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Wave analysis for two-point measurements in the Polish EEZ of the Baltic Sea

Analiza falowania dla pomiarów dwupunktowych na obszarze polskiej wyłącznej strefy ekonomicznej Morza Bałtyckiego

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Abstract: Results of field measurements of surface gravity waves conducted for two neighbouring points at the Baltic Sea were compared. However, deep-water conditions are met there, noticeable differences for wave heights, periods and directions can be observed. In some cases they increase with the magnitudes of wave parameters, in other ones they remain constant. These two-point measurements indicate that the wave field can be differential even within small aquatic sites of the open sea, which, for instance, can have an effect on offshore structure stability or on a wave energy productivity. The aim of this paper is to point out the importance of this issue.

Keywords: simultaneous two-point wave measurements, waves at open sea, ADCP instruments, Baltic Sea, Polish EEZ, spatial variability of wave field, statistical analysis of sea waves

Streszczenie: W pracy porównano wyniki pomiarów terenowych na Morzu Bałtyckim dla grawitacyjnych fal powierzchniowych przeprowadzonych w dwóch sąsiadujących ze sobą punktach. Mimo, że były tam spełnione warunki głębokowodne, zaobserwowano znaczne różnice wysokości, okresów i kierunków fal. W niektórych przypadkach rosły one wraz ze wzrostem wielkości analizowanych parametrów falowych, w innych zaś pozostawały niezmienne. Wykonane dwupunktowe pomiary wskazują na fakt, że pola falowe mogą się zauważalnie różnić nawet na małych obszarach otwartego morza, co na przykład może mieć wpływ na stabilność konstrukcji pełnomorskich lub wydajność generatorów energii falowej. Zwrócenie uwagi na to zagadnienie jest głównym celem niniejszego artykułu.

Słowa kluczowe: jednoczesne pomiary ruchu falowego w dwóch punktach, fale na otwartym morzu, przyrządy pomiarowe typu ADCP, Morze Bałtyckie, Polska Wyłączna Strefa Ekonomiczna, przestrzenna zmienność pola falowego, statystyczna analiza fal morskich

Introduction

Nowadays, a continuous growth of interest in the offshore environment is observed. It especially concerns exploration and extraction of mineral resources, production of energy from renewable sources and an increasing role of different ecological aspects. As a result, more and more large engineering structures such as oil and gas platforms, measurement towers, wind turbines and wave energy converters are built at open seas. Acquisition of reliable long-term metocean information for them is essential both at the planning stage and in the operation period. These data are useful for estimation of environmental forcing on designed man-made structures to avoid damage during extreme weather conditions. Moreover, the data should provide necessary information for assessment of the impact of the designed investments on the natural marine environment. Additionally, in case of offshore power plants, which utilize wind or wave energy, the reliable metocean data allow to optimize a set of energy converters and more realistically estimate their productivity.

Long-term field surveys on the open sea, conducted somewhere far from the coastline, are much more difficult and costly than surveys on mainland. Technical equipment, which is used to perform measurements, must be durable and resistant to a very adverse environment. Moreover, service and maintenance of the instruments as well as periodic data acquisition hamper considerable distances from seaports and randomly-appearing harsh weather conditions. All these difficulties cause that the number of measuring stands installed at selected aquatic sites, which usually reach tens or even hundreds of square nautical miles, is sometimes limited to one. Then, data recorded in single points are treated as representative for the whole sites. Undoubtedly, this approach can distort the true picture of spatial variability of physical quantities. Moreover, some local singularities of physical phenomena, if they appear, can be unnoticed there.

Recently, several works pointed out to this issue. Ashton et al. ([1], [2]) analysed the deep-water site at the Celtic Sea which had been destined for a wave farm installation. Shape of the area is close to a square with 500-m sides. They observed that directional wave buoys moored at the corners recorded a noticeable difference in the wave climate which can influence the productivity of wave energy converters. Therefore they suggested installation of the machines within the site of various capacity. Liu et al. also draws attention to the problem of spatial variability of the wave filed for points lying relatively close to each other [3].

In this paper a wave field of the offshore aquatic site located at the southern Baltic Sea, south to the Middle Bank was analysed. The wave motion was recorded there simultaneously by means of two autonomous Acoustic Doppler Current Profilers (ADCPs) deployed at a seafloor, with the distance from one to another being 1.5 NM. Wave records for these neighbouring points at the open sea, which include heights, periods and directions, were first carefully selected to remove spikes and any other errors and then compared using statistical analysis. The main aim of the study in this paper is to examine differences which appeared between measured physical quantities.

Site description and field measurements

Marine site analysed in the paper is located at the southern Baltic Sea in the Polish EEZ, about 45 NM north of the Łeba port (see Fig. 1). Seafloor of the area is flat, slightly inclined, without any defaulting visible objects. Mean water depths differ there slightly in the range from 25 to 30 m below chart datum.

Field surveys were carried out by the Maritime Institute in Gdańsk in the period from 25 November 2012 to 25 January 2013. Two Acoustic Wave and Current (AWAC) profilers made by Nortek, which belong to the ADCP family, were installed in frames and next deployed on the seafloor to carry out measurements. Both instruments took measurements in the water body autonomously in a stand-alone mode. Instant water elevations were measured by use of acoustic sensors with the transmit frequency of 600 kHz ([4]). The applied system in the instruments can resolve directional waves from 1 to 100 s and record their heights, periods and directions. Distance betwe-

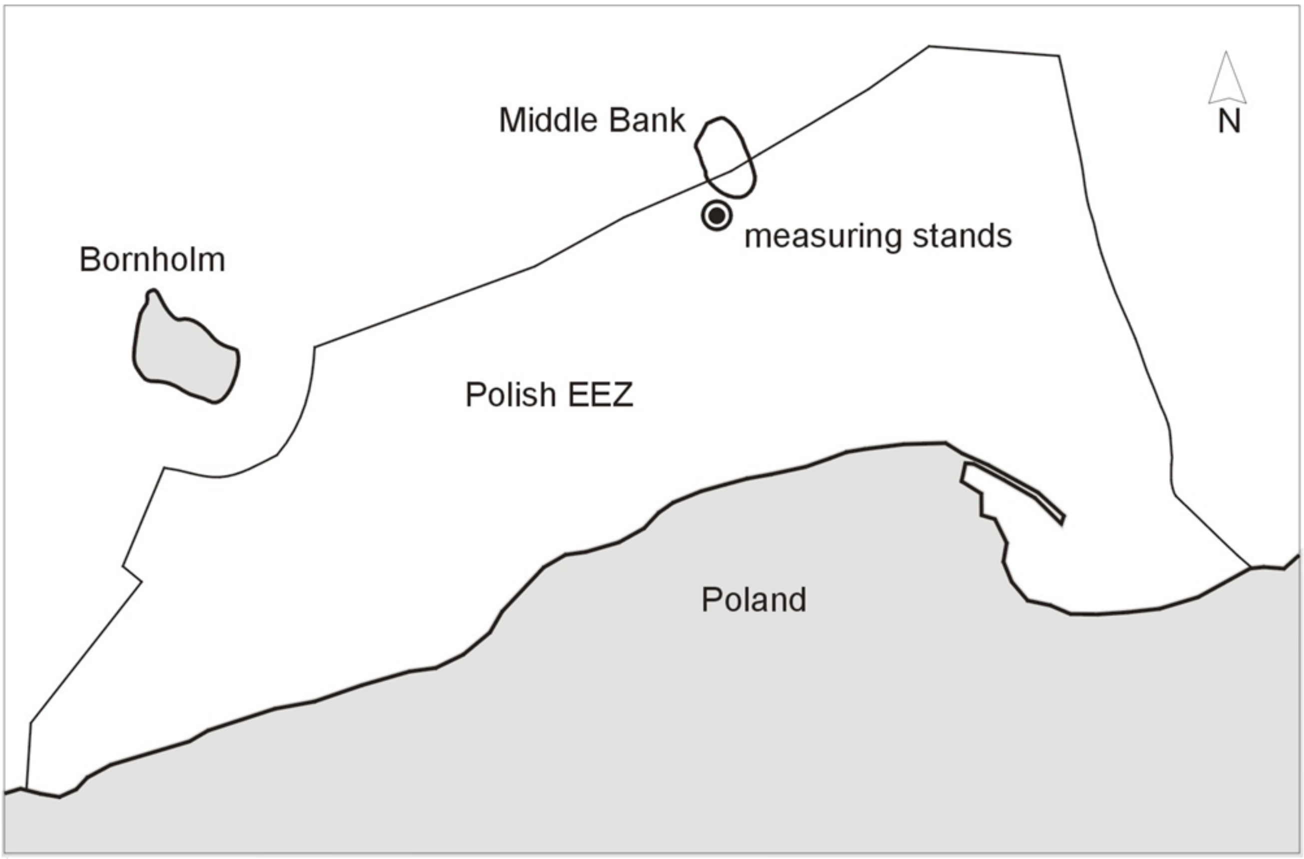

Fig 1. Location of a two-point measuring stand.

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en the instruments was 1.5 NM and mean depths of water columns for the analysed measuring points were 29 and 25 m.

Both ADCP profilers before the installation on the sea floor were time-synchronised and set up identically to allow easy and precise comparison of output data. Namely, each burst was capturing 2048 samples of instant water elevations at a frequency of 2 Hz. It approximately corresponds to 17 minutes of a continuous recording. Such bursts were repeated once an hour during the whole measurement period. In the meantime, instant elevations of the free water surface and near-surface water velocities for each burst were averaged to parameters describing a single wave: mean, significant and maximum height, mean and peak period as well as mean and peak direction (H_{mean}, H_{mo}, H_{max}, T_{mean}, T_{peak}, Θ_{mean} and Θ_{peak}, respectively). During a two-month survey about 1500 records were collected.

Data selection and analysis

Data selection

All field data retrieved from both acoustic profilers followed quality control procedures. First, such indicators as battery level, strength and quality of transmitted acoustic signals and stability of the instruments installed at the seafloor for the whole measurement period were checked. Next, all records of the surface wave motion were analysed. Time gaps in the data sets, which lasted a few hours, were observed there. They were caused by routine services which included maintenance of the instruments and data acquisition. Next, a few single unrealistic data (spikes) from the time series, which appeared occasionally, were found and removed. Finally, for the purpose of comparative analysis, all odd data were skipped. This means that those wave records retrieved from one instrument were removed for which missed counterparts were retrieved from the second profiler. The procedure was performed separately for wave heights, periods and directions.

Tab. I. Summary of selected parameters concerning two-point wave measurements.

Start of data recording	25 Nov 2012
End of data recording	25 Jan 2013
Total number of wave records	1486
Coverage of approved wave heights	99.4%
Coverage of approved wave periods	99.4%
Coverage of approved wave directions	99.6%

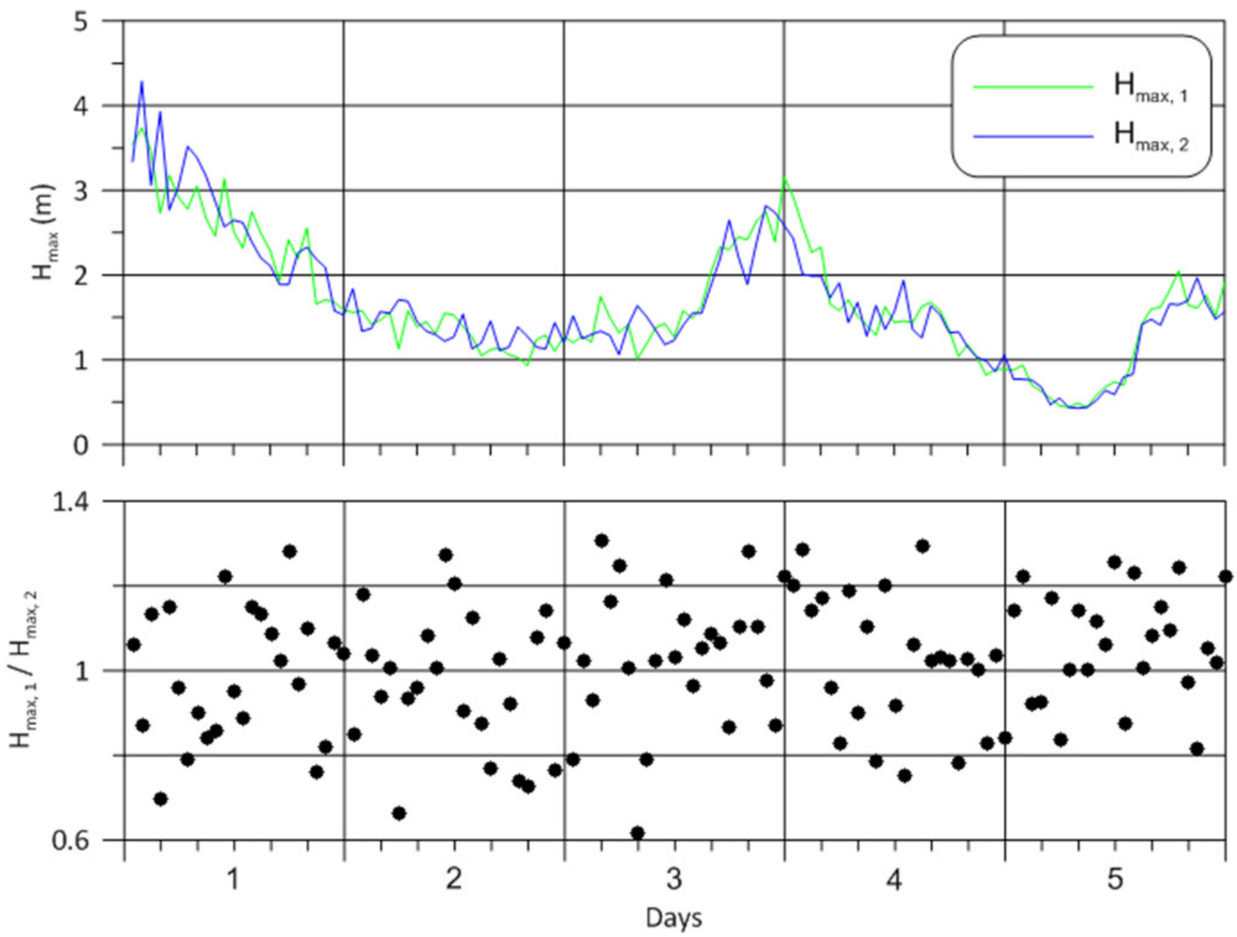

Fig 2. Maximum wave height distributions in mid-January 2013.

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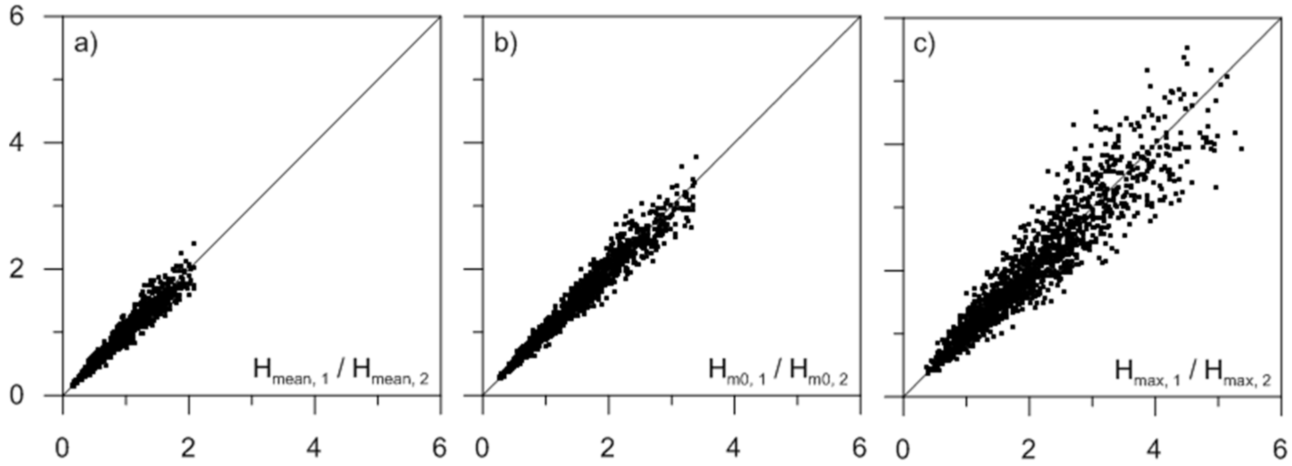

Fig 3. Comparison of mean (a), significant (b) and maximum (c) wave heights measured in two neighbouring points (in metres)

All these restrictions slightly decreased the amount of data which were accepted for further statistical analysis. Results of the performed data selection are presented in Table I.

Total number of wave records given in Table I is the number of records which would have been retrieved for perfect continuous measurements.

Data evaluation

Proper evaluation of spatial variability of surface gravity waves at the open sea should be preceded by bathymetric surveys because the shape and direction of propagating waves can be changed with a distance when deep-water conditions are not satisfied locally. The waves affected by the seafloor become higher, steeper and more asymmetrical. Additionally, tectonic faults or very large obstacles resting on a floor can partially reflect the waves causing their interaction with the oncoming ones.

Deep-water conditions for surface waves will be considered as satisfactory if the measured wave lengths are smaller than the doubled minimum water depth (well-known ratio of wavelength to water depth <2 is satisfied). Wave periods recorded *in situ* by the profilers were recalculated into wave lengths using the linear wave theory. Simple computations gave 50 hourly gathered wave records whose lengths were slightly higher. It jointly corresponds to two days for which the waves could insignificantly interact with the seafloor. In other words, deep-water wave conditions covered 97% of the measurement period.

Bathymetric surveys for the analysed aquatic site were additionally supported by sonar scanning of the seafloor. These works excluded existence of any factors which could disrupt the surface gravity wave propagation.

Statistical analysis

It can already be concluded that there are noticeable differences in magnitudes, despite relatively close proximity of the measuring stands at the sea, which are the effect of the random nature of gravity surface waves. A typical example of the time series of maximum wave heights measured in both points is given in Figure 2. A five-day measuring period was chosen for mid-January 2013. In the figure below it is shown that the observed differences reach 1.4. The numbers 1 and 2 indicate individual measuring points.

The purpose of the following study is to determine whether the differences in magnitudes of the recorded directional waves are negligible or, in contrast, may have a significant impact on offshore construction stability or efficiency of wave energy production within a relatively small site at the sea.

Scatter plots for mean, significant and maximum wave heights measured in two neighbouring points are given in Figure 3. In all cases the differences increase with the increase of the wave height.

Analogous drawings were made for a mean wave period and for a spectral peak period (see Fig. 4). Noticeable increase of the scatter is observed with the increase of the mean wave pe-

Tab. II. Summary of mean and extreme differences for measured wave heights and periods.

	$H_{MEAN,1}/H_{MEAN,2}$	$H_{M0,1}/H_{M0,2}$	$H_{MAX,1}/H_{MAX,2}$	$T_{MEAN,1}/T_{MEAN,2}$	$T_{P,1}/T_{P,2}$
Minimum	0.74	0.77	0.62	0.81	0.51
Maximum	1.42	1.32	1.58	1.32	1.37
Mean	1.01	1.01	1.02	1.01	1.00

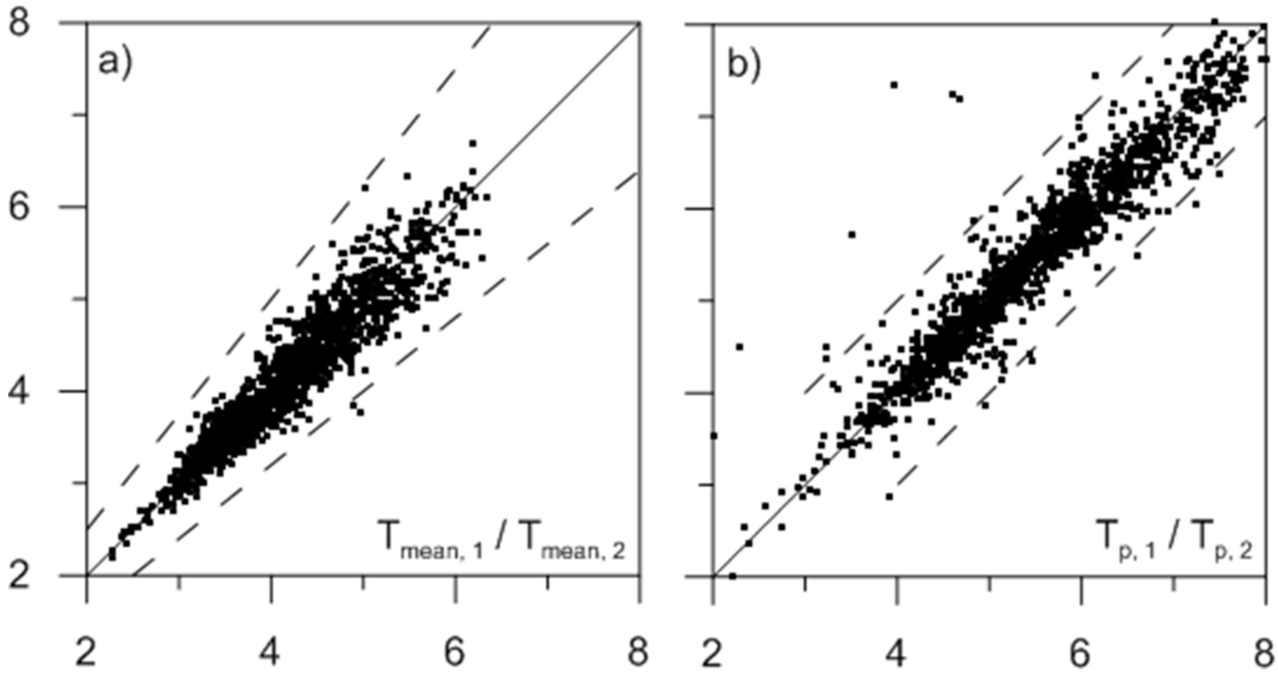

Fig 4. Comparison of mean wave period (a) and spectral peak period (b) measured in two neighbouring points (in seconds).

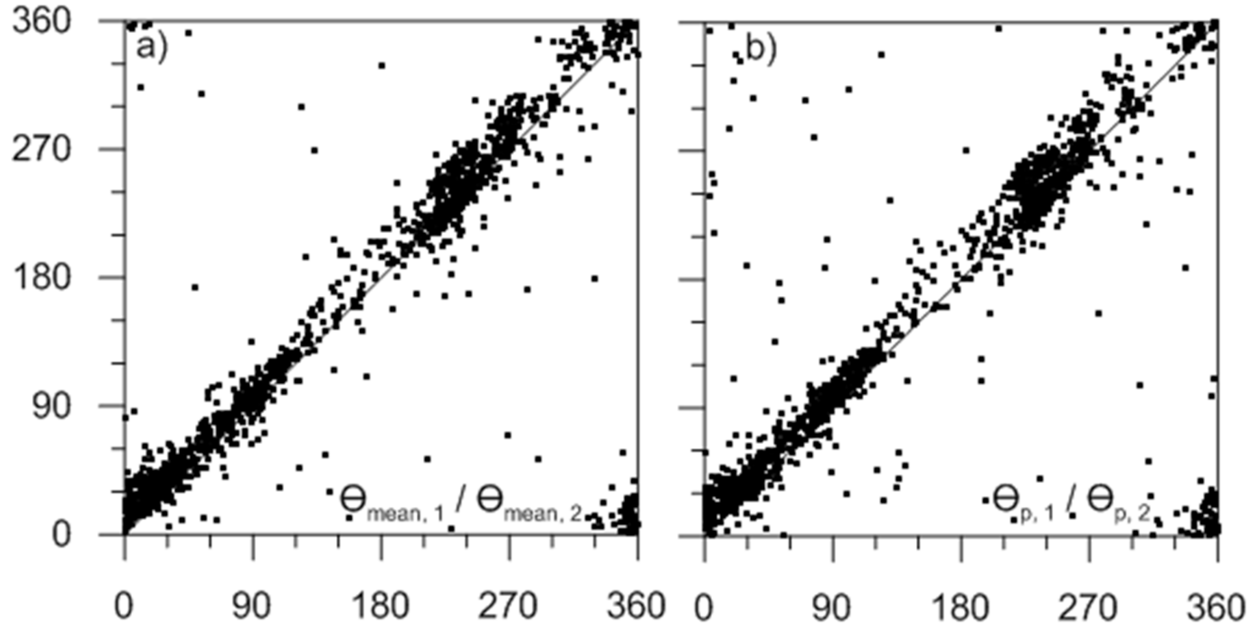

Fig 5. Scatter plots of mean (a) and peak (b) wave directions for two-point measurements (in degrees)

riod, whereas a relatively constant scatter seems to be for the spectral peak period.

Mean and extreme differences of wave heights and periods, presented in Fig. 3 and 4, are summarised in Table II.

In a similar way, scatter plots for mean and peak wave directions were drawn. The results given in Fig. 5 show great resemblance of both graphs. The scatters do not depend on the direction of the wave approach. Moreover, maximum differences in directions usually do not exceed +/- 20 degrees.

Summary

In this paper two-point measurements of surface gravity waves at the deep-water aquatic site of the Baltic Sea were described. The distance between measuring stands was 1.5 NM. A comparison of fundamental parameters revealed noticeable differences for measured magnitudes of wave heights, periods and directions despite a short distance between the analysed points. For recorded mean and maximum heights as well as for mean periods the discrepancies increase with the increase of their magnitudes,

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whereas the scatter of spectral peak periods for longer i.e. better-developed waves (T > 4 s) and for mean and peak directions seems to be independent from their magnitudes. The presented results demonstrate existence of spatial variability of a deep-water wave field even for little distant points. This means that in case of surveys carried out only in one point of a selected aquatic site at the open sea, the measured data should be interpreted with caution.

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