period (the average time period of the 1/2 highest waves),
$T_p(s)$ – peak period: $T_p = 1/f_p$, where f_p is the frequency corresponding to the peak of frequency spectrum.

Table 1. Maximum and mean values of selected wave parameters. Results of wave measurements

	Wave parameters						
	H_{max} (m)	T_{max} (s)	H_s (m)	T_s (s)	H_m (m)	T_m (s)	T_p (s)
Max. value	6.5	9	3.3	8	2.1	6.3	11.1
Mean value	×	×	0.8	4.1	0.5	3.5	

The greatest measured height of an individual wave was 6.5 m and the maximum value of a measured wave period was 9.5 s. The highest significant wave height was 3.3 m. The mean value of the significant wave height over the period of measurements amounts to 0.75 m and mean significant period – 4.0 s. The highest peak period of spectrum occurred on 3rd November 1997 at 5 p.m. During this storm winds from the N-NNE sector blew along the longest possible fetch in the Baltic. Narrow spectra with 1 Hz frequency at the peak were characteristic for the wave energy distribution. Examples of wave spectra are shown in Figure 2.

On the basis of four months measurements the exceedance probabilities (in percents) of significant wave height and significant wave period have been determined. The results are shown in Figure 3. Most of the time (90%) significant wave heights do not exceed 0.2 m and significant wave periods 2.6 s, 50% of the time respectively 0.65 m and 4.2 s. Significant wave heights of over 1.0 m occurred 28% of the time.

Exceedance probability for one class of significant wave height ($H_{m0} > 0$) for eight directions of wave approach is shown in Figure 4. Direction is defined as the angle of the vector measured from geographical north clockwise – the direction in which the waves are travelling. 25% of waves move in an easterly direction (ENE-ESE sector), 21% and 20% respectively SW (SSW-WSW sector) and SE (ESE-SSE sector). The coastline at that point has ENE-WSW direction. Only 16% of the waves move south.

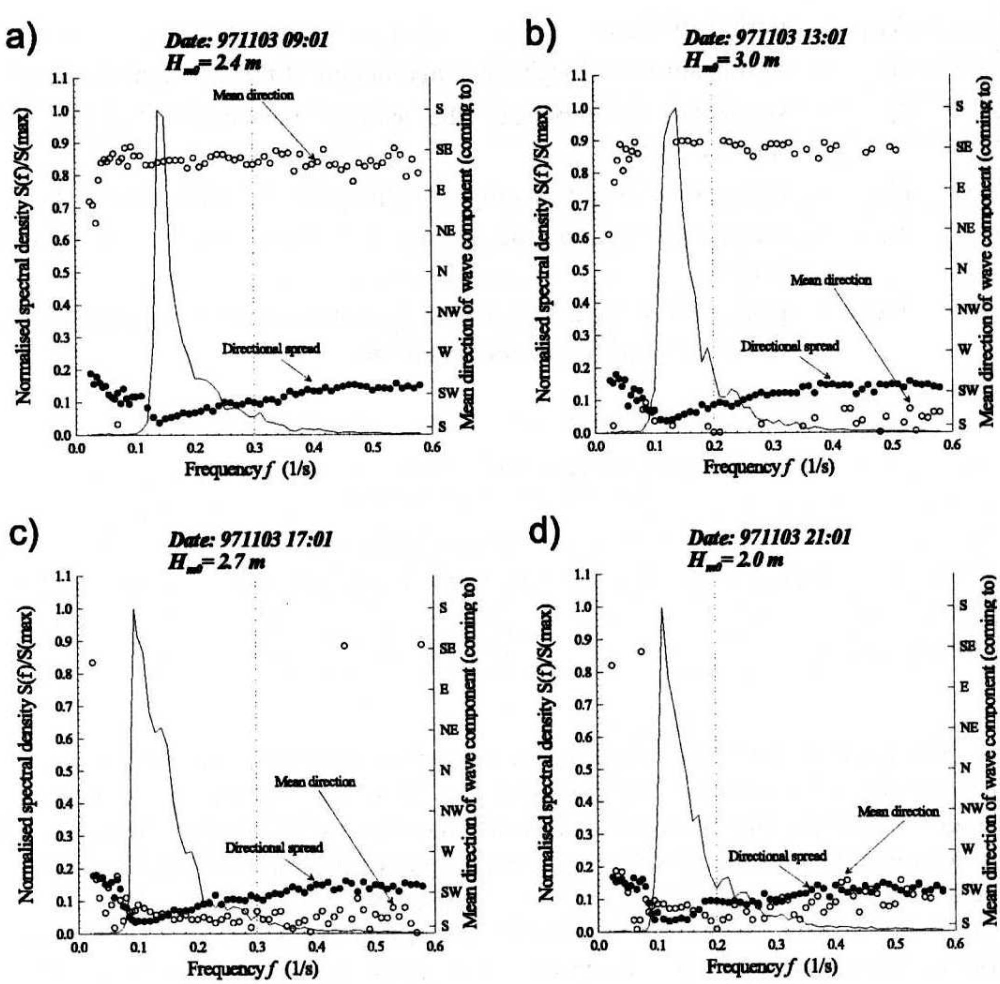

Fig. 2. Examples of frequency wave spectra measured during the storm on 3rd November 1997

2. Description of Calculations Performed

The calculations were carried out with the help of a WAM4 wave model (Komen et al. 1994). The adaptation of the model for Baltic conditions was described in detail in (Paplińska 1998). All calculations were carried out with a NEC SX 4B/2A vector computer available in ICM. Model parameters used in the calculations are presented in Table 2.

Main model input data in the form of analysed wind fields have been generated by atmospheric model UMPL provided by ICM (Jakubiak 1997). This is a mesoscale version of the British UKMO model being a source of the boundary files for the Polish local model.

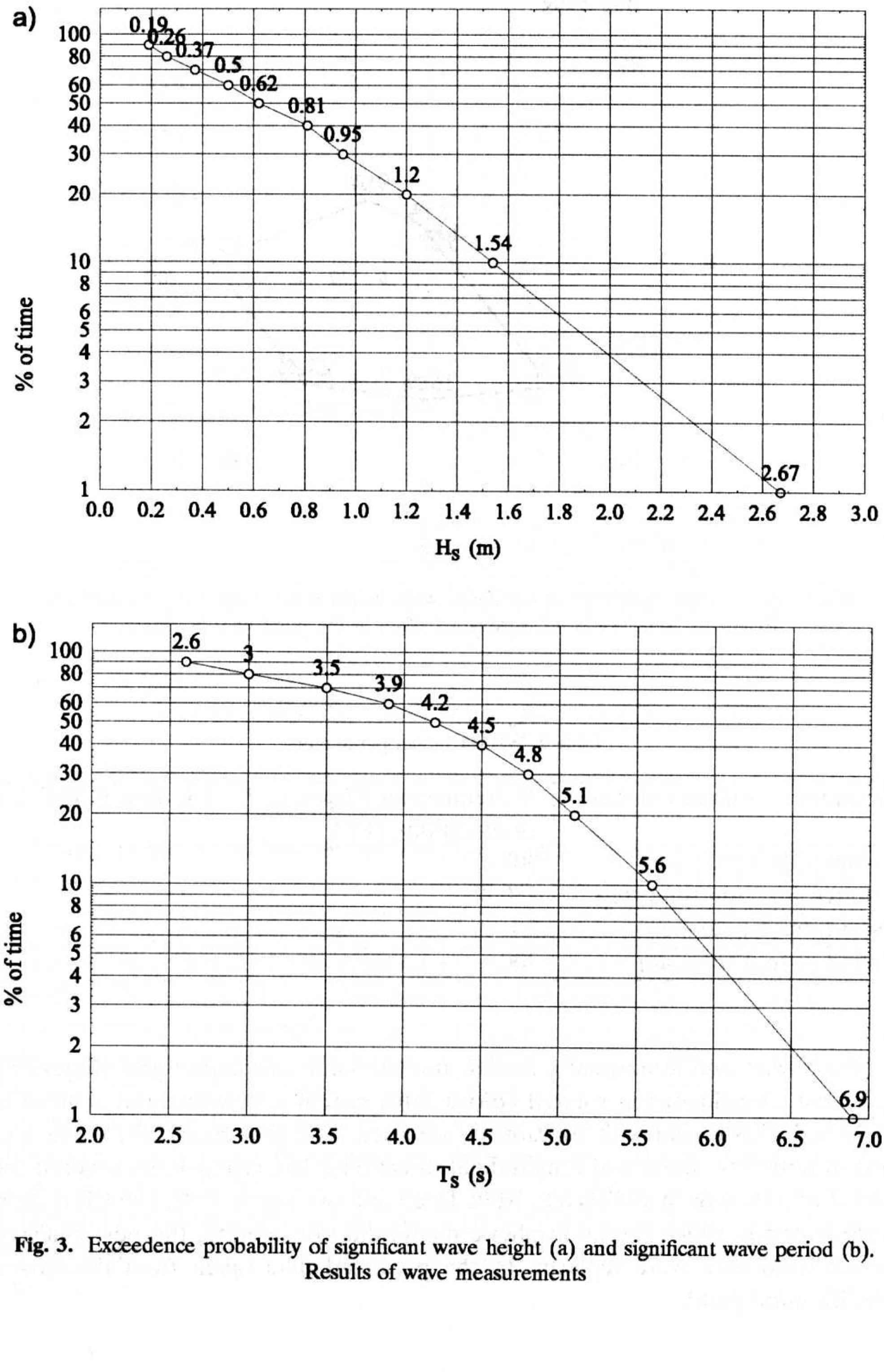

Fig. 3. Exceedence probability of significant wave height (a) and significant wave period (b). Results of wave measurements

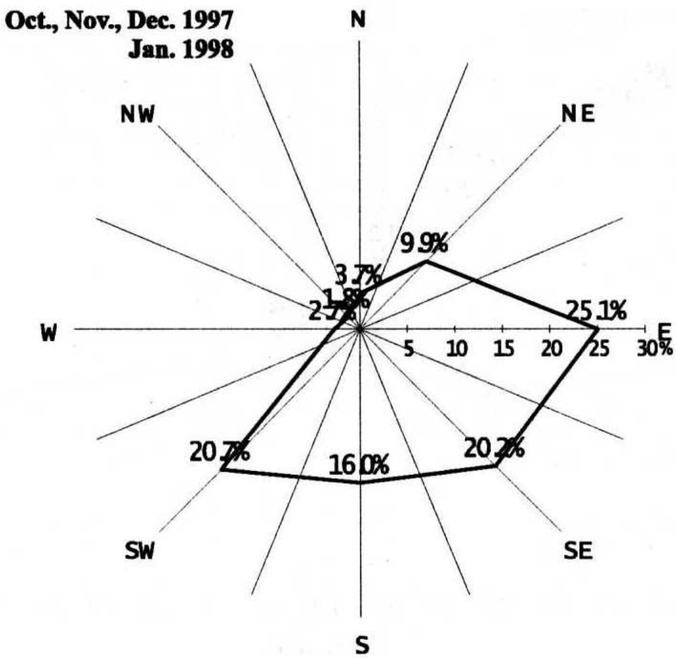

Fig. 4. Exceedence probability of significant wave height (over 0 m) in eight directions. Results of four month measurements taken at the point near Niechorze

Table 2. WAM4 model parameters

Frequency – directional grid	25 frequencies ($f_{(n+1)} = f_n \cdot 1.1$, $f_1 = 0.0505$ 1/s) 24 directions (15°)
Propagation time step	300 s
Source function time step	150 s
Wind input time step	3 h
Wind output time step	300 s

Both wave and atmospheric models use the same calculation grid (Figure 5). Spherical co-ordinates in rotated co-ordinates system with equatorial centred at 56°N and 19.3°E and with rotation 0° are used. The grid step is 0.15° (ca 16.7 km) in both latitudinal and longitudinal directions. The calculations covered the period of 3 months in 1997 (Oct., Nov., Dec.) and two years: 1998, 1999. For short periods during which the atmospheric model did not operate, the post-analysed output wind data were replaced by the predicted data taken from the closest possible time point.

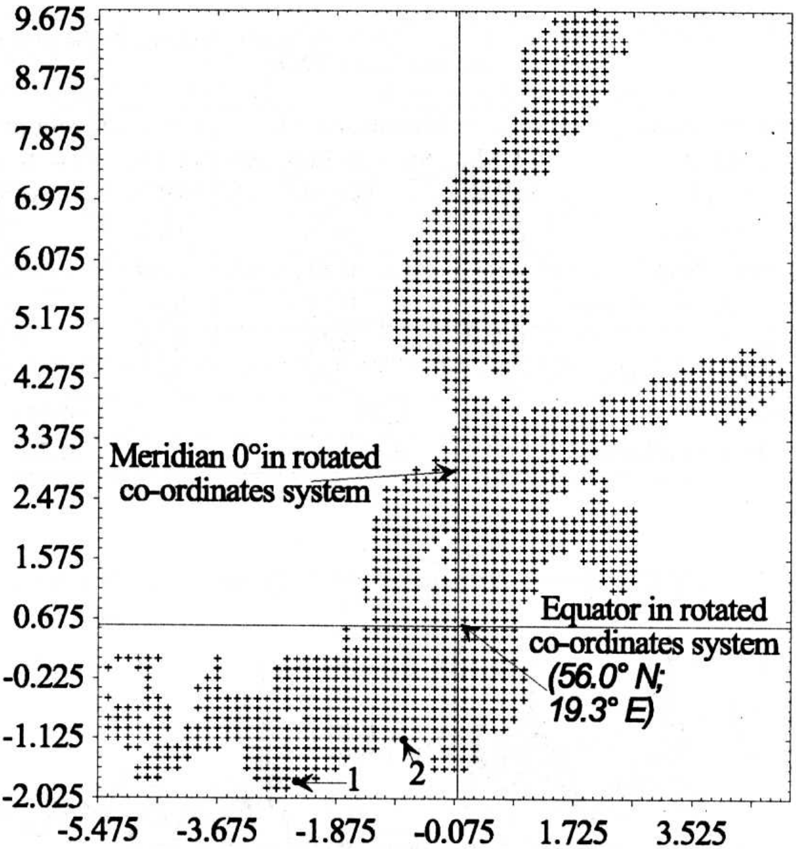

Fig. 5. Computational grid in rotated co-ordinates system used in the wave calculations and location of Directional Waverider buoy: 1 – Niechorze, 2 – Lubiatowo

Comparison of Calculation Results Produced by WAM4 Model with Field Measurements

Calculated significant wave height H_{m0} (WAM4) has been compared with the values of H_{m0} (DWR) corresponding to measurements made by a Directional Waverider buoy located near Niechorze and Lubiatowo. Location of the measurement points with respect to the calculation grid is shown in Figure 5. The comparison was made for the following periods: from 1st October 1997 to 14th January 1998 (Niechorze) and from 1st March 1998 to 28th February 1999 (Lubiatowo). For statistical analysis measured time series have been approximated by spline function in order to create data corresponding to the same time points as in the wave model: at Niechorze every 1 hour and at Lubiatowo every 3 hours. The gaps in measured time series have been excluded from further analysis. Basic statistical parameters of measured and calculated time series are shown in the Table 3.

Table 3. Basic statistical parameters of significant wave height predicted by the model (WAM4) and measured (DWR)

Significant wave height	Lubiatowo (1 Mar. 98 – 28 Feb. 99)		Niechorze (1 Oct. 97 – 14 Jan. 98)	
	DWR	WAM4	DWR	WAM4
Number of data	2629	2629	2369	2369
Mean value (m)	0.93	0.85	0.80	0.75
Standard deviation (m)	0.63	0.59	0.60	0.50
Variance	0.39	0.35	0.36	0.25
Maximum value (m)	3.6	5.0	3.5	3.6
Bias (m)	0.08		0.05	
Correlation coefficient	0.86		0.74	

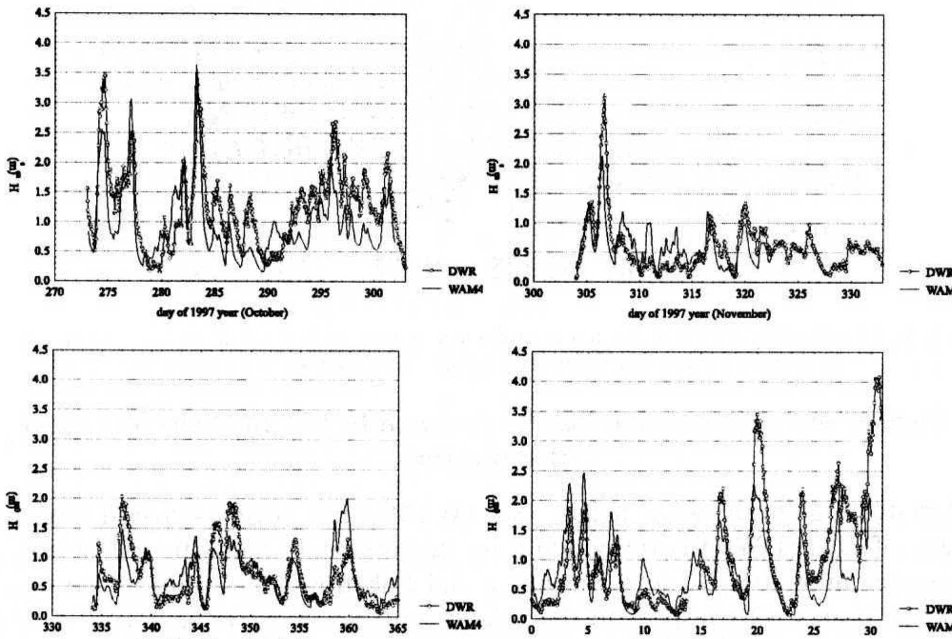

Fig. 6. Time series for significant wave heights. Comparision of field measurements (DWR) with predicted values (WAM4) for Niechorze

Time series of H_{m0} (WAM4) and H_{m0} (DWR) for the subsequent four months at Niechorze are shown in Figure 6. Rough comparison of the results of measurements with modelled values reveals moderate agreement between those values. The only available wave measurements were taken at the end of 1997. At that time the atmospheric model UMPL had just started and tested. The discrepancies between modelled and measured values can be due to the wind fields used in wave calculations. Measurements of waves in a later period were made only at one location near Lubiatowo and better conform with the values predicted by the model (Paplińska 1998). The correlation coefficient amounts 0.86 affording very good prediction of significant wave height by WAM4 model.

3. Offshore Waves in the Pomeranian Bay – WAM4 Model Results

As the output of WAM4 numerical model calculations various wave parameters are produced among which only four have been taken for further analysis, namely:

Significant wave height $H_{m0} = 4\sqrt{m_0}$.

Mean wave period $T_m = m_{-1}/m_0$, where $m_n = \int_0^\infty f^n S(f)df$ is the n order spectral momentum.

Peak period $T_p = 1/f_p$, where f_p is the frequency corresponding to the peak of frequency spectrum.

Mean wave direction $MDIR = \arctan(a/b)$, where:

$$a = \int S(f)\cos[\theta_m(f)]df \bigg/ \int S(f)df,$$

$$b = \int S(f)\sin[\theta_m(f)]df \bigg/ \int S(f)df.$$

Mean yearly values of the mean wave height, the mean wave and peak periods, were calculated. The results are presented in Figs 7a, b; 8a, b; 9a, b, where letter 'a' refers to the year 1998 and letter 'b' refers to 1999.

All presented results are valid some distance off the shore.

The calculated mean yearly values of wave parameters increase gradually going north-east, consistently with increase of fetch. The yearly mean value of significant wave height in 1998 amounted 0.9 m in the north-eastern part of the Bay and decreased to 0.5 in the south-western part. In 1999 the spatial distribution was similar. The mean yearly value of the mean wave period varies from below 2.5 s in the south-western part of the Bay to 4.5 s in the north-eastern. The peak period varies from 3 s to 5.5 s.

On the basis of WAM4 model results, an exceedance probability of significant wave height for eight directions of wave approach, was calculated at Niechorze (at model grid point closest to the Waverider buoy location), for the period of two years: 1998, 1999, with step 3 hours. The results are presented in Table 4 as a percentage over the total number of wave data points. Graphically the results are shown in the polar plot in Figure 10. The easterly direction dominates for waves

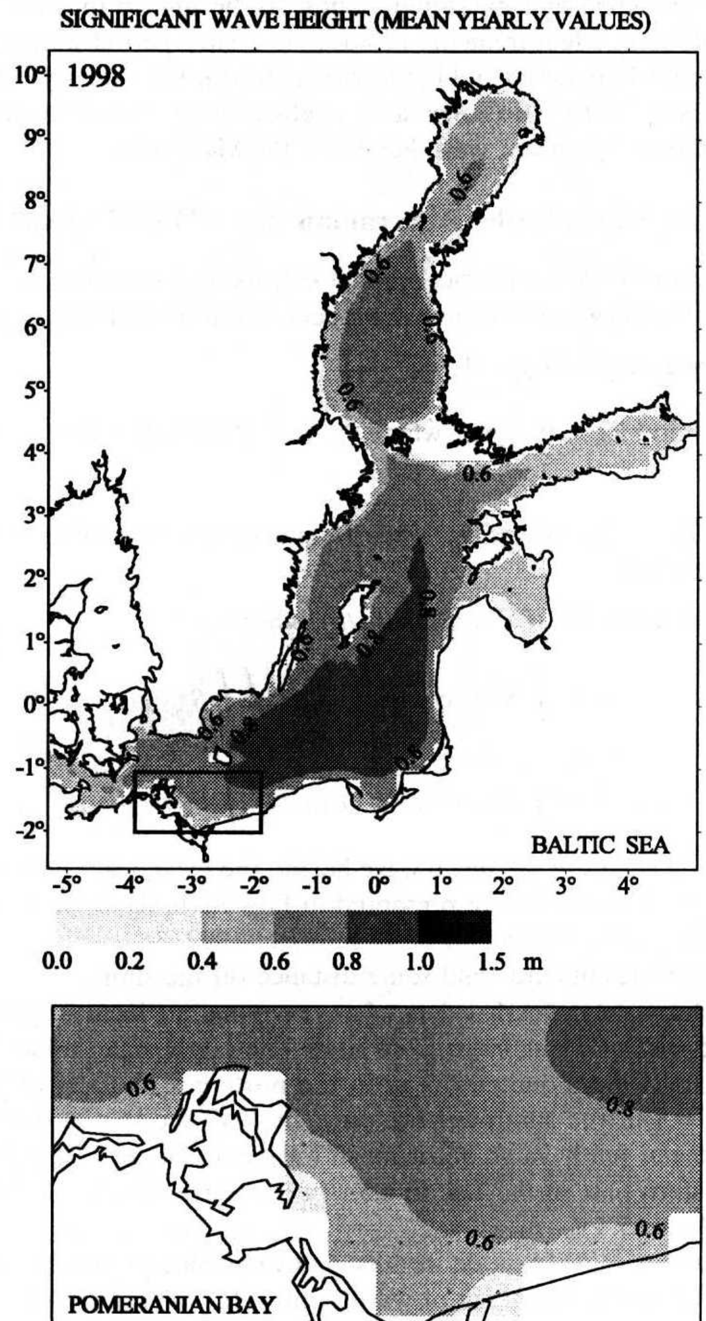

Fig. 7a. Map of mean yearly values of significant wave height – 1998

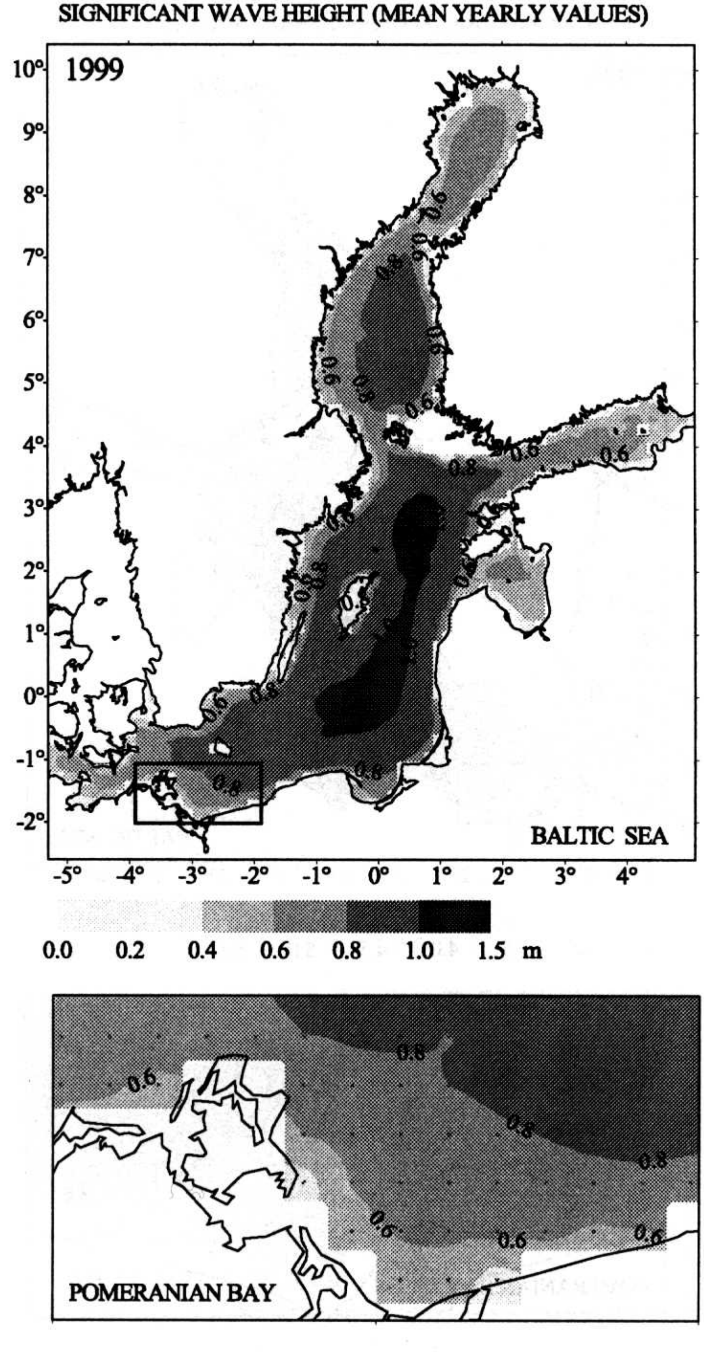

Fig. 7b. Map of mean yearly values of significant wave height – 1999

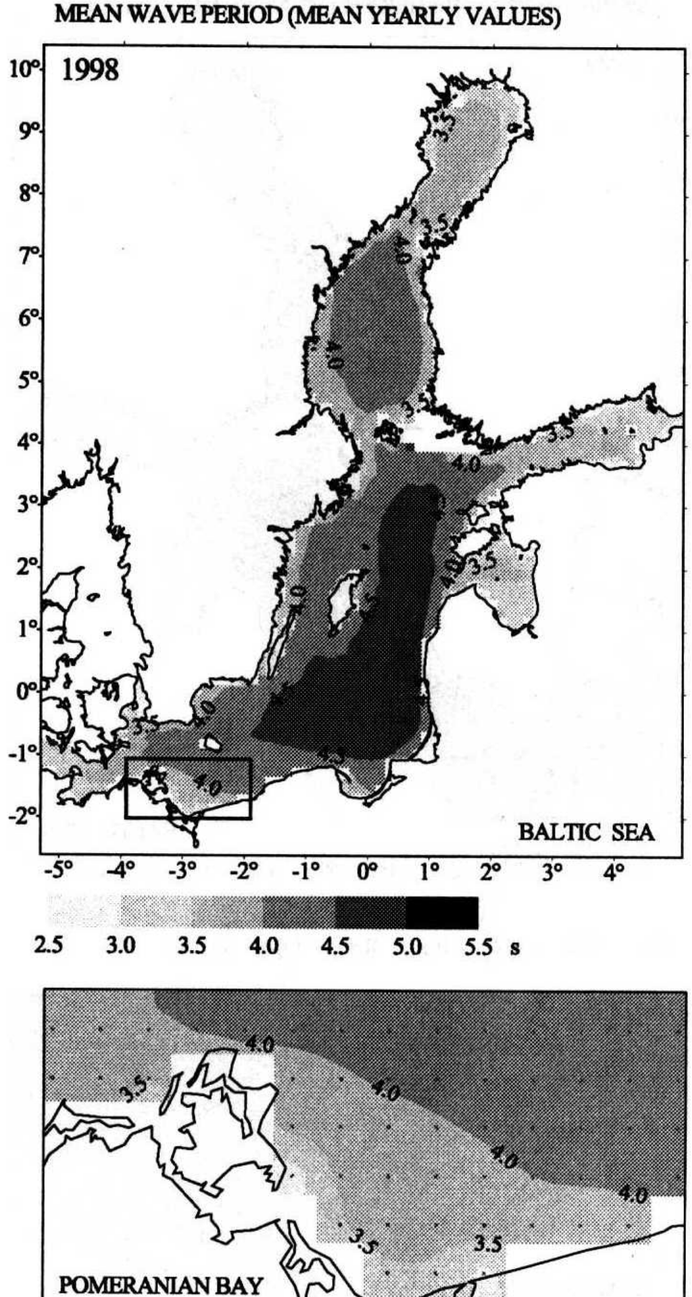

Fig. 8a. Map of mean yearly values of significant wave period – 1998

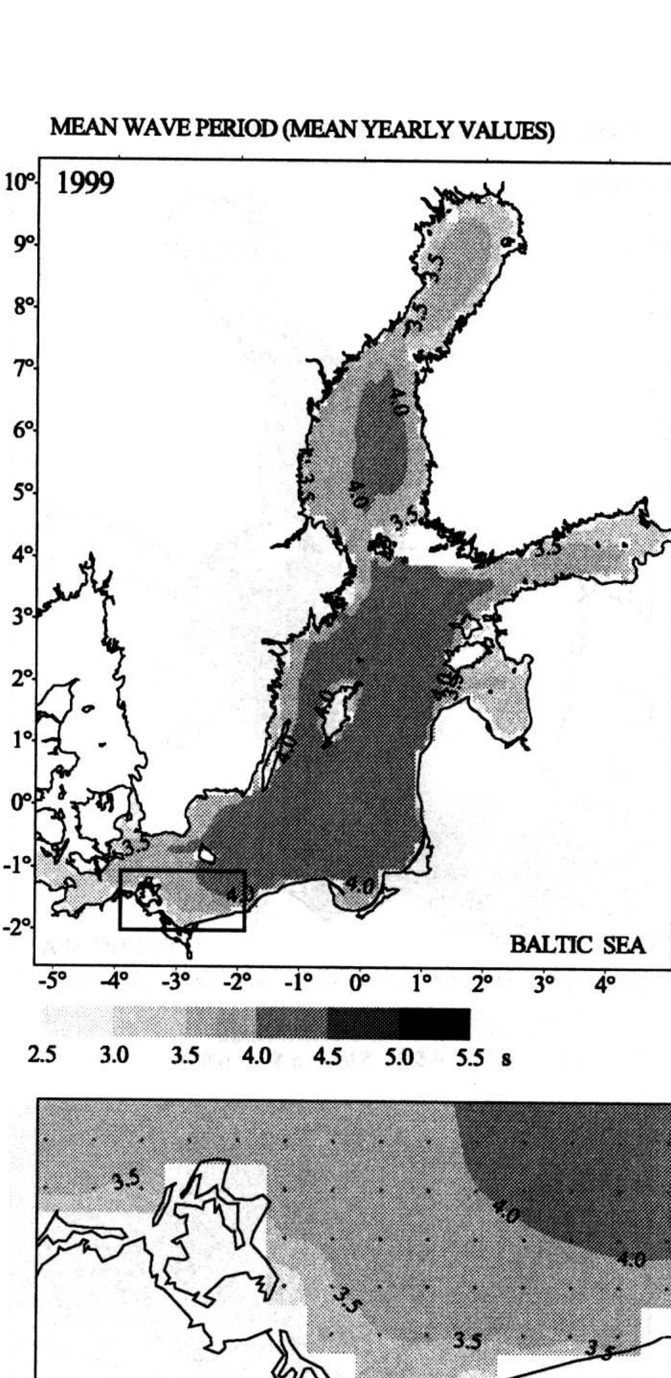

Fig. 8b. Map of mean yearly values of significant wave period – 1999

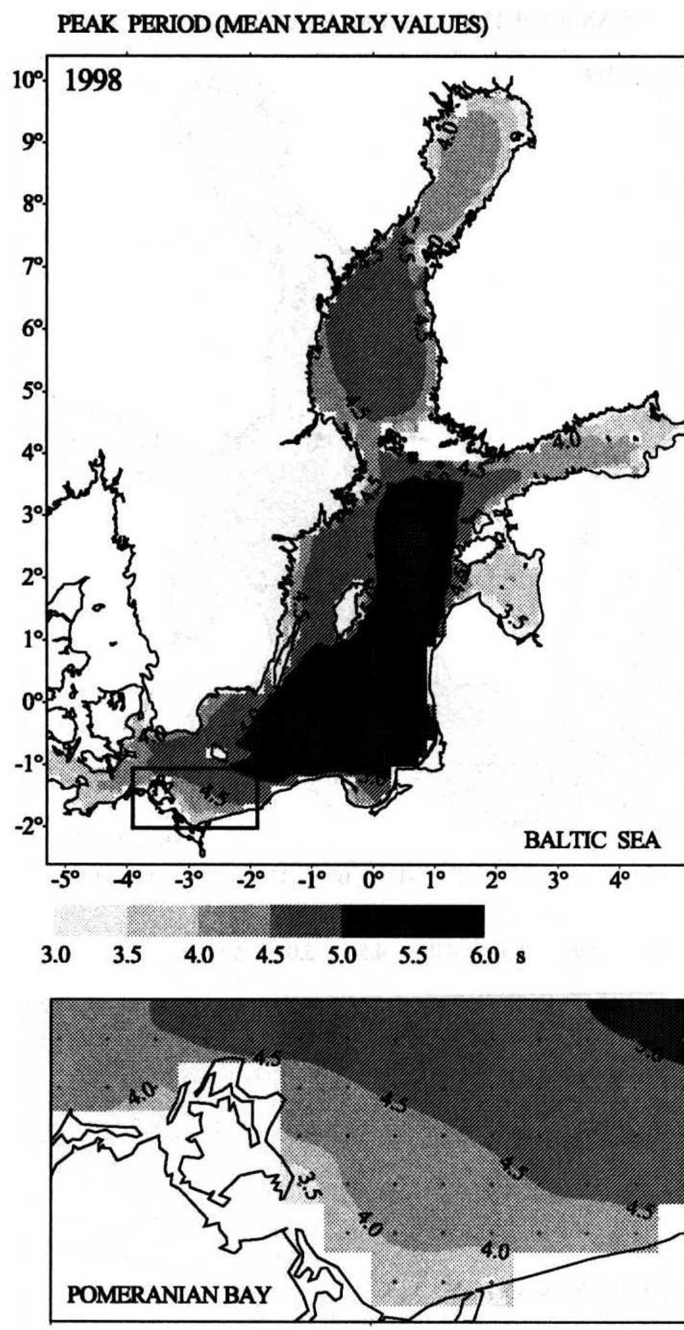

Fig. 9a. Map of mean yearly values of peak period – 1998

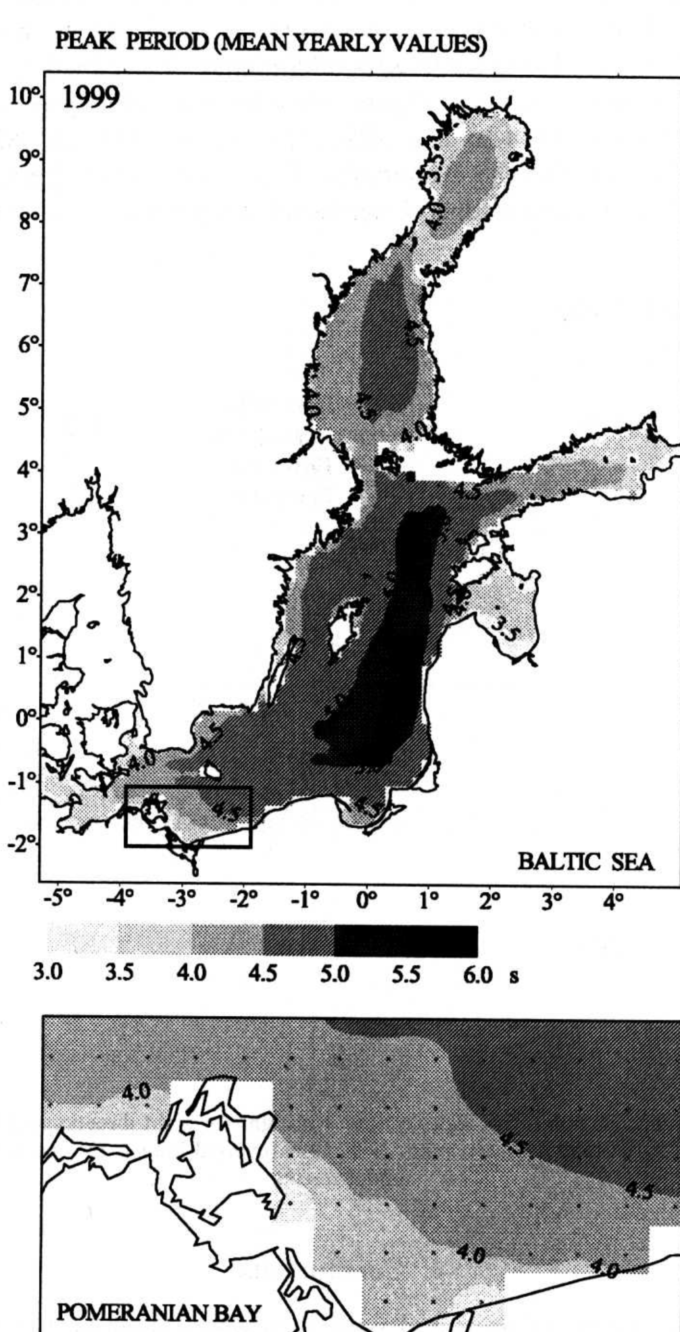

Fig. 9b. Map of mean yearly values of peak period – 1999

with significant wave height of over 1 m, this conforms with the wind climate in this region. If all waves are considered ($H_{m0} > 0$ m), directional distribution with prevailing E, SE, SW directions, is additionally determined by the shape of the basin and length of fetches (Figure 10). The amount of waves approaching to the south is lower than to any other onshore direction (E, SE, SW). The influence of the shape of the Pomeranian Bay is even more pronounced if we compare directional distributions of significant wave height at different locations (Figure 11).

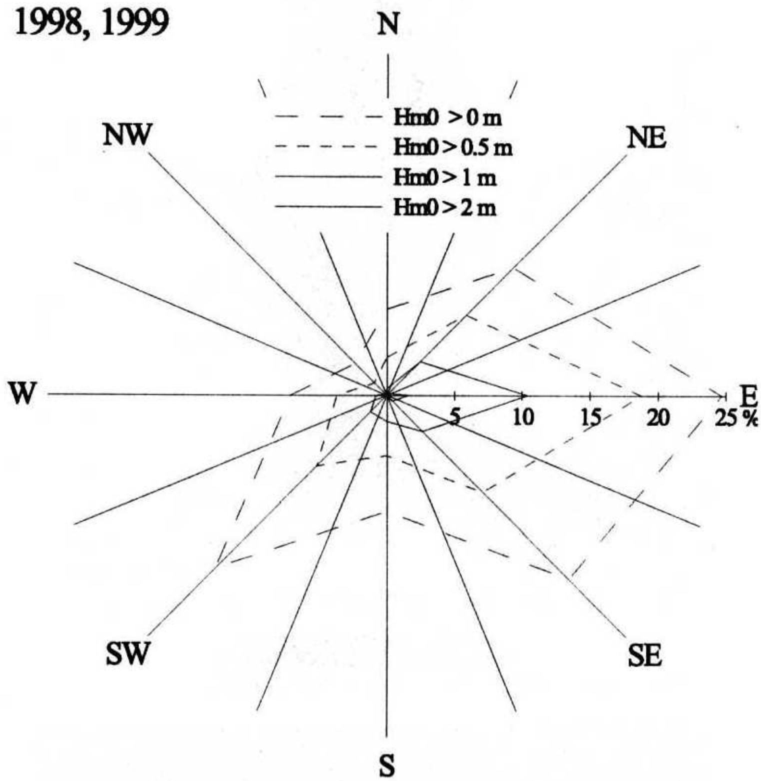

Fig. 10. Exceedance probability of significant wave height for eight directions of wave approach at Niechorze for the period of two years 1998, 1999 (every 3 hours). On the basis of WAM4 model results

4. Conclusions

The presented analysis of measured wave data would describe the waves only at one point and over a short period of four months. Measurements are the most reliable source of information of waves, but available data sets are too short for reliable investigation of regional variability of the wave climate in the Pomeranian Bay. Thus the numerical wave model WAM4 was used to reproduce real wave

Table 4. Exceedance probability of significant wave height in different directions in Niechorze

Wave mean direction	Significant wave height				
	> 0 m	> 0.5 m	> 1 m	> 2 m	> 3 m
	%	%	%	%	%
N	6.3	2.8	0.5	0.1	0
NE	13.2	8.3	3.5	0.2	0.1
E	24.7	18.8	10.4	1.6	0.1
SE	19.0	10.0	3.7	0.6	0.2
S	8.5	4.4	1.9	0.1	0
SW	17.9	7.3	1.7	0	0
W	7.1	3.7	0.8	0	0
NW	3.3	1.3	0.1	0	0.4
Total	100.0	56.5	22.5	2.5	0.4

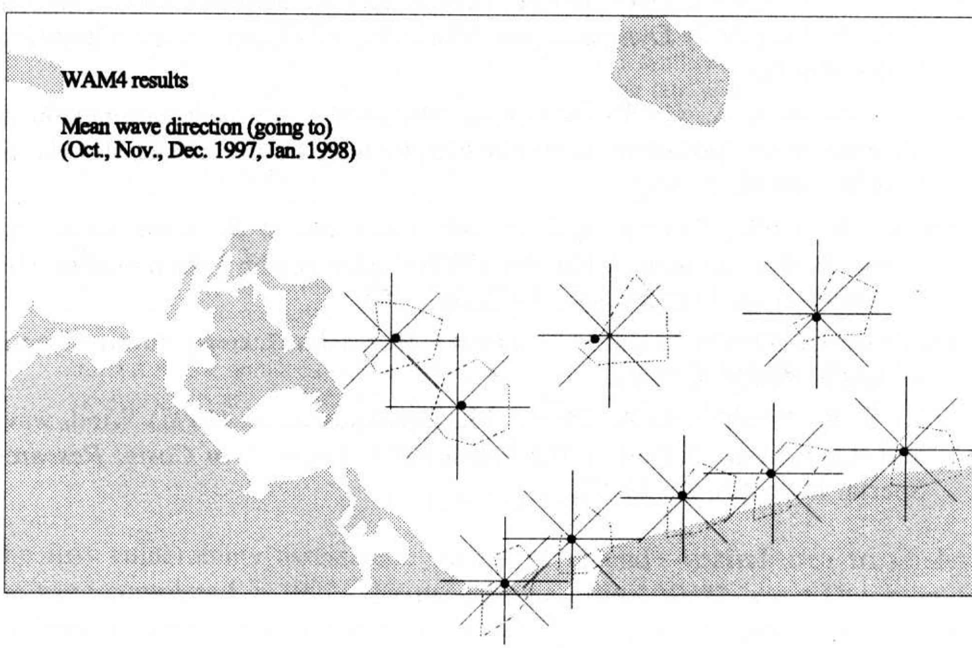

Fig. 11. Exceedance probability of significant wave height for eight directions of wave approach at different location in the Pomeranian Bay (for the period of four month). On the basis of WAM4 model results

conditions during the period of two years. Analysis of wave modelling results shows that wave fields are not homogeneous over the whole area. The gradual increase (up to 50%) of yearly mean values of selected wave parameters can be observed from south-westerly part of the Bay in a north-easterly direction. Directional distribution of significant wave height is determined by wind climate and shape of the basin, and prevails easterly, south-easterly, south-westerly directions.

The authors are fully aware of the short period of time the data taken for the analysis concerns. In the light of difficult access to reliable reports and data, the calculations made for the period of 48 months, based on the non-stationary wind fields can constitute a valuable source of information. Two years is too short period for a comprehensive analysis, however, it can be to extended to cover the following years. The calculations for years previous to 1998 cannot be carried out due to the lack of appropriate wind fields.

References

Jakubiak B. (1997) Simulation of the frontal system evolution by NWP model, *Proc. INM/WMO Int. Symp. Cyclones and Hazardous Weather in the Mediterranean*, Palma de Mallorca (Spain), 669–674.

Komen G. J., Cavaleri L., Donelan M., Hasselmann K., Hasselmann S., Janssenn P. A. E. M. (1994) *Dynamics and Modelling of Ocean waves*, Cambridge University Press.

Paplińska B., Reda A., (1999) *Określenie zmienności głównych parametrów falowania wzdłuż polskiego wybrzeża Bałtyku w oparciu o model WAM4*, Intern. Report IBWPAN.

Paplińska B., (1999) Wave analysis at Lubiatowo and in the Pomeranian Bay based on measurements from 1997/1998 – comparision with modelled data (WAM4 model, *Oceanologia*, 41(2), 241–254.

Paszkiewicz Cz. (1988) *Falowanie wiatrowe Morza Bałtyckiego,* Intern. Report of AMW 808/88, Gdańsk.

Zeidler B. R., Wróblewski A., Miętus M., Dziadziuszko Z. (1995) Wind, wave, and storm surges regime at the Polish Baltic Coast, *J. of Costal Research*, Special Issue No. 22, 33–57.