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# PROTOTYPE MONITORING STUDY OF WAVE CLIMATE AND BEACH PROFILE IN THE SURFZONE

BY

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# Prototype Monitoring Study
# of Wave Climate and Beach Profile in the Surfzone

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## Abstract

This paper deals with a beach monitoring field study. The monitoring program includes both beach profile surveys and wave climate measurements and was done at the East-Frisian island of Wangerooge in the German Bight. The aim of the field study was to get more information about the interactions between wave climate and beach profile after a beach nourishment. From the results of wave climate characteristics and beach profile surveys an analytic approach for hindcasting the monitored beach profile history have been evaluated.

## Introduction

Due to the heavy conditions in field during storm surge periods surveying of beaches is very difficult, sometimes impossible. Therefore beach surveying often is done only in longer time intervals, mostly once in autumn ( before storm surge period ) and once in spring ( after storm surge period ) and the results are presented in terms of total volume balancing within beach profiles and along the beach. Furthermore synchronous wave climate measurements are seldom and results often are presented in the sense of total occurred wave energy without any distinction, which parts of the wave climate time history have changed beach profiles in a certain manner and magnitude during the observed time period. Thus the understanding of the detailed process of wave-induced beach profile changing due to the steady changing of wave climates and waterlevels still does not seem to be very sufficient. Consequently there is still a great need for such data.

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Field boundary conditions

The beach survey and wave climate monitoring program was done at the north west corner of the East-Frisian island Wangerooge, which is situated in the southern German Bight ( Führböter, Grüne 1889 ). The bathymetry conditions around the island are given in Fig.1. The dephtlines ( dimensioned in meters ) are related to Low Tide. The 10 m waterdepth is roughly 3 km offshore from the beaches on the north. The wadden sea lies southern of the island and is characterized by extended tidal flats with narrow deep gullies. The main gully between the island Wangerooge and the western one is extremely deep, its position is fixed by an artificial partly underwater groyne from the western point of the island to the gully.

The main sediment transport northly of the East-Frisian islands is oriented from west to east. From the gullies between the islands this transport is superimposed by a seawards direction. Further east due to main tide and wave direction sediments are transported back towards the island. This leads to an nearshore sediment transport from the middle center of the island both to east with positive balance and to west with negative balance.

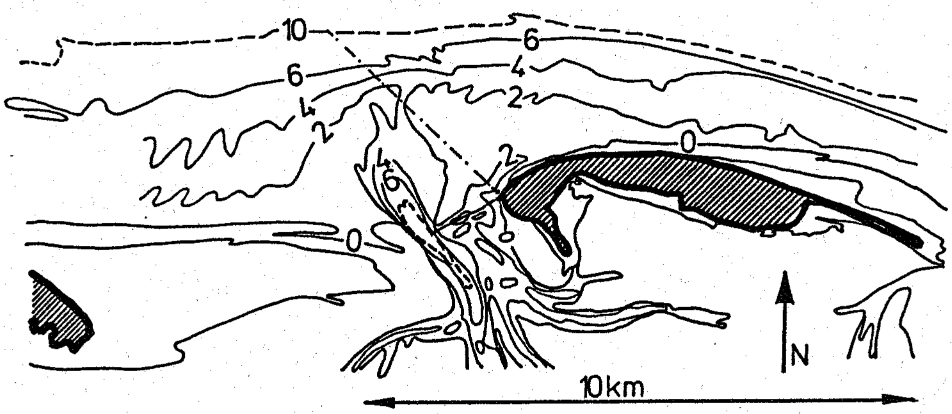


Fig. 1 Bathymetry around the island Wangerooge

Fully developed sea, coming in from the deeper parts of the shelf will be damped extraordinarily mainly due to the sandbanks around the bow of the depthlines, until reaching nearshore. However, under storm surge conditions there is a considerable rising of water level up to some meters abouve Mean High Tide and then wind waves with significant waveheights between one and two meters occur at nearshore.

Field Measurement Equipment

The beach level surveys have been started after a beach nourishment along the north-western beaches. Wave climate measurements were done in one survey profile. Fig. 2 shows the cross-section of that beach profile. The beach profile was surveyed manually at the 6 piles within a total lenght of the monitored range of roughly 100 m. Waves were measured at three positions ( WP ) with pressure cells.

The pressure data have been transferred to surface elevations by linear theory, extended with correction factors for waveheights and -periods, found in model and field tests. At the outer and the inner point of the monitored "control unit" P3 and P1 the water particle velocities were recorded each with 2 two-component velocity probes ( S ) ( three-dimensional measurements in two planes ). The upper bottom line was the beach profile after finishing the nourishment in October 83 and the lower bottom line was surveyed one year later.

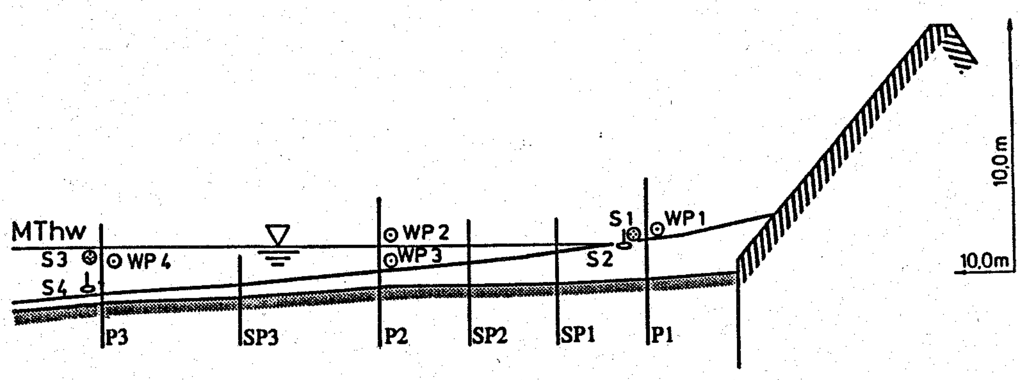


Fig. 2 Beach level survey profile with wave measurement equipment

Field surveys and measurements

The beach surveys have been done during one complete winter and summer season in time intervals depending on beach level changing. In the profile with the wave measurement equipment ( Fig. 2 ) further surveys have been done during strong sea and storm surge conditions as often as it was possible at Low Tide. Within the paper only data from this survey profile will be presented. In the upper part of Fig. 3 the time histories of the beach levels at the six measured positions are plotted, linear interpolated between the surveys. Wave climate measurements were done during strong sea conditions as much as possible due to the possibility to reach the island by ferry or airplaine during higher storm surges, because at that time recording devices had to set in operation manually. The time history of the High Tides *Thw*, related to Mean High Tide *MThw* is shown in the lower part of Fig. 3. The periods with wave climate measurements are marked with a star.

Results from wave climate measurements

Beach level changing is a direct function of wave-induced velocities acting on the sea bottom. With this equipment such direct measurements during storm surge conditions only are possible in sense of summerized results for time intervals of one or more High Tides, which are too long for detailed investigations. Thus and due to the approach for beach level hindcasting given in the next chapter, the following wave climate results are only focussed on the relations between waterdepth and wave parameters. Firstly some results for waveheight and -period parameters were described, in the second part some results for energy flux distribution.

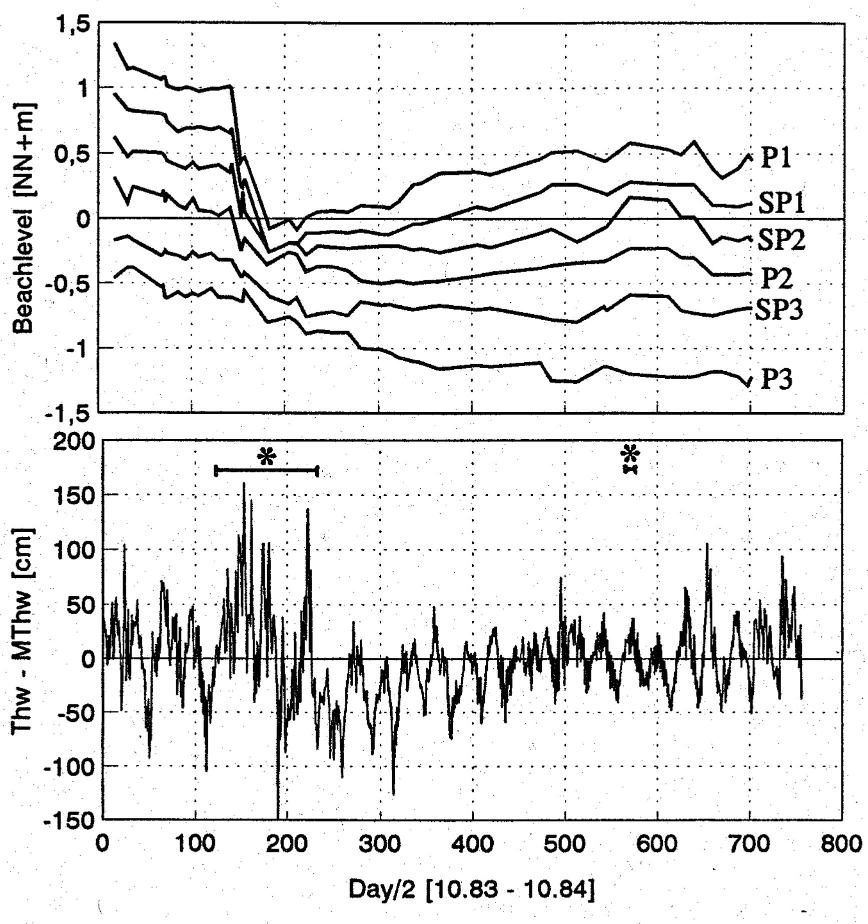


Fig. 3 Time histories of beach levels and of High Tide levels

Previous results from investigations on wave climate in nearshore areas, which are influenced strongly by onshore bathymetry, have demonstrated, that the waterdepth is the most accurate indicator for waveheights, whereas the correlations between waveheights and windspeeds have a much higher scatter. In Fig. 4 the significant waveheights $H_{1/3}$ measured at the three wave gauge positions cross-shore, are plotted versus the local waterdepth $D$. The gradients $\Delta H_{1/3} / \Delta D$, calculated by the least-square linear regression method decrease in wave propagation direction, which indicates energy losses due to bottom friction and wave breaking. Because the differences of the gradients are rather equal between each other, it can be assumed a constant wave breaking of spilling type cross-shore within the control unit.

The fact, that windspeed only has an indirect influence, comes out very clearly in Fig. 5 with the same waveheight data for position WP 4 as plotted in Fig. 4. From all measured data with different windspeeds and wind directions those with windspeeds U > 20 m/s within the wind sector SW to NW are separated. Also the wind direction has no or small influence on waveheights. The data confirm, that the increase of the local waterdepth by the local storm surge set-up contains all informations about the total two-dimensional windfield as well as the wave generation process on the shelf including the wave transfer process to nearshore ( Grüne, 1991 ). Thus local wave climate is a function of local surge set-up.

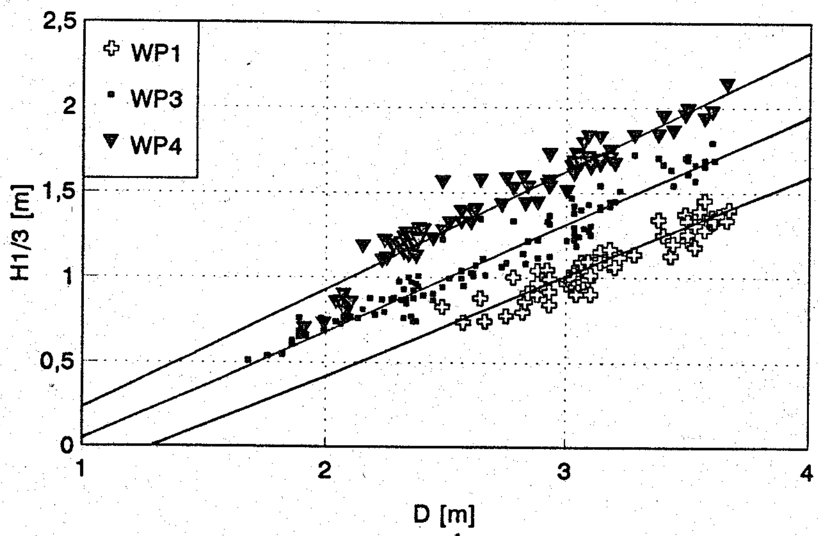


Fig. 4 Significant waveheight $H_{1/3}$ versus local waterdepth $D$

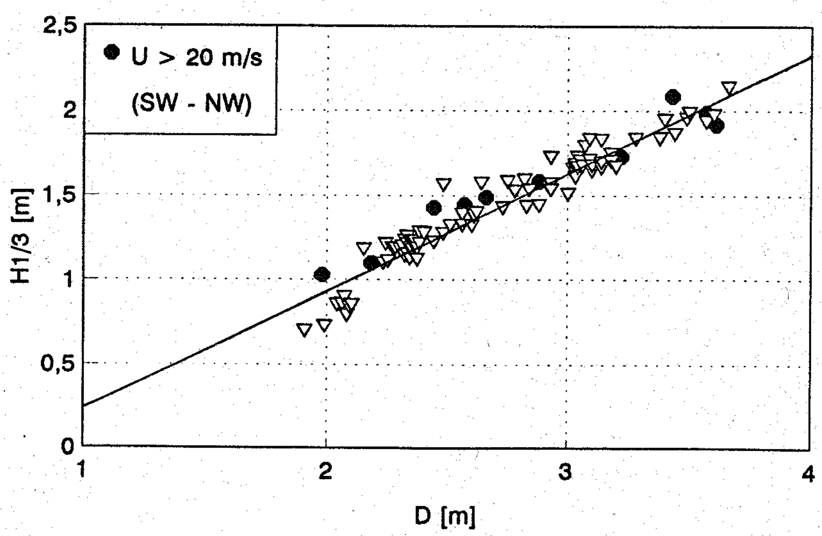


Fig. 5 Influence of wind parameter on waveheight-waterdepht correlation

In Fig. 6 the different waveheight parameters of the outer position WP 4 are plotted versus $H_{1/3}$ . The correlation is quite well, as usually found for wave measurements. The results from the other both positions agree quite well ( Table 1 ), which indicates nearly constant conditions for the waveheight related parameters within the control unit. Also the mean wave periods $T_m$ derived from the time domain correlate fairly well with the significant waveheights $H_{1/3}$ as shown in Fig. 7 . A much more scatter occur for the peak period $T_p$ correlation. The

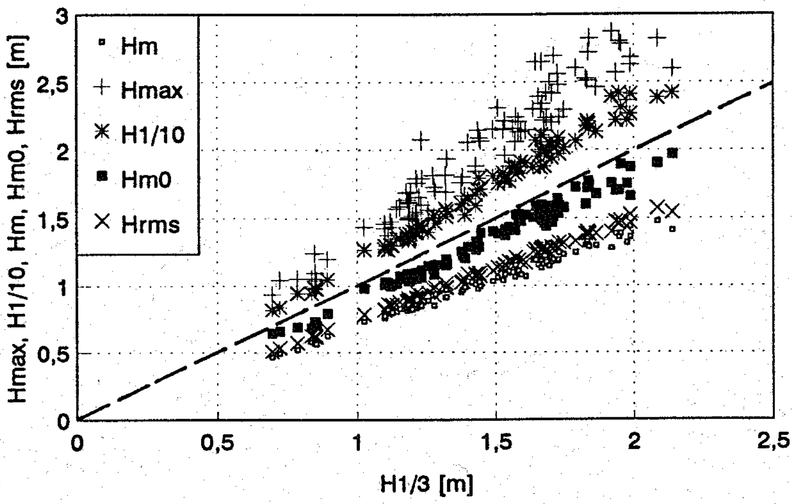


Fig. 6 Relations between waveheight parameters at position WP 4

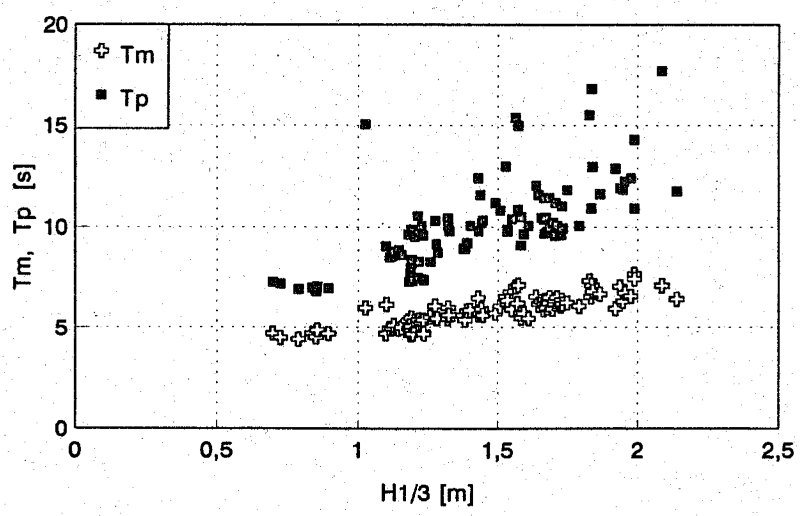


Fig. 7 Waveperiod parameter $T_m$ and $T_p$ versus $H_{1/3}$ at position WP 4

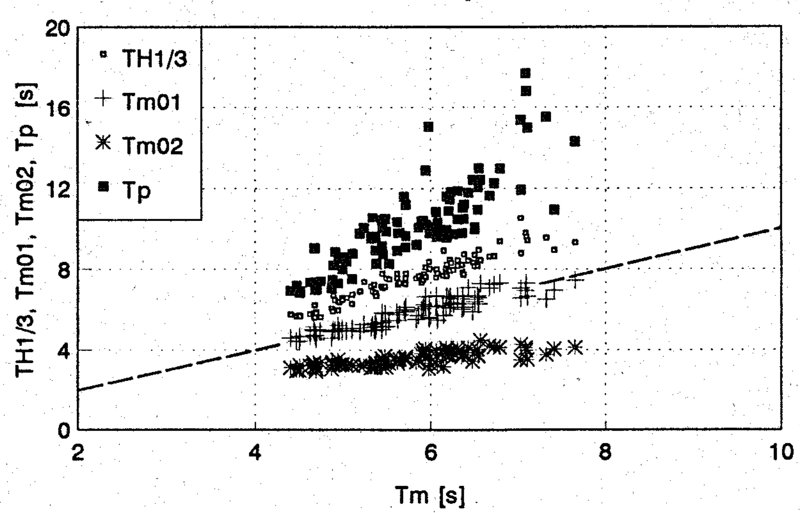


Fig. 8 Relations between wave period parameters at position WP 4

relations between the different waveperiod parameters between each other are given in Fig. 8. The correlation for mean values both from time ( $T_m$ ) and frequency domain ( $T_{m0}$ ) is also quite well, whereas the peakperiods $T_p$ have a broad scatter. From all parameter comparisons it can be stated, that within the control unit the waveheight and waveperiod conditions are roughly constant.

| | WP4 | WP3 | WP1 |
|---|---|---|---|
| $H_{max}/H_{1/3}$ | 1.423 | 1.373 | 1.354 |
| $H_{1/10}/H_{1/3}$ | 1.193 | 1.181 | 1.133 |
| $H_{m0}/H_{1/3}$ | 0.944 | 0.904 | 0.824 |
| $H_{rms}/H_{1/3}$ | 0.751 | 0.745 | 0.753 |
| $H_m/H_{1/3}$ | 0.704 | 0.694 | 0.706 |

| | WP4 | WP3 | WP1 |
|---|---|---|---|
| $T_p/T_m$ | 1.77 | 1.96 | 2.17 |
| $T_{H1/3}/T_m$ | 1.377 | 1.441 | 1.241 |
| $T_{m01}/T_m$ | 0.975 | 1.081 | 1.011 |
| $T_{m02}/T_m$ | 0.544 | 0.613 | 0.613 |

Table 1 Relations between waveheight and waveperiod parameters

The impact of an wave-induced velocity field on sand movement may be expressed in terms of energy flux, which stands for the wave energy, transmitted along wave propagation direction. The wave energy flux generally is defined by this formula:

$$J = E_o \cdot N \cdot C = E_o \cdot N \cdot L \cdot 1/T$$

with:

$$E_o = 1/8 \cdot \rho \cdot g \cdot H^2$$
$$C = L_o/T \cdot \tanh\,(2\pi D/L)$$
$$L_o = g \cdot T^2/2\pi$$
$$N = C_g/C = 0.5 \cdot (\,1 + 2\,kD/\sinh(2kD))$$

It must be remarked, that the energy flux values $J$, presented in the following, were calculated for each individual wave with the measured parameters $H$ and $T$, which have been analyzed one by one from a measured wave train. Fig. 9 shows the mean values of the energy flux $J$ versus the significant waveheight $H_{1/3}$ and the mean value of the terms $E_0$, $C$, $C_g$ and $N$. The correlation shows only a very few scattering, which can be explained by the strong correlations of the measured mean values of wave heights and periods, as mentioned before and consequently the correlations are quite well also for the wave propagation velocity $C$, the group velocity $C_g$ and the ratio $N$ between both. In the lefthand part of Fig. 10 the energy fluxes at the three wavegauge positions are related to $H_{1/3}$ . This data confirm again that the wave climate within the control unit is homogeneous with respect to wave parameter relations. Consequently the energy flux related to the local waterdepth in the righthand part of Fig. 10 differ between the three wavegauge positions in the same way as the waveheights do.

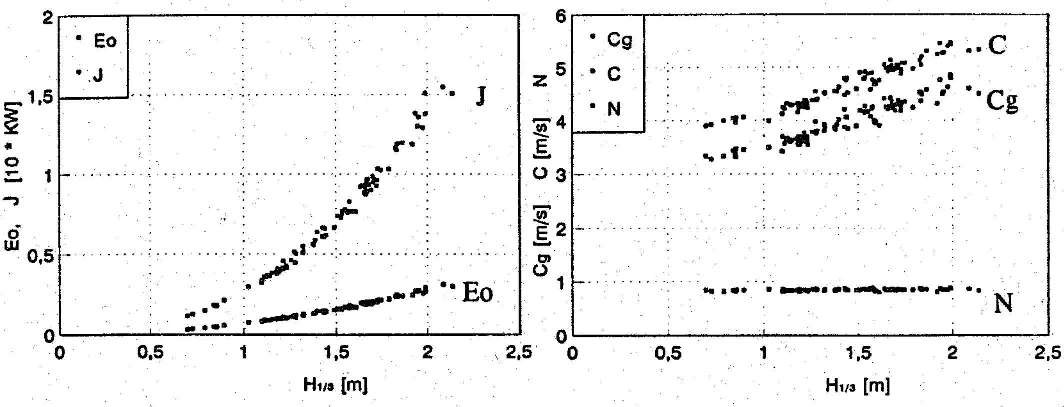


Fig. 9 Energy flux and terms versus $H_{1/3}$ at position WP 4

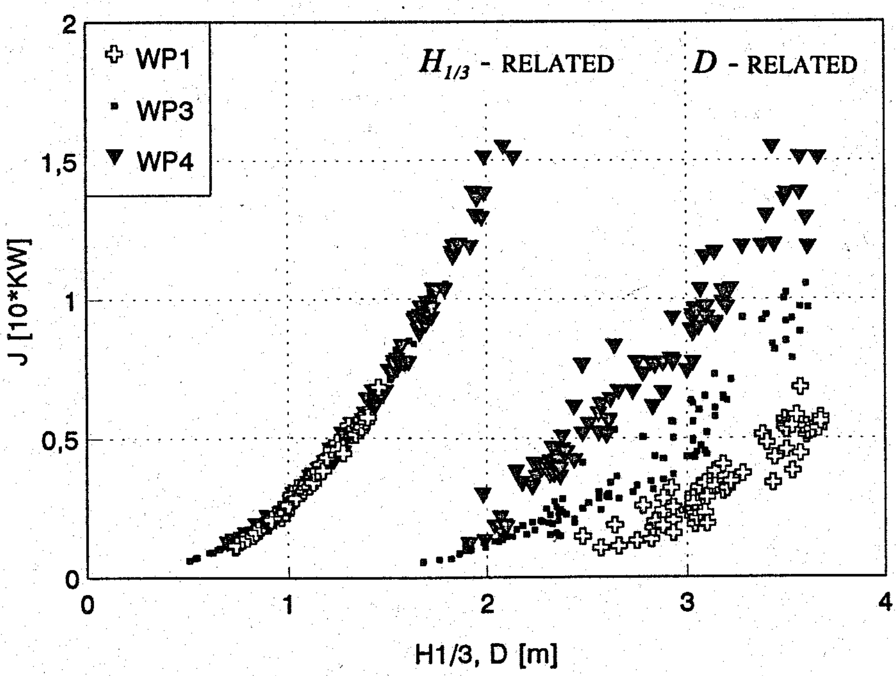


Fig. 10 Energy flux $J$ versus $H_{1/3}$ and $D$

Fig. 11 shows the relative loss of energy flux $J$ in dependence of the local waterdepth $D$ at the outer position WP 4. The value Zero means no loss, the value 1 means 100% loss of energy flux between the compared positions. There are trends of decreasing energy loss with increasing waterdepth. This means, that with higher waterdepths and consequently higher waves the part of energy loss due to spilling breakers on the beach decreases and the one due to plunger breakers at the revetment increases. These few results confirm the dominant role of the local waterdepth or the local surge set-up, respectively.

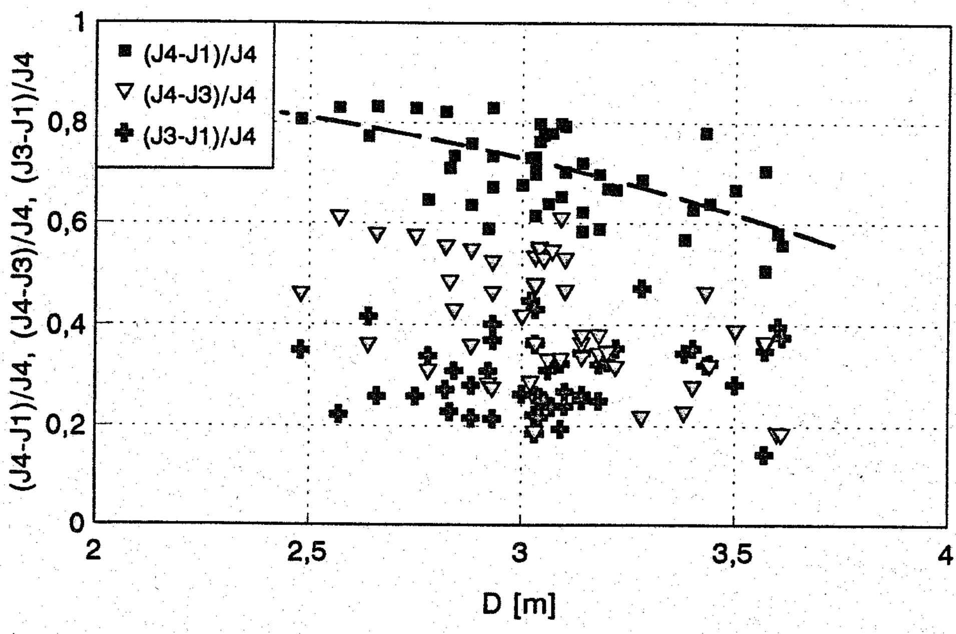


Fig. 11 Relative loss of energy flux *J* versus local waterdepth *D*

<u>Beach profile hindcasting</u>

If one compare the time history of the High Tide levels *Thw* with the contours of the beach level time history in Fig. 3, the relations between both are evident. Thus and the strong correlation between wave climate parameters and waterdepths as described before, have leaded to the idea to correlate the beach level changings directly with the corresponding High Tide levels *Thw*.

For the first tests on such a correlation approach all recorded High Tide levels *Thw* were related to a constant value around the mean High Tide level *MThw*. The *MThw* value is a significant one with respect to wave action in shallow water areas at most parts of the German Coast, because wave action with higher waveheights than roughly 20 cm mostly starts around or above this value due to bathymetry conditions onshore of the shelf. The best approximation was found for the squared difference between actual *Thw* and mean value *MThw* $(Thw - MThw)^2$, separated in three classes of $(Thw - MThw)$:

| | | | |
|---|---|---|---|
| 1.: | K1 | $(Thw - MThw)$ | > 0.4 m |
| 2.: | K2 | $(Thw - MThw)$ | < 0.4 m and > - 0.1 m |
| 3.: | K3 | $(Thw - MThw)$ | < - 0.1 m |

In Fig. 12 as an example for one survey position the vertical beach level changings $\Delta h$ are plotted versus the sum of the squared differences between the occured High Tides *Thw* and the Mean High Tide *MThw*. For High Tides higher than 0.4m above

*MThw* the correlation is quite well. A linear regression between vertical beach level changing and High Tide levels may be expressed by

$$\Delta h = K \cdot \Sigma\, (\,Thw - MThw\,)^2$$

The data with High Tide levels between below and 0.4m above Mean High Tide level scatter very much. Similar relations were found for the other survey positions on the beach.

A best fitting for the K - values has been found with try - and - error method. In Fig. 13 the cross-shore distributions of these values are shown for the three different classes. The K - values depend on the position on cross-shore, generally

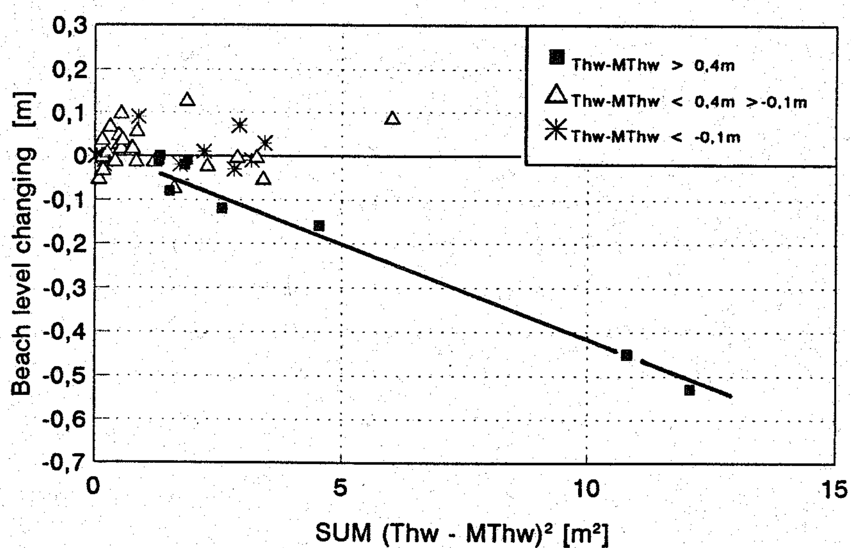


Fig. 12 Relations between beach level changings and High Tide levels

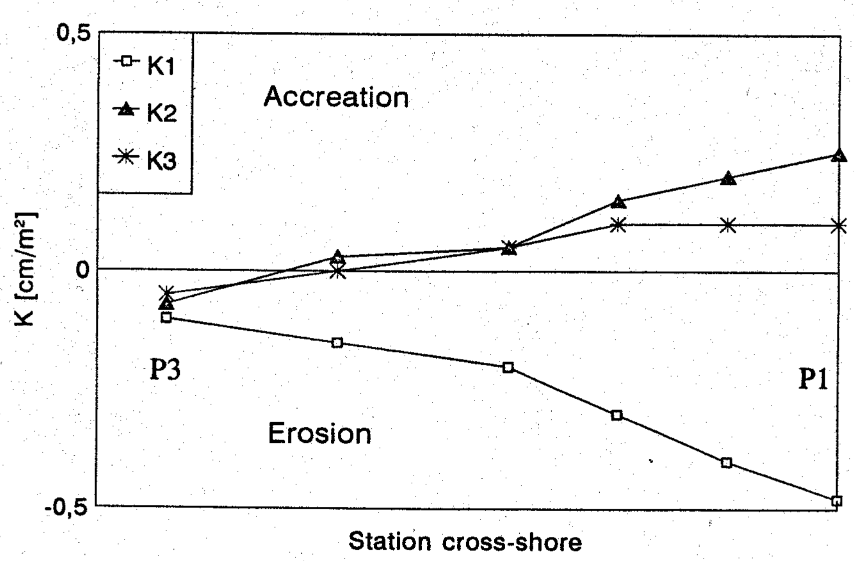


Fig. 13 Cross-shore distribution of K - values

they increase in wave propagation towards the breaking point. The K1 - values give erosion for High Tide levels of more than 0.4 m above *MThw* value, the K2 - and K3 - values lead to accreation for smaller High Tide levels than 0.4 m above *MThw*. With these K - values the beach level time histories were hindcasted, the results are plotted in Fig. 14 for all 6 survey positions cross-shore. It must be mentioned, that for this first approach only one type of the these classes was chosen for each survey interval. Differences between measured and hindcasted beach level mostly occur for the accreation period after the heavy storm surge period.

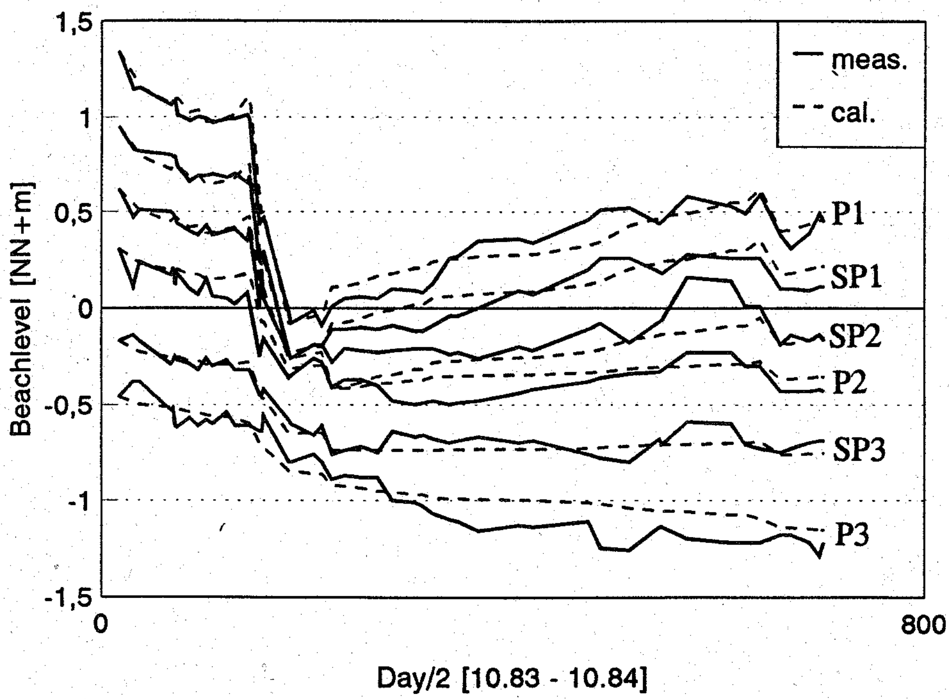


Fig. 14 Comparison between surveyed and hindcasted beach level time histories

From some further detailed tests it was found, that the differences might be caused by the fact, that the K - values are not constant for each position on the beach as used for the first step hindcasting, but also are effected by the different slopes, which occurred during the total survey time. In Fig. 15 the time history of the mean slopes values N ( slope 1 : N ) between the three wave gauge positions show three different time domains:

- The first one with light erosion with roughly constant slopes.
- The second one with strong erosion with much more smoother slopes, and a local changing of the smoother slope from the first half part of the control unit in wave propagation direction to the second half part.
- The third one with a light accreation in the second half part and light erosion in the first half part with an increasing of the slopes, until the original slopes were reestablished.

Modifying the K - values to the different slopes, it might be possible to reduce the differences of the hindcasted beachlevels.

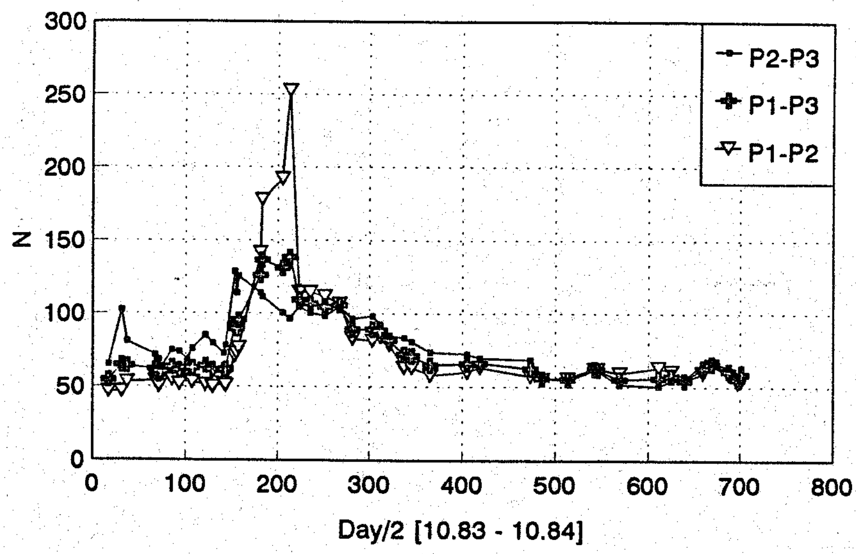


Fig. 15 Time histories of slopes

## Conclusion

The results of monitoring confirmed statements from previous investigations, that the different occurring wave climate characteristics have a distinct influence on beach profile changing during the total winter season. The strongest initial beach profile changings with erosion are caused by storm surge wave climate events, whereas the weak interactions with a partly accreation are caused by strong and normal wind wave climate events. The strong interactions from storm surge events firstly lead to more gentle slopes, but later with the weak interactions from normal wind events the slopes return towards their original values.

The relations found between actual waterdepth and accompanying wave climate parameters have leaded to an simple analytical oriented method for hindcasting the monitored beach profile time history using the High Tide level time history.

## References

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