CHAPTER 41

WAVE MODEL APPLICATION IN A WADDEN SEA AREA

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ABSTRACT

A verification study of the numerical 2D wave propagation model HISWA is presented for a complex coastal area. Model predictions are confronted with field measurements. Also the effects of specific model possibilities and limitations are examined. Results have been fair: mean errors in wave height of 12% and in wave period of 4%, at a distance of 4 km from the incoming boundary over which measured wave heights reduced 40% and periods 21%.

1 INTRODUCTION

The aim of using wave propagation models, is to estimate nearshore wave conditions from offshore available wave data, by considering the onshore wave processes. In this paper the performance of the wave propagation model HISWA in a German part of the Frisian Wadden Sea (fig. 1) is discussed. As the study is still continuing, only intermediate results will be presented, unsolved questions might be answered in the near future.

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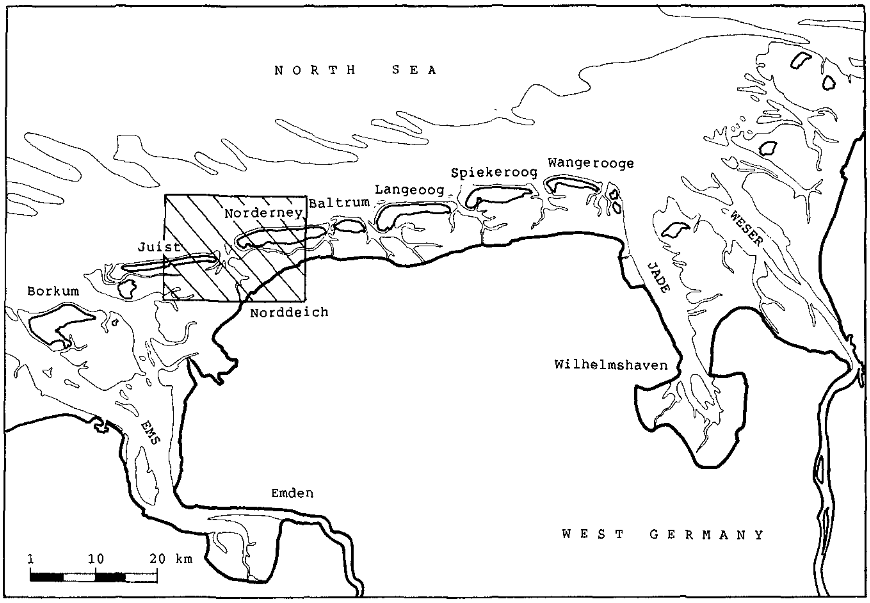


fig. 1 location of the investigation area

2 THE MODEL HISWA

To get an idea of the sort of model, the basic formulation of HISWA and the physical processes involved will be discussed briefly. Detailed information can be found in papers by BOOIJ et al. (1985) and HOLTHUIJSEN et al. (1988).

HISWA is a numerical, 2D wave propagation model, based on the action balance equation for stationary conditions. Action is an energy derived quantity, by dividing energy by the relative frequency. Unlike energy, action is also conserved in the presence of a current. The action balance equation has the following shape:

$$\frac{\partial(c_x A)}{\partial x} + \frac{\partial(c_y A)}{\partial y} + \frac{\partial(c_\theta A)}{\partial \theta} = S \qquad (1)$$

On the left hand side the transport terms (gradients) of the action density integrated over the frequency (A) are written. c_x and c_y denote the translation speeds of A, c_θ the speed with which A changes its direction. The transport terms cause a redistribution of existing energy in space and over the directions, which implies propagation and shoaling and refraction but not diffraction.

On the right hand side the S, denoting sinks and sources, stands for the sum of all external processes removing wave energy from or introducing wave energy into the system. These are wave breaking, bottom friction, current dissipation and wind growth. They are represented by suitable semi-empirical functions.

The frequency is not constant; there is an equation similar to (1) from which the action averaged frequency can be found. By employing the θ-dimension, the concept of a directional wave spectrum is retained. The action balance is projected on a regular grid (x, y, θ) for numerical operation.

HISWA can produce several types of output, for a number of wave parameters. In this study the wave height and period serve as test parameters. HISWA operates with a significant wave height $H = 4(M_0)^{0.5}$ and a mean period $T = M_{-1}/M_0$ in which M_0 and M_{-1} are the 0th and the -1st frequency moments of the wave spectrum. Anywhere in this paper H and T are those given by the above definitions.

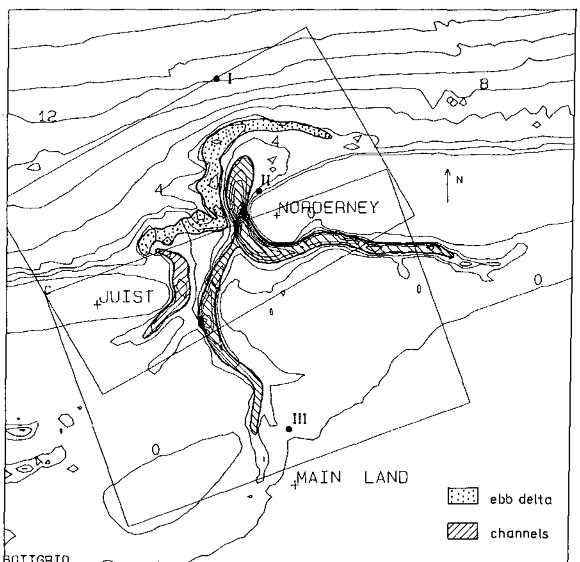


FIG. 2 LOCAL MORPHOLOGY

BOTTOM CONTOURS AND COMP. GRIDS

1000 M

Δ 2.00x10⁰ M

3 MORPHOLOGY

Because of its relevance for wave propagation, a short outline of the local morphology is given (fig. 2). The area of interest lies in the surroundings of the barrier islands Norderney and Juist. North of the islands initially there is a mildly sloping bottom. This smooth topography is interrupted by an ebb delta, lying at a distance of at most 2 km out of the northwest coast of Norderney. It partly shelters the tidal inlet between Norderney and Juist. In the tidal inlet two main channels have formed. The larger eb channel in the east splits up into two tributaries, one bending around the west end of Norderney and another directed to the main land coast in the middle. The flood channel in the west, bends around the eastern shore of Juist.

South of the islands physiographically quite a different situation occurs. Here the area consists of a system of tidal flats and narrow channels, a typical part of the Wadden Sea stretching along the Dutch, German and Danish coasts. But currently the investigations are focussed on the northern part.

Two dominating features with respect to wave propagation are the ebb delta and the tidal channels. The ebb delta causes a lot of wave breaking during storm occasions. The channels are corridors through which wave energy penetrates. Also the course of wave directions along the channels remains rather constant for a wide range of incoming wave directions (NIEMEYER, 1986).

The frames in fig. 2 indicate the computational areas, measuring about 7.5 x 12 km and 9 x 12 km north and south. Points I, II and III are observation points.

4 FREQUENCY SHIFT

HISWA simulates the frequency change associated with each of the dissipative or generative processes. For wave breaking and bottom friction the frequency change can optionally be switched on or off. The change of frequency is based on certain assumptions of the frequency spectrum in relation to energy dissipation. As indicated by DINGEMANS (1987) these assumptions do not fully match physical reality. Compared with a laboratory experiment (DINGEMANS, 1987) the frequency would get too high (or the period too low). A constant frequency on the other hand, is physically also unrealistic in relation to wave breaking and bottom friction.

A change in frequency will affect the processes on both sides of the action balance equation and thus the wave height. Refraction, getting weaker with increasing frequency, has especially much influence on the steep slopes of the main channel along Norderney. So it is of importance to have a good estimation of the frequency. To examine the effect of the frequency change, ratios between the wave height computed at a constant frequency and at a changing frequency were calculated for regularly spaced points over the area. It was found that these ratios ly between 0.60 in the eastern main channel and 1.25 at the western part of the ebb delta. Just as an example fig. 3 shows a block print of such ratios for a part of the area. (A block print is a table of values for a grid of regularly spaced points, like a value map with different x,y-scales).

VOGEL et al. (1988) applied HISWA in a comparable sort of area with the frequency change switched on. Instead of the expected underestimation of the wave period by letting the frequency change, their computations showed a small overestimation of the period of 7% on average.

1.16	1.15	1.13	1.10	1.07	1.05	1.05	1.05	1.05	1.07	1.08
1.17	1.15	1.11	1.07	1.03	1.03	1.04	1.04	1.05	1.06	1.08
1.16	1.13	1.08	1.03	1.01	1.01	1.02	1.03	1.05	1.07	1.08
1.14	1.09	1.04	1.00	0.99	1.00	1.01	1.03	1.05	1.08	1.09
1.11	1.05	1.00	0.97	0.98	0.99	1.01	1.03	1.06	1.08	1.09
1.08	1.01	0.97	0.96	0.96	0.98	1.01	1.05	1.07	1.09	1.10
1.03	0.97	0.94	0.94	0.95	0.98	1.02	1.06	1.09	1.10	1.11
0.98	0.94	0.92	0.92	0.94	0.98	1.04	1.08	1.11	1.12	1.13
0.95	0.91	0.90	0.91	0.94	1.01	1.07	1.11	1.14	1.15	1.16
0.92	0.88	0.87	0.90	0.97	1.07	1.12	1.14	1.15	1.16	1.15
0.89	0.85	0.85	0.90	1.02	1.13	1.25	1.37	1.29	1.32	1.41
0.86	0.81	0.83	0.92	1.08	1.37	1.74	nney	nney	nney	nney
0.83	0.78	0.81	0.92	1.17	1.17	nney	nney	nney	nney	nney
0.79	0.77	0.83	0.95	1.42	1.42	nney	nney	nney	nney	nney
0.76	0.77	0.85	0.95	nney	nney	nney	nney	nney	nney	nney
0.75	0.77	0.84	0.92	nney	nney	nney	nney	nney	nney	nney
0.74	0.76	0.82	0.90	nney	nney	nney	nney	nney	nney	nney
0.74	0.75	0.82	0.91	nney	nney	nney	nney	nney	nney	nney
0.74	0.77	0.85	0.95	nney	nney	nney	nney	nney	nney	nney
0.74	0.78	0.87	1.00	1.14	1.14	nney	nney	nney	nney	nney
0.74	0.79	0.87	0.93	0.92	0.92	nney	nney	nney	nney	nney
0.73	0.77	0.83	0.87	0.87	0.87	nney	nney	nney	nney	nney
0.71	0.73	0.79	0.85	0.86	0.86	nney	nney	nney	nney	nney
0.69	0.70	0.76	0.83	0.85	0.83	0.80	nney	nney	nney	nney
0.68	0.68	0.72	0.78	0.83	0.80	0.79	nney	nney	nney	nney
0.67	0.66	0.69	0.72	0.75	0.73	0.72	0.71	nney	nney	nney
0.66	0.64	0.64	0.67	0.71	0.69	0.67	0.68	0.71	nney	nney
0.65	0.63	0.61	0.62	0.65	0.66	0.63	0.60	0.64	0.94	nney
0.66	0.62	0.60	0.59	0.60	0.61	0.60	0.58	0.54	0.68	1.01

fig. 3 ratios of the wave height obtained with the frequency switches turned off and turned on

In order to decide for this area whether to run HISWA with a changing or a constant frequency, tests were done both with the frequency change switched on and off. For both situations the calculated wave periods and wave heights were compared with field measurements. For the wave period an overall better performance was found by having the frequency change switched on, as can be seen in figure 4 and table 1: a mean percent error $\overline{e(T)}$ of -4% with the frequency change switched on against 29% with the frequency change switched off. The percent error of the period is defined as $e(T) = 100\% * (T_{his} - T_{obs})/ T_{obs}$, with the subscripts his and obs referring to HISWA and observed values. For the wave height there is hardly any difference between cases with a changing or a constant frequency: mean errors $\overline{e(H)}$ of 12% for both cases (fig. 5, table 1). This could be due to the position of the observation point (II) in front of the deep channel along Norderney, where the wave height is still relatively unaffected by refraction. The scatter (standard deviation sd) gets a little lower when the frequency change is switched on. On account of the improvement of the wave period, it was decided to run HISWA with the frequency change switched on.

TABLE 1 : FIELD MEASUREMENTS AND HISWA PREDICTIONS

INCIDENT WAVES		INSHORE WAVE HEIGHTS H (m)			INSHORE WAVE PERIODS T(s)		
height H (m)	period T (s)	observed	HISWA freq. switch on	HISWA freq. switch off	observed	HISWA freq. switch on	HISWA freq. switch off
2.69	6.4	1.50	1.53	1.69	6.1	4.6	6.4
2.69	6.4	0.98	1.08	0.97			
2.61	8.1	1.48	1.64	1.59	4.3	5.4	8.1
1.53	5.5	1.13	1.12	1.16	5.2	4.3	5.5
1.70	6.2	1.20	1.34	1.40	4.8	4.8	6.2
1.65	6.2	1.32	1.51	1.52	4.7	5.2	6.2
1.69	5.4	1.14	1.38	1.36	4.6	4.5	5.4
1.77	5.7	0.92	1.07	1.07	4.6	4.1	5.7
1.69	5.7	0.91	1.30	1.34	4.7	4.5	5.7
1.93	6.6	0.98	0.89	0.84	4.7	4.0	6.6

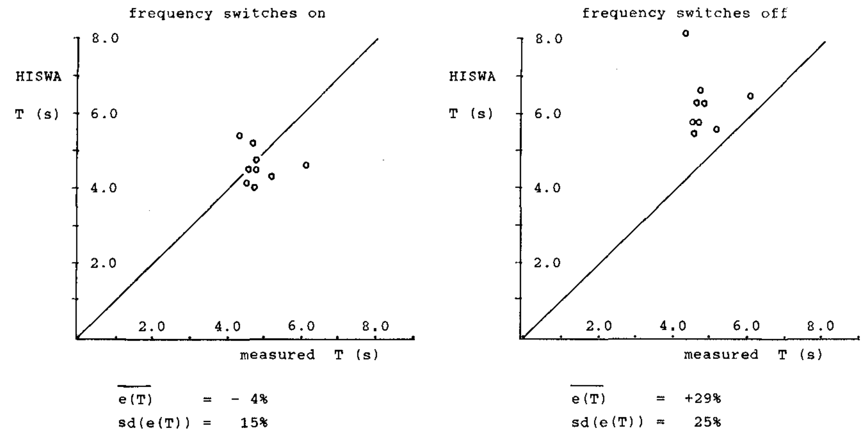


fig. 4 WAVE PERIOD TESTS WITH THE FREQUENCY SWITCHES TURNED ON AND TURNED OFF

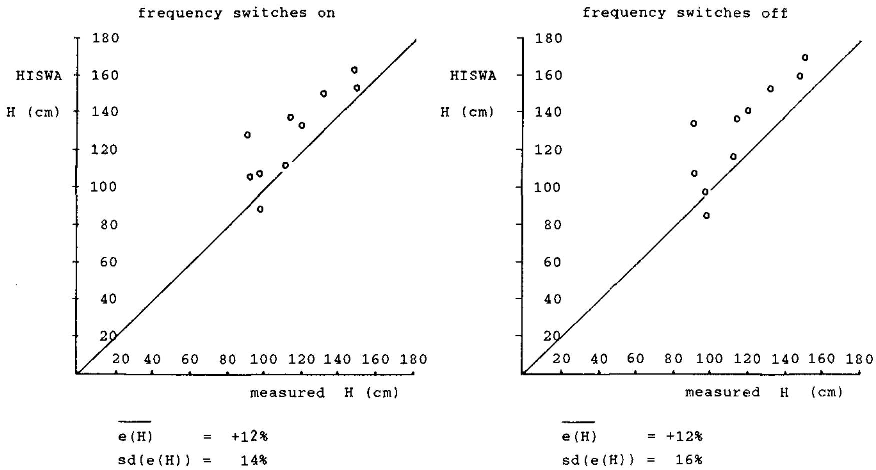
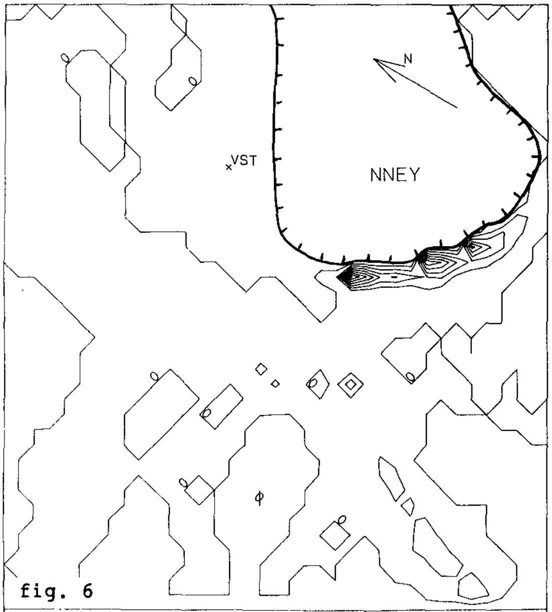


fig. 5 WAVE HEIGHT TESTS WITH THE FREQUENCY SWITCHES TURNED ON AND TURNED OFF

5 ENERGY LEAK

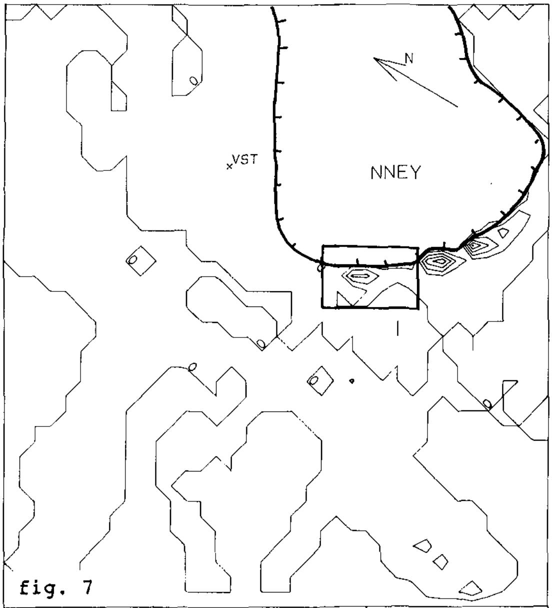
For reasons of numerical stability HISWA can only operate within a directional sector of limited range. The sector width should be predefined and usually is taken near 120 degrees. Energy transported beyond the directional limits



ENERGY LEAK AT STANDARD DIRECTIONAL SECTOR (141 DEGR.)

is removed out of the system. This unintended energy loss, called (energy) leak, is thus caused by numerical restrictions and should not physically occur. So leak arises when the wave energy is distributed over a wider directional range than the predefined directional sector.

In the area of investigation leak occurs on the steep slopes of the deep channel along Norderney due to strong refraction (fig. 6). To get an idea of the error in the wave height caused by leak, the directional sector was enlarged to 162 degrees (which is about the maximum attainable and not suited for operational purpose). By this, leak will be reduced and the wave height increased and so a link can be made between leak and wave height. In the region where leak was largest, it was reduced strongest by expanding the directional sector as can be seen in figs. 6 and 7 (within the small rectangle). By means of block prints it was found that leak reduced here about three times whereas the wave height only increased 4%. This is about the largest effect leak can have upon the wave height, because here leak reduces from the highest value to a rather low value. So leak has only little effect upon the wave height.



ENERGY LEAK AT ENLARGED DIRECTIONAL SECTOR (162 DEGR.)

Besides expanding the directional sector there are some other ways to influence the leak. The computational grid can for instance be rotated in such a way that as much energy as possible falls within the directional limits (fig. 8). In this way an orientation with lowest leak was found, the x-axis directing 150 to 160 degrees clockwise from the north. Because wave directions in the tidal channels are rather consistent, this orientation will be suited for incoming waves of all relevant (onshore) directions.

Leak will also be influenced by the use of the frequency switches. Switching on the frequency change will reduce refraction because of an onshore frequency increase. Thus the energy will be spread over a smaller directional range and the leak will be reduced. In case of a changing frequency leak is about 3 times less than in case of a constant frequency.

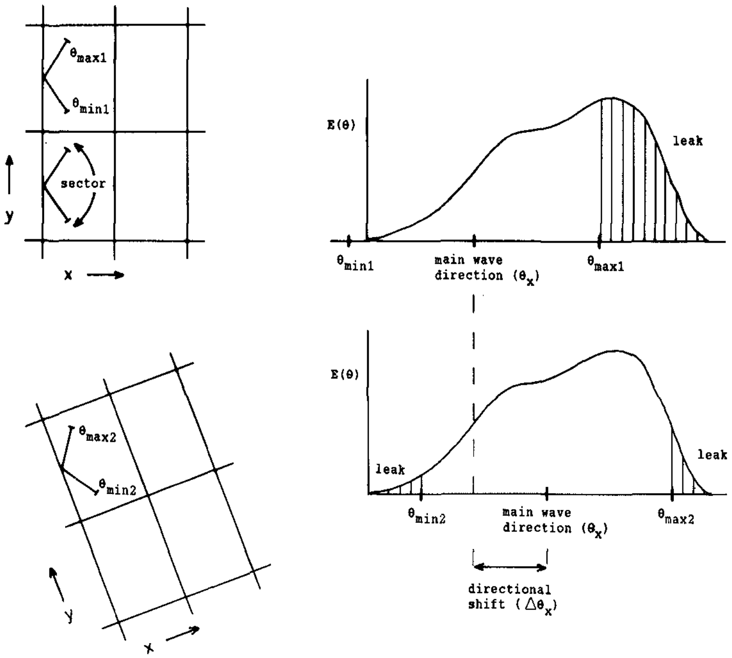


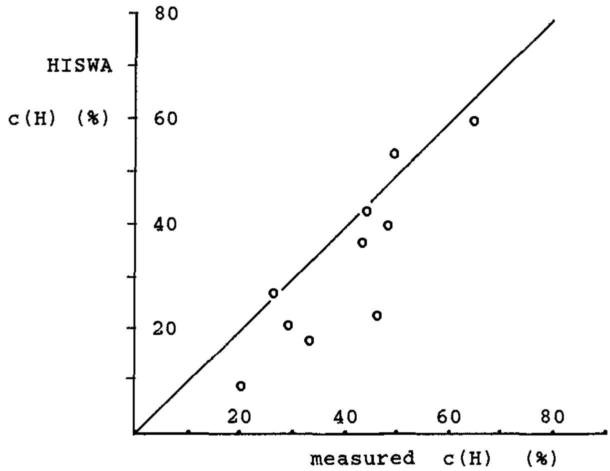
fig. 8 turning the computational grid and energy leak

6 MODEL RESULTS

Before looking at the results it should be noted that the sink and source functions of HISWA contain some empirical coefficients for which default values are assumed, which can however be adjusted. A calibration took place, based on two storm occasions, after which both wave breaking coefficients of Miche were lowered. They were given values of 0.75 and 0.90 for shallow and deep water respectively. Their standard model values were 0.8 and 1.2.

As test conditions, wind speeds ranged from 10.3 to 18.6 m/s at 10 m height, wind directions from 280 to 340 degrees and wave directions from 270 to 320 degrees (going clockwise from the north to the incoming direction). Currents were not included, but computations were generally done at low stream conditions.

Results have already been shown at the tests with the frequency switches (table 1, figs. 4 and 5). It might



$\overline{e(c)}$ = - 21%

sd(e(c)) = 24%

fig. 9 COMPARISON OF PREDICTED AND MEASURED ONSHORE WAVE HEIGHT CHANGES

however be more convenient to use the change in wave height between offshore boundary and nearshore observation point as test parameter, rather than the wave height. By this it will be more apparent whether the predictions concern situations of substantial onshore change or not, indicating the quality of the tests. In fig. 9 the percent onshore wave height change of the HISWA computations is plotted against the measurements. The percent onshore wave height change is defined as $c(H) = 100\% * (H_{off} - H_{near})/H_{off}$, with the subscripts off and near referring to offshore and nearshore observation points. As is seen HISWA predicts too small changes which means wave heights are still too high despite the downward adjustment of the wave breaking coefficients. The mean percent error $\overline{e(c)}$ of the percent onshore wave height change is -21% at a standard deviation sd(e(c)) of the percent error of 24%.

Fig. 10 shows a typical wave height plot for onshore directed waves. A rapid wave height decrease occurs along the ebb delta. In the inlet channels wave heights are more persistent.

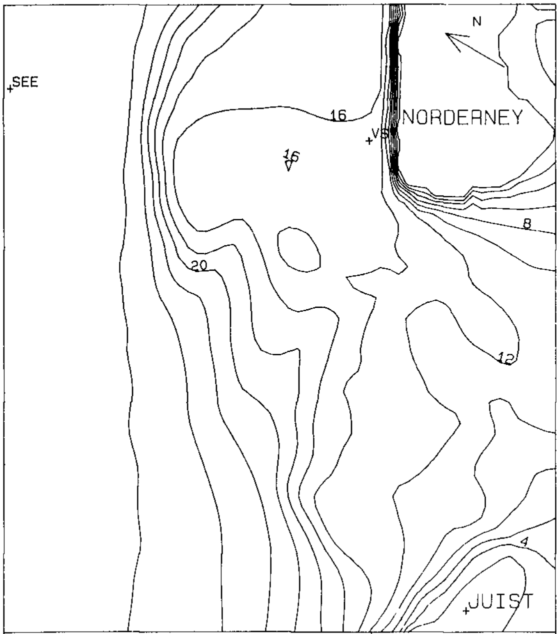


fig. 10 WAVE HEIGHT ISOLINES AROUND NORDERNEY

7 SINKS AND SOURCES

The sensitivity of the model to the processes of wave breaking, bottom friction and wind growth was tested by putting alternately one of these processes out of order and comparing the results with the normal case (all processes functioning). In fig. 11 wave height profiles between incoming boundary and observation point show the evolution of the wave height for each case. It is seen that wave breaking is a most dominating process, reducing the wave height up to 45% (beach margins excluded, as waves totally diminish there). The influence of bottom friction and wind growth is much less, at most 4% and 3% respectively. The calculated value comes closest to the measurement when all processes are considered or when the wind growth is not functioning. The wave height reduction between the incoming boundary and the observation point calculated by HISWA is 43%. This lies close to the 42% which NIEMEYER (1987) found as a mean value over a large range of field measurements.

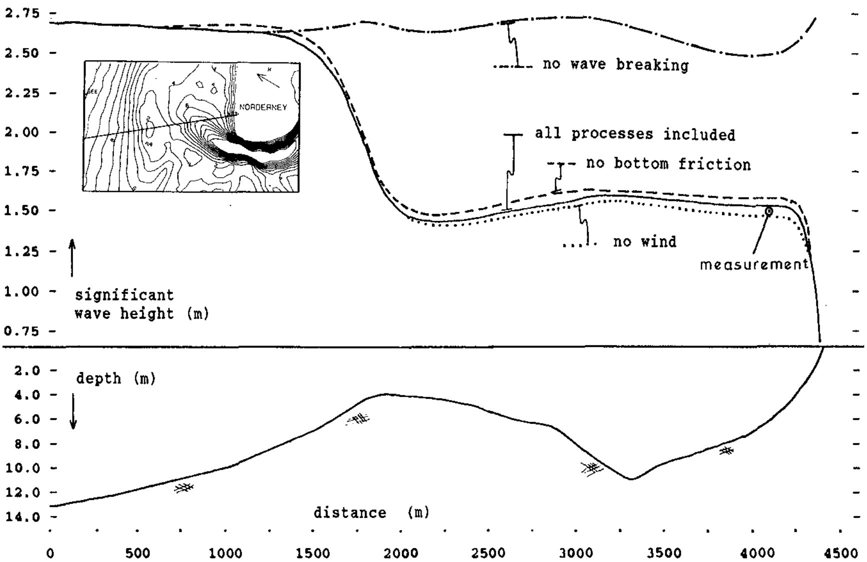


fig. 11 onshore wave height evolution in dependence of energy sinks and sources

The distribution of the percent changes over the total area was examined by means of block prints. Wave breaking can reduce wave heights up to 60% in the centre of the tidal inlet. In the same way the maximum reduction by bottom friction was found to be 7% and the maximum increase by wind growth 9% (at the end of the fetch). Of course these figures depend upon each situation individually and only serve to get an idea of the relative importance of the various sinks and sources in this area. In the study by VOGEL et al. (1988) it was for instance shown that under their conditions, wind growth can be a much more dominating process.

CONCLUSIONS

- Running HISWA with the frequency changes switched on has a positive effect on the wave period and the energy leak. The computed wave height in the observation point hardly improved by use of the frequency switches.

- The presence of leak does not harm the model results significantly.

- Of the various energy sinks and sources, wave breaking has the largest influence upon the wave height.

- HISWA does give fair results in the area of investigation where wave breaking is a dominating process.

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REFERENCES

BOOIJ N., HOLTHUIJSEN L.H. AND HERBERS T.H.C., 1985, The shallow water wave hindcast model HISWA, Part 1: physical and numerical background. Delft University of Technology, Dept. of Civil Engng., Group of Fluid mechanics. Report no. 6-85.

DINGEMANS M.W., 1987, Verification of numerical wave propagation models with laboratory measurements. Delft Hydraulics Laboratory, Report H-228.

HOLTHUIJSEN L.H., BOOIJ N. AND HERBERS T.H.C., 1988, A prediction model for stationary, short-crested waves in shallow water with ambient currents. Coastal Engineering, vol. 12, pp. 23 - 54.

NIEMEYER H.D., 1986, Wave propagation and damping in the offshore and Wadden Sea area near Norderney (in German: Ausbreitung und Dämpfung des Seegangs im See- und Wattengebiet von Norderney). Jahresbericht 1985, Forschungsstelle Küste, Band 37

NIEMEYER H.D., 1987, Changing of wave climate due to breaking on a tidal inlet bar. Proc. 20th Intern. Conf. Coast. Engng. ASCE, Taipei, vol. 2, pp 1427 - 1443.

VOGEL J.A., RADDER A.C. AND DE REUS J.H., 1988, Verification of numerical wave propagation models in tidal inlets. Proc. 21st Intern. Conf. Coast. Engng. ASCE, Malaga, vol. 1, pp 433 - 447.