WAVE PROPAGATION DIRECTIONS UNDER REAL SEA STATE CONDITIONS

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Abstract

This paper deals with the analysis of wave propagation directions from wave climate measurements in field. A simple method is presented to analyse wave approach directions from signals of a current meter and a wave gauge in time domain. Results using this method of analyzation are demonstrated exemplarily with data from field monitoring.

Introduction

Wind waves coming in from deeper parts of the shelf in areas with extremely restricted water depths, keep their general three-dimensional characteristic with respect to the water particle movement. Even when the breaking wave crests seem to be transformed into a considerable two-dimensional behavior, the wave-induced velocities keep their three-dimensionality, however often with a distinct strengthening towards a main axis system.

It is well known, that wind direction and wave approach direction don't agree necessarily in areas with restricted water depths like the wadden seas in the German Bight. This is due to the strong influence of the complex three-dimensional underwater topography on wave climate propagation. Thus, forecasting the wave propagation direction sometimes can be very difficult and a more detailed knowledge about wave approach on wadden seas is desirable.

In general, some different methods are used to evaluate wave approach directions. These methods depend on the type of sensors which are used for field measurements of wave climate and may be the following ones:

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- One method uses the analysis in time domain from two synchronously recorded signals of the velocity components from a two - component velocity sensor in horizontal plane (method A).

- Another method uses the analysis from three synchronously recorded signals: two signals of the components from a velocity sensor as in method A and additionally one signal of the surface elevation from a wave staff. This analysis is done either in frequency domain (method B) or in time domain (method C).

The evaluation of wave approach direction with analyzation method A only works sufficiently for strongly orientated velocities, which seldom occur in real sea state wave climate.

About the evaluation with analyzation method B it has been reported in a lot of previous papers. Analysing the co- and quad-spectra in frequency domain from data triplets of the two horizontal velocity components and the water surface elevation, the directional distribution and from this the main wave approach may be estimated. This method is very complex and in most papers the essential details of this method never are described.

The evaluation of wave approach from the same data triplets using an analysis in time domain (method C) is much more simple compared with such in frequency domain. In addition to the easy practicability this method has a clear physical sense. Due to these advantages this paper will be focussed on this method.

Field measuring locations and equipment

The data used for the estimation of wave approach direction were measured within a comprehensive field research program on wave climate and wave run-up. This program has been running in cooperation with the Regional State Board for Water Management (ALW Heide, supervision Dipl.-Ing. J. Gärtner) of the State of Schleswig-Holstein for many years at 4 different locations at the landside borders of the wadden sea and in the Elbe river estuary in the German Bight. The data presented in this paper, are recorded at the wadden sea location Heringsand at the coastline of the Dithmarscher Küste, which is shown in Fig. 1. The field locations and the measuring equipments already were described in previous papers in connection with first results on wave run-up (Grüne, 1996) and on wave climate (Grüne, 1997 and Wang & Grüne, 1997).

At each of these locations roughly 1 km in front of the dykeline a support pile with the measuring sensors is installed. The surface elevations are estimated from the records of a pressure cell, using the 1st order theory with empirical transfer function. The velocity components are measured in horizontal plane with an electromagnetic two-component sensor. The sensors are connected by cables with a computer controlled recording system, which is placed in a shelter behind the dyke.

Fig. 1 Measuring locations at the Dithmarscher Küste

Definitions and modalities of analysing wave approach directions

As already mentioned, this paper is focussed on analysing wave approach directions in time domain, using a data triplet of surface elevation η and two rectangular velocity components V_y (normal to dykeline) and V_x (parallel to dykeline) in a horizontal plane as shown in Fig. 2 schematically. An example of such a synchronously recorded data triplet is shown in Fig. 3, where the time histories of the signals of the wave gauge WP1 and the horizontal velocity components S1Y and S1X are plotted for a period of 95 seconds. This example will be used in this paper, to explain the analyzation method.

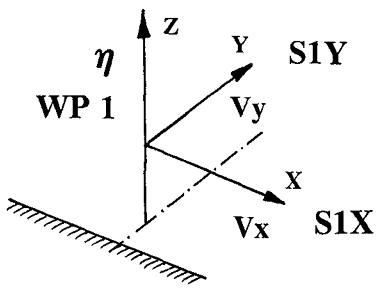

Fig. 2 Scheme of coordinate system of installed sensors

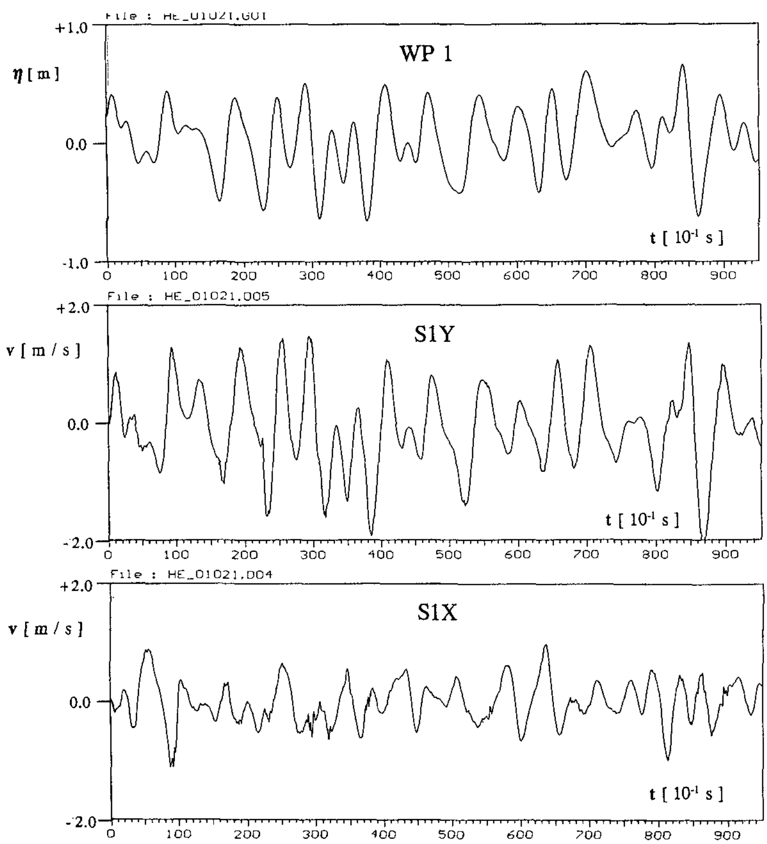

Fig. 3 Example of synchronously recorded wave and velocity data

The data of the two horizontal velocity components V_x and V_y as well as those of the surface elevation η, shown in Fig. 3, are recorded digitally with 10 Hz. With the data from the time period in Fig. 3 the vector course of the two velocity components is plotted in Fig. 4. This course plot seems to have a main direction roughly along the Y-axis. But using the least square correlation method alternating for both independent velocity components V_x and V_y, a mean value from both regressions of - 39.8° will be calculated. This method (one possibility for method A as mentioned before) will create mostly such similar failure results due to the fact, that the mean value from two independent regression lines each with a bad correlation tends always around 45 degrees. A comparison with the result from Fig. 8 (Aw = - 15.6°), which is evaluated with method C as explained later, indicates, that this method don't lead to sufficient results.

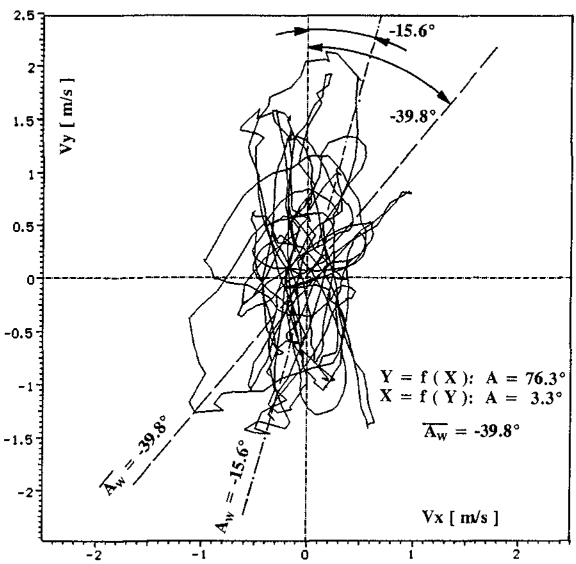

Fig. 4 Velocity vector course of velocity data S1X and S1Y from Fig. 3

But nevertheless, the vector course data itself are very helpful for an evaluation of wave approach directions as demonstrated in Figs. 5 a and 5 b, which give a kind of anatomy of a data triplet in time domain. The time history of surface elevation data η (WP 1) from Fig. 3 has been used to split the wavetrain in 17 consecutive waves, each labelled with continious number 1 to 17. Wave crests and wave troughs of all 17 waves are marked and labelled with time. For this procedure the unscaled pressure data may be used, a transfer to real surface elevations is not necessary. Below the time history of the surface elevation the vector course with the two horizontal velocity components V_x and V_y is plotted separately for each wave event. The vector positions at the dividing troughs between each of the consecutive waves are connected with a dotted line.

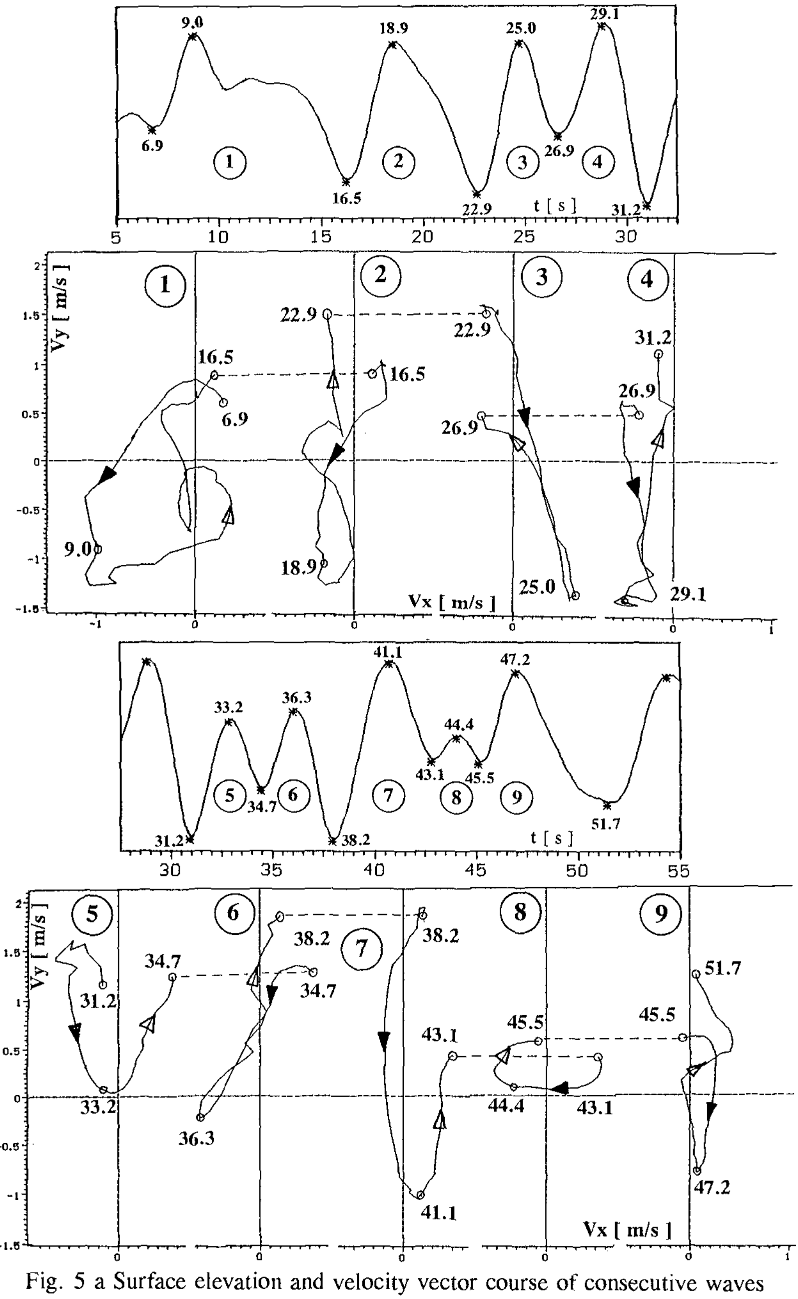

Fig. 5 a Surface elevation and velocity vector course of consecutive waves

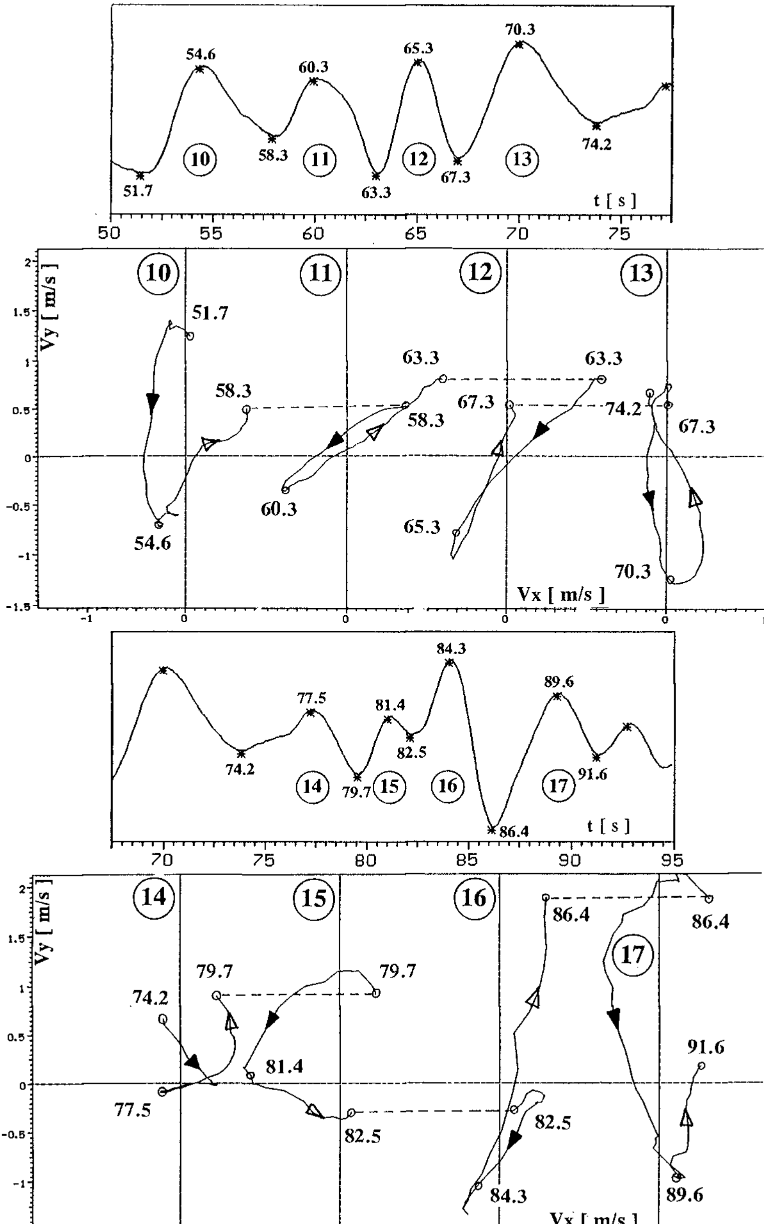

Fig. 5 b Surface elevation and velocity vector course of consecutive waves

Comparing the vector plots of the separated waves in the wavetrain in Figs. 5 a and 5 b, one finds a more or less distinct changing of the approach direction of the water particles at each wave crest and wave trough, which is self-evident for pure two-dimensional waves. This leads to the evaluation of wave approach directions for real sea state conditions from the vector course data between wave crests and troughs. The wave approach directions for such a mode are defined in Fig. 6 schematically.

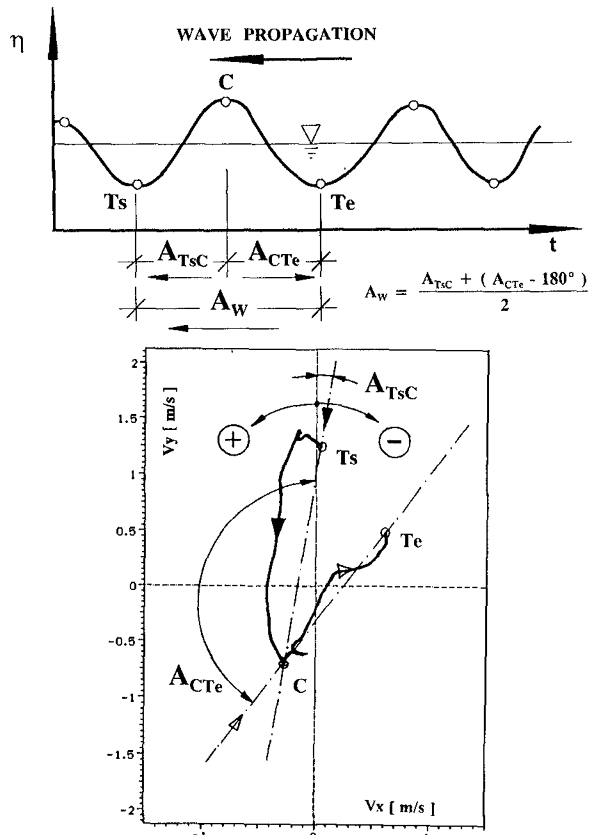

Fig. 6 Definitions for wave approach directions

The definitions in Fig. 6 may be described as follows:

The direction A_{TsC} is defined as mean direction between trough Ts and crest C. Ts is the trough at the start of the wave event according to the time and C is the crest, both are identified from the surface elevation in time history. Troughs and crests are related to time. According to physical sense this means the oncoming rising front of the wave. A_{TsC} is determined as angle between normal direction (Y - axis of horizontal plane) and linear connection between vector course positions at trough Ts and crest C, as defined in the lower part of Fig. 6, where the rules of sign for the directions A_{TsC} and A_{CTe} are defined as well. The vector course of the oncoming rising front is marked with a black arrow in all figures.

The direction A_{CTe} is defined as mean direction between crest C and trough Te, where Te is the trough at the end of the wave event and this part of the vector course is marked with an open arrow in all figures.

A_W is defined as the total approach direction of each wave event. A_W is calculated as the mean value of A_{TsC} and A_{CTe}. It must be noticed, that A_{TsC} and A_W have approximately the same directions as the main direction of wave propagation has, whereas A_{CTe} has the opposite direction (see also the lower part of Fig. 6, where the rule of sign is defined).

The vector plots in Figs. 5 a and 5 b demonstrate the manifoldness of the vector course anatomy and its complexibility. The vector course of event Nr. 1 in Fig. 7 (right plot) confirms, that nearly each small crest or trough of surface elevation (left plot) creates a significant changing of course direction, even within a defined wave event.

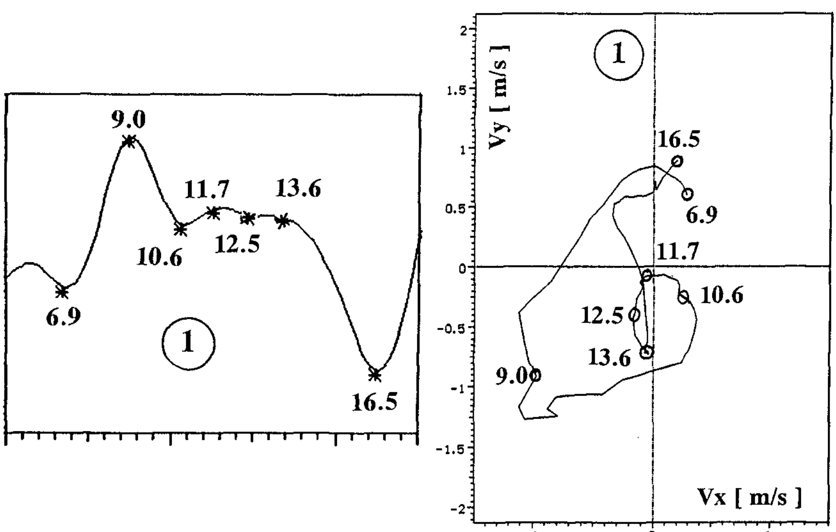

Fig. 7 Example of a wave with complex velocity vector course

Comparing all wave events in Figs. 5 a and 5 b one can find wave events, where the vector courses are as well straightened relatively strong within each wave event and the directions A_{TsC} and A_{CTe} don't differ very much from each other (e.g. wave events

Nr. 2, 3, 4, 6, 11, 12 and 16). Nevertheless, the mean directions A_W differ from those events next to distinctly.

Furthermore there are wave events, where the direction of A_{TsC} differ considerable from that of A_{CTe}, which means a changing of main direction within the wave event (e.g. Nr. 5, 8, 10, 14 and 15). From these events it is obvious, that mostly the chaotic vector courses may be created by the smaller waves between larger ones (e.g. event Nr. 8, 14 and 15).

All estimated approach directions from the test example in Figs. 5 a and 5 b with totally 17 consecutive wave events are plotted in Fig. 8. Significant differences between the different defined directions within one wave event only occur for the smaller waves like e. g. Nr. 8 and 15, as already mentioned before. The result for the mean approach direction (A_W = -15,6°) is compared in Fig. 5 with the results, using method A with the mean value of two independent correlations with the digitally recorded (equidistant with 10 Hz) velocity data. The failure of using the components alone in such a manner is manifest.

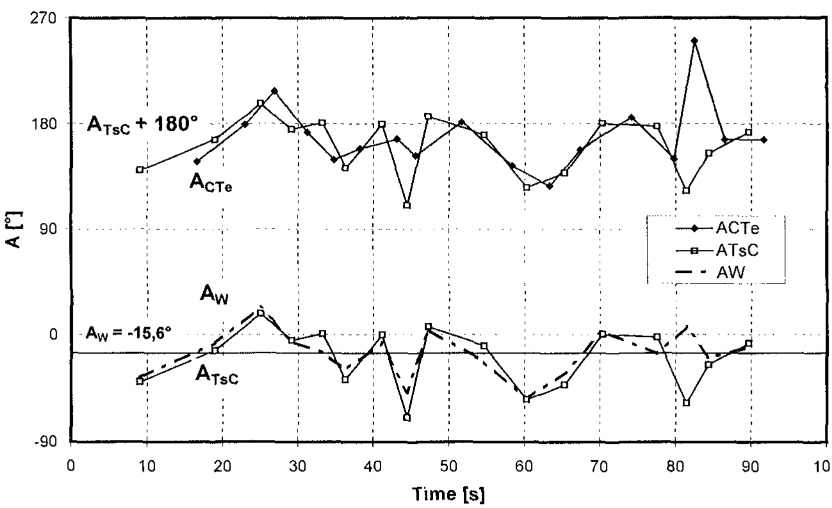

Fig. 8 Wave approach directions evaluated from the waves in Figs. 5a and 5b

First results

As already mentioned, the evaluated approach directions of consecutive waves in a wave train have strong fluctuations. This comes out clearly in Fig. 9, where the evaluated values for A_{TsC} and A_{CTe} are plotted as time history for a period of 15 minutes, measured in field. But beyond a certain time period the mean values are relatively constant. In Fig. 9 for example the fat line in the upper part stands for the A_{TsC} mean values of 9 consecutive time periods, each 100 seconds long. The differences compared with the mean value of the total period (A_{TsC} = 305,9°) are very small. It must be noticed, that in Fig. 9 and in all following figures the wave approach directions are transferred to the geodetic coordinate system with 0° = North.

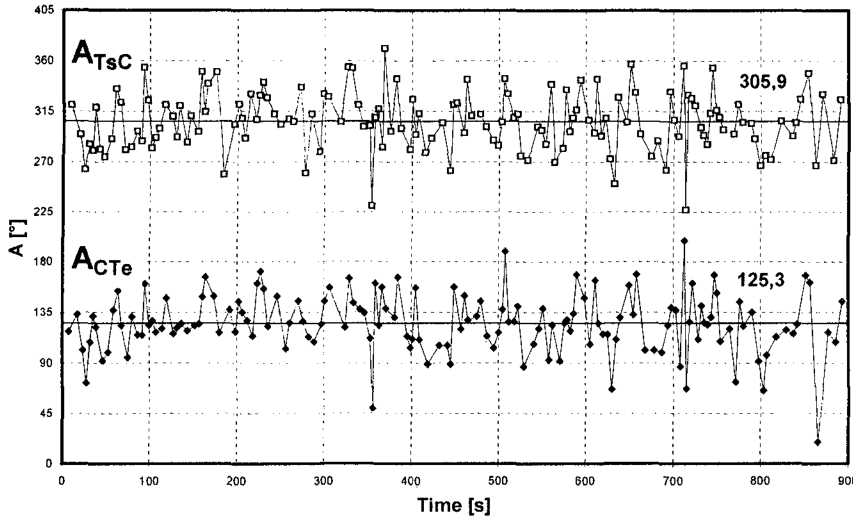

Fig. 9 Fluctuations of A_{TsC} and A_{CTe} during a period of 15 minutes

The values for A_{TsC} and A_{CTe} from the example in Fig. 9 are plotted as frequency distributions in Fig. 10. The mean values of A_{TsC} and (A_{CTe} + 180°) for the total period differ only 0.6 degrees from each other. The agreements with the calculated Normal - distributions are quite good. The total range of fluctuation of the evaluated approach directions is roughly ± 70° and the standarddeviation is roughly 26°. The frequency distribution of the total wave approach directions A_W is plotted in Fig. 11 . Similar wide sectors of fluctuation of wave approach were found for other measurements. With respect to the influence on wave run-up these results indicate, that a possible reduction on wave run-up values due to oblique wave approach should be smaller than expected by excisting formulae, verified with long-crested sea state.

Results of wave approach directions measured during one storm surge event are given in Fig. 12 examplarily. The stillwaterlevel SWL, the local winddirection R_0, the local windvelocity U_0 and the measured wave approach directions A_W are plotted as time history. Each plotted point is the result (mean value) of one of the time periods, which have each a duration of 15 minutes and were recorded consecutively.

During this storm surge event the local wind velocities U_0 as well as the local wind directions R_0 were relatively constant, whereas the wave approach directions A_W

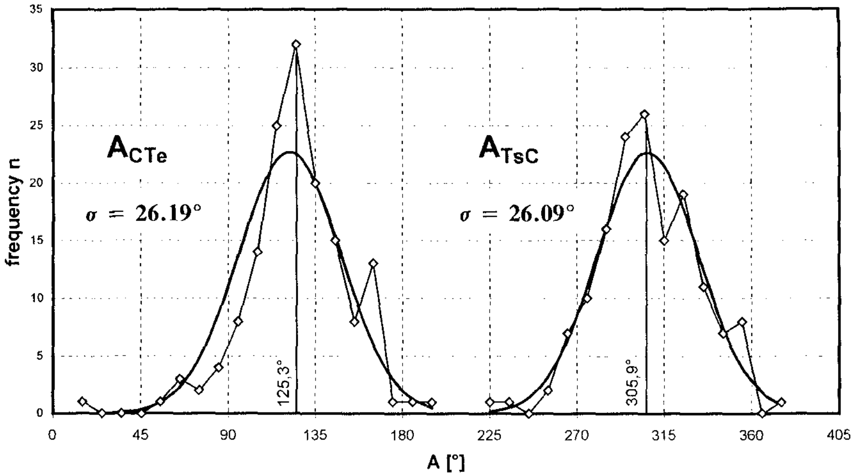

Fig. 10 Frequency distributions of A_{TsC} and A_{CTe} from the data in Fig. 9

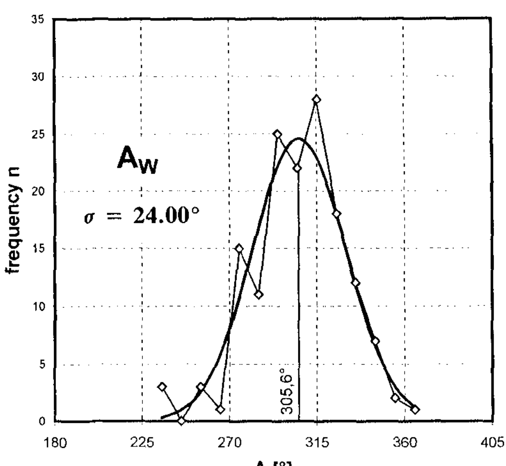

Fig. 11
Frequency distribution of A_W from the data in Fig. 9

partly differ considerable from the wind directions R_0. It is well known, that in such areas the wave propagation direction is strongly influenced by the local morphology and that waves are even propagating against the wind, as far as they run along gullies. Thus, it must be expected, that the differences between winddirection and wave approach direction are mainly caused by the influence of the morphology. Comparing the time histories of the wind- and wave approach direction in Fig. 12 it can be stated, that the differences between both directions decrease with increasing water depth.

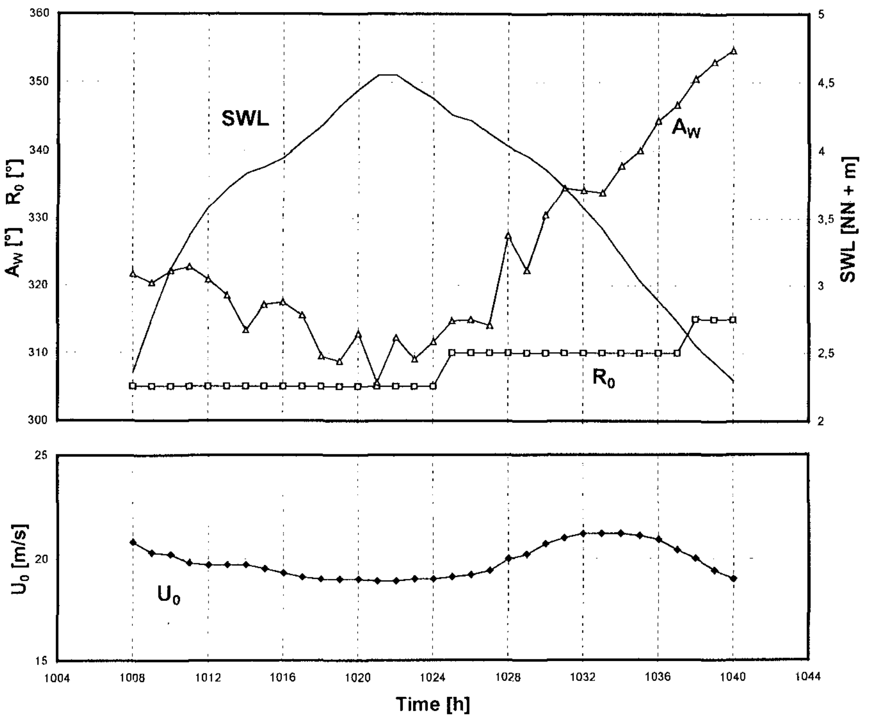

Fig. 12 Time histories of stillwaterlevel SWL, local winddirection R_0, local windvelocity U_0 and wave approach directions A_W during a storm surge

From the morphological conditions around the location Heringsand in Fig. 1 it may be supposed, that the mean wave propagation directions during the rising and falling part of the storm surge stillwaterlevel are adjusted to the end of the main gully.

The influence of water depth comes out clearly in Fig. 13, where the difference between the wave approach direction and the local wind direction A_W - R_0 is plotted versus the stillwaterlevel SWL. The phaseshift A_W - R_0 decrease with increasing water depth, but with different order of magnitude for rising and falling part of the storm surge stillwaterlevel. The phaseshift of the falling part of the storm surge has roughly up to twice the value of that of the rising part, whereas in the summit range it tends to zero. The different phaseshift for rising and falling part may be explained partly by the general trend of tidal motion from South to North in this part of the German Bight. From the ongoing analysis similar results are found for other storm surge events, often

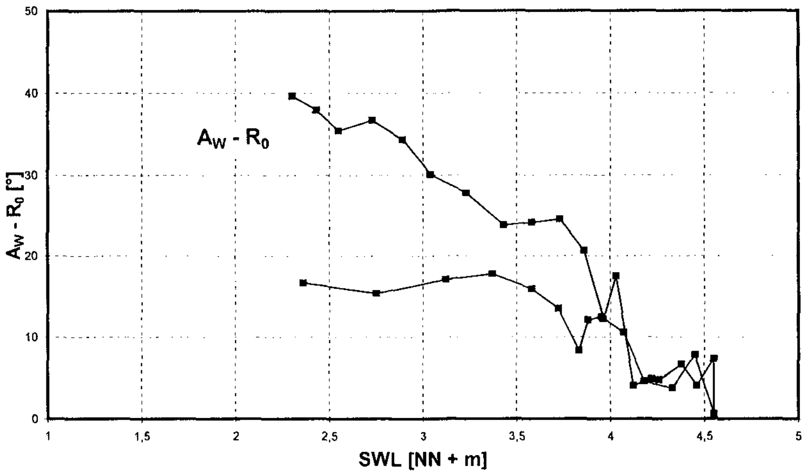

Fig. 13 Phaseshift between wave approach directions A_W and winddirection R_0

in a more complex shape, especially for storm surges with lower summits of stillwaterlevel. Furthermore it was found that the phaseshift also depends on the absolut winddirection and that gullies like the one at Stinteck location have strong influence. All results confirm the strong influence of the local morphology.

Conclusion

For the analysis of wave approach directions from triplet field data of surface elevation and horizontal velocity components a simple method is dicussed with the aid of an example and first results are presented from measurements during a storm surge event. These results indicate the wide range of fluctuations of wave approach directions as well as the strong influence of morphological conditions on approach directions. This topic has to be investigated during the ongoing research work in more detail, especially with the data recorded at the locations in the Elbe river estuary.

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