CHAPTER 167

INFLUENCE OF OFFSHORE BANKS ON THE ADJACENT COAST

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Abstract

A numerical model has been used to study the influence of offshore sand banks on the wave climate along a stretch of the Belgian coast. Results of the model have been interpreted to provide predictions of wave height under several scenarios, assuming that the banks do not respond quickly to changes in the local hydrodynamic environment. Results show that the sand banks afford substantial protection to the coast and that this effect may be reduced as a result of rising mean sea level and dredging.

Introduction

As part of the EC MAST II Programme, the Circulation and Sediment Transport Around Banks (CSTAB) project has brought together coastal engineers, oceanographers and geologists from five European countries to study of the role of sand banks in the processes and development of the nearshore hydrodynamic and littoral environment. The CSTAB project, scheduled to run between 1992 and 1995, is centred around an ambitious field programme measuring hydrodynamics and sediment dynamics in a typical linear sand bank system off the Belgian coast.

The field study site, which includes the inter-tidal and surf zones of the adjacent beach as well as the offshore sand banks, covers an area of approximately 400 km^2. Since this entire region cannot be covered completely in a field study, computer models are being used to provide the necessary additional information to link together the various field campaigns and to provide a valuable predictive capability. This paper describes the application of a wave climate computer model to quantify the influence of offshore sand

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banks on the adjacent coast.

Sand banks and the coast

Large linear sand banks are a feature of many continental shelves throughout the world (Off, 1963). These sand banks occur in both tide and wave-dominated coastal seas, and in most instances, do not appear as lone features but as part of a regional group. The sand banks being investigated in the present paper are part of the Flemish Banks, which are situated on the Belgian coastal shelf in the southern North Sea. This bank system can be described, broadly, as a group of linear sand banks of the order of 10 to 20 km in length, 1 km in width and 10 to 20 m in height. A comprehensive review of the Flemish Banks has been presented by de Moor (1989).

One of the effects of offshore sand bank systems is to shelter the adjacent coast. This is believed to result primarily from the increased frictional drag on storm surges and increased friction on, and breaking of, the larger short-period storm waves. This latter feature has also been investigated by Tucker et al. (1983) who studied wave attenuation over a sand bank on the East Anglian coast of the UK. Using measurements taken by two wave rider buoys, they found negligible attenuation for small waves and a saturation level for larger waves determined by the breaking conditions over the bank.

If existing sand banks were reduced in size, or removed altogether from a system, the coast would experience a significant increase in the amount of wave energy reaching it. This would result in intensified erosion of the shoreline and the possible necessity to reinforce existing coastal defences. Sand banks also significantly modify the regional distribution of wave energy impacting on the coast. The local wave height field is determined by interaction with the local currents and the shoaling, refraction and diffraction which results from the reaction of the propagating waves to changes in bottom bathymetry. Changes in the offshore depths, either actual morphological changes or as a result of water level variation, could have serious implications for individual locations along the coast far beyond that expected for the coast in general.

The size and orientation of the sand banks may also change with long-term changes in mean sea level providing sufficient material is available. However, the time scale at which the banks can react may be very long. A number of linear sand bank systems, such as the Celtic Banks, were at one time active but are now moribund, having been unable to respond to rapid changes in sea level. De Vriend (1990) and van de Meene (1994) have both noted that, while the smaller-scale features on the sand banks (such as sand waves or smaller) can react quite rapidly, the morphological time scale of sand bank development is on the order of decades to centuries. In the present work

the bathymetric features are assumed to be unaffected by any change in mean sea level which may result due to climate change.

Climate Change

Recently, studies have indicated that the growth in the level of greenhouse gases in the atmosphere can lead to a gradual increase in mean global temperature. One consequence of a gradual increase in mean global temperature is a rise in mean sea level (MSL). Pirazzoli (1989) found the rate of increase of MSL for the North Sea to be 1.0 to 1.5 mm/year. This was confirmed for the southern North Sea by Jensen et al. (1990) who calculated an average MSL rise of 1.2 mm/year across 12 tidal recording stations over a 100 year period. Jensen et al. (1990) also found some evidence to suggest that MSL increases may be accelerating.

Warrick and Oerlemans (1990) have presented sea level predictions based on a compilation of existing results and new computations. Their High, Best and Low predictions, for the Business-as-Usual scenario are given in Fig. 1. There is considerable spread in the three estimates given - a 20 cm rise in MSL could be realized anytime from 2020 to 2070 - but, all do show a gradually accelerating rise in MSL. For the purpose of the present paper, this Best Estimate will be used to relate simulation water levels to future dates.

Increased MSL will have serious consequences for coastal regions. A higher MSL will result in a general retreat of the shoreline and will allow larger waves to penetrate further inshore. An increase in MSL will also lead to larger tidal ranges because of the decreased frictional losses. This increase in tidal range will result in higher high water levels which will permit even larger waves to penetrate inshore than would be expected from increases in MSL alone.

Another possible consequence of climate change is increased storminess for some locations. Mitchell et al. (1990) have indicated that, while tropical disturbances may increase in frequency, the mid-latitudes may experience reduced storminess as a result of a decrease in the polar to equatorial mean temperature gradient.

The Bathymetric Grid

Surveys from the Belgian Service of Coastal Harbours, were collected to model the region from the banks to the shore in very fine detail. Over 100 000 bathymetric values, with an average separation distance of 5 m, were used to generate the finite difference grid of the area. A contour plot of depths for this grid at the present-day MSL is shown in Fig. 2. The grid is 201 x 181 with a grid spacing of 100 m in both dimensions. The grid has its origin at

(51°07'30"N, 2°40'00"E) and its positive y-axis is aligned at 327° so that the alongshore side, or x-axis, is roughly parallel to the coast.

The Numerical Model

Due to the size of the area being modelled it was decided to employ a wave-period averaged computer model since this type of model is not restricted to a limiting number of solution points per wavelength. The model selected was a simplified version of the WC2D model which is based on the work Yoo and O'Connor (1986) but which has been substantially improved since its initial development. The model has been validated against numerous laboratory and field results (Yoo and O'Connor, 1986; Yoo and O'Connor, 1988) as well as against wave rider measurements at Flemish Banks taken during the CSTAB field programme (O'Connor, 1993) where computed wave heights were within 5% of measured.

Wave kinematics are obtained through solution of a combined refraction-diffraction kinematic conservation equation for linear surface waves:

$$\frac{\partial K_i}{\partial t} + C_g \frac{K_j}{k} \frac{\partial K_i}{\partial x_j} + \frac{\sigma G}{2h} \frac{\partial h}{\partial x_i} + \frac{C_g}{2kA} \left[\frac{1}{A} \frac{\partial A}{\partial x_i} \left(\frac{\partial^2 A}{\partial x_j^2} \right) - \frac{\partial}{\partial x_i} \left(\frac{\partial^2 A}{\partial x_j^2} \right) \right] = 0 \quad (1)$$

where K_i is the wave number vector, $i=\{x,y\}$, k is the wave separation factor, h is the depth, A is the wave amplitude, σ is the wave frequency, C_g is the group velocity and $G = 2kh/\sinh 2kh$. The second term of Eq. (1) describes the advection of wave number, the third describes the effects bottom slope and the final term permits diffraction of the wave field. Since the forcing, and consequently the solution, of the model is steady, the first term in Eq. (1) is retained only as a iteration parameter. An approximate non-linear solution is achieved through use of the non-linear dispersion relation of Hedges (1976).

The wave dynamics are obtained from the combined refraction-diffraction wave energy conservation equation for linear surface waves:

$$\frac{\partial A}{\partial t} + \frac{1}{2A} \frac{\partial}{\partial x_i} \left(A^2 C_g \frac{K_i}{k} \right) + F_b A^2 = 0 \quad (2)$$

The final term in Eq. (2) has been introduced to include the effects of frictional dissipation. The calculation of F_b using an improved Bijker approach is described in O'Connor and Yoo (1988).

The numerical scheme is a simple explicit formulation with upwinding methods employed for the advection terms. The solution is obtained on a

staggered grid in an iterative approach until a steady-state solution is achieved. Boundary conditions of wave amplitude and wave direction must be supplied at the offshore boundary. At the side boundaries a radiation boundary condition is applied and at the shoreline all energy must be dissipated through breaking.

Application to the study site

Three MSLs were selected: the present-day; +0.25 m; +0.50 m. According to Warrick and Oerlemans (1990), the latter two MSLs relate to the years 2040 and 2075. These levels were used in tests with four wave climates and five wave directions (see Tables 1 and 2). Analyses of a wave hindcast performed for this location by the UK Meterological Office (pers. comm.) show that wave climates A through D have rates of occurrence of 1.36%, 0.72%, 0.24% and <.01% for the sectors between directions 1 to 5, respectively. No account was made of any tidal effects in the present work.

A k_s value of 10 cm was used for the roughness height for the area. This value was used to take into account the sub-grid scale bed features, such as the sand waves, mega-ripples, and ripples, that are known to occur on the sand banks in this area.

Results

A simple illustration of the effectiveness of the sand banks in protecting the coast can be seen from the cross-shore transformation characteristics of the model for the present-day bathymetry and for the case where the sand banks do not exist. This is most easily done in a one-dimensional test, so as to eliminate any influence of longshore variability in the bathymetry. For the present-day situation, the wave height field produced by the model for normal wave approach on the two-dimensional bathymetry was averaged between 5 km and 15 km in the alongshore direction from a line 2 km from the coast to the offshore boundary. These were compared with the results of the model for an equivalent plane slope (see Fig. 3). Figure 4 shows the ratios of present-day wave height with banks to plane slope wave height for wave climates A through D. The sheltering effect of the sand bank system is clearly visible in each of the four wave climates. The results also indicate that the sand banks have a greater influence on the larger wave climates, with reductions in wave height approaching 30% a distance 2 km offshore. Clearly, the longer waves are influenced by the bottom bathymetry over a much larger fetch.

When examining the effects of sea level rise on the entire system it is more informative to examine the full two-dimensional results. A typical result of the simulation is shown in Fig. 5. Here a contour plot of wave height is presented for the present-day MSL and an increase of 0.5 m for condition D3 ($H=5.0$ m, $T=9.0$ s, $\theta=327°$). Although both patterns of contour lines are

complex, it is evident from their rhythmic pattern that the sand banks have a significant effect on the wave climate in the region. While there are substantial losses in energy over the domain, especially in the shallower regions, there are areas of increased wave height due to the focusing. The sheltering effects of the sand banks are discernible by the decrease of wave height over each successive bank. The increase in MSL has the effect of permitting larger waves to progress further shoreward, as is most evident in the nearshore zone.

Substantial alongshore variation in the change in wave height due to increased MSL was found in most tests. Figure 6 shows the percentage change in wave height for condition 4B along a line 1 km offshore for the two increased MSLs. Under an assumption of a 0.5 m rise in MSL, the resulting increase in wave height varies from 8% to 25%. This alongshore non-uniformity in wave height is reduced to 8% to 10% when the results for all tests are averaged together, as is shown in Fig. 7. The results for the entire domain, see Fig. 8, shows a general pattern of increasing wave height towards the shoreline. Individual wave climates also exhibited some variation, as shown in Fig. 9, where the results for the line 1 km offshore are plotted against projected dates.

In order to illustrate some possible consequences of the effects of offshore dredging on the adjacent coast, a hypothetical dredged region was constructed within the bathymetric grid. This area is delineated by the dashed line in Fig. 10. The depth was reduced to a constant 10.25 m below present MSL over this region, corresponding to approximately 1.5×10^6 m^3 of material removed.

A typical contour plot of the change in wave height is shown in Fig. 11 for condition C5. The influence of the increase of depth is apparent almost immediately and extends over a large area, although the differences away from the direct shadow zone are minute. The effect towards the shore is again dependent upon the wave climate. Figures 12a and 12b show the alongshore distribution of the change in wave height for each of the wave climates from directions 1 and 5 , respectively. In both cases the wave height immediately behind the dredging site has decreased, while it has increased to either side. In both cases the larger wave climates are affected for a greater distance along the coast.

Conclusions

Nearshore sand bank systems protect the coast by dissipating wave energy offshore. Rising sea levels, however, will lessen their effectiveness and permit larger waves to reach the coast. For the sea level rise scenario used in the present work, wave heights at a line 1 km off the Belgian coast was

predicted to increase by the order of 10% by 2075. The effects closer to the surf zone may be greater, as increases in wave energy were generally found to get larger towards the shore.

Substantial variation in the change in wave climate along the coast was noted in all tests, although this effect was modulated when tests from several directions were combined. The situation with regards to the sediment dynamics in these locations will more extreme, however, due to the highly non-linear relationship of sediment transport with wave height.

The illustration of possible consequences from the extraction of sediment from the top of an offshore bank showed that in each case the wave height immediately behind the dredging site was decreased while it increased to either side.

Acknowledgements

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Table 1 Test wave climates

Climate	H (m)	T (s)
A	1.0	4.0
B	2.0	6.0
C	3.0	7.0
D	5.0	9.0

Table 2 Test wave directions

Direction	°N
1	347°
2	332°
3	327°
4	322°
5	307°

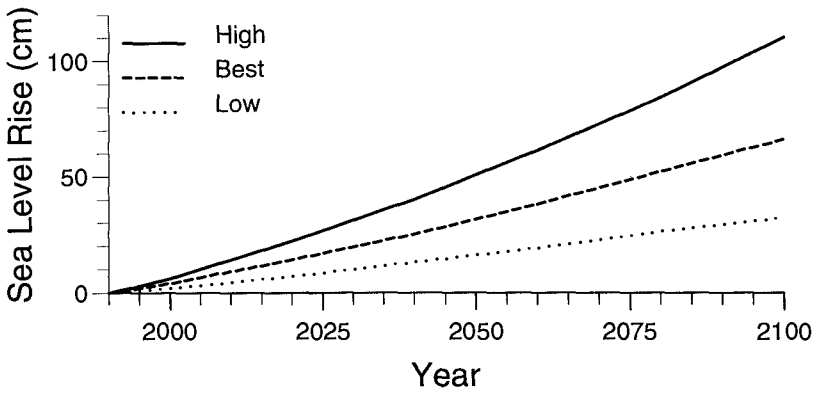

Figure 1 Predicted MSL Rises (after Warrick and Oerlemans (1990)).

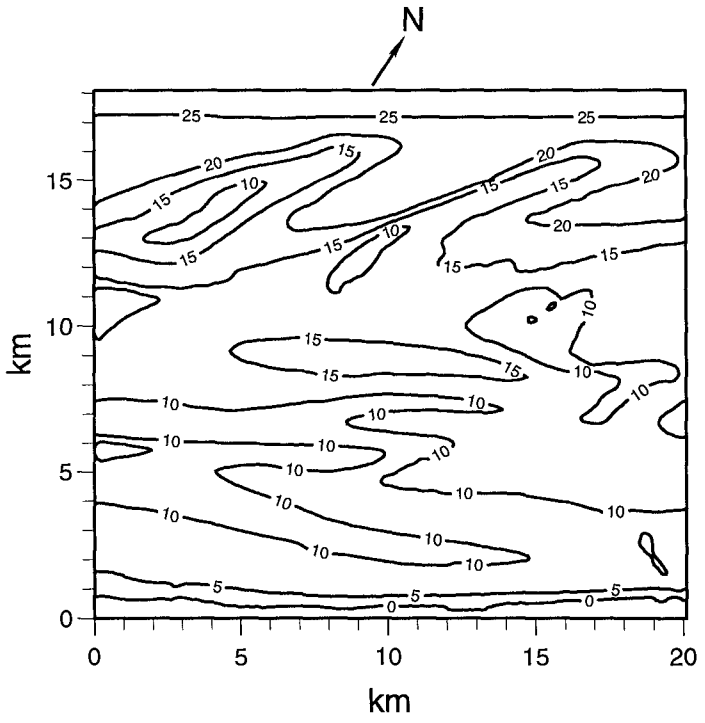

Figure 2 Bathymetric grid (m).

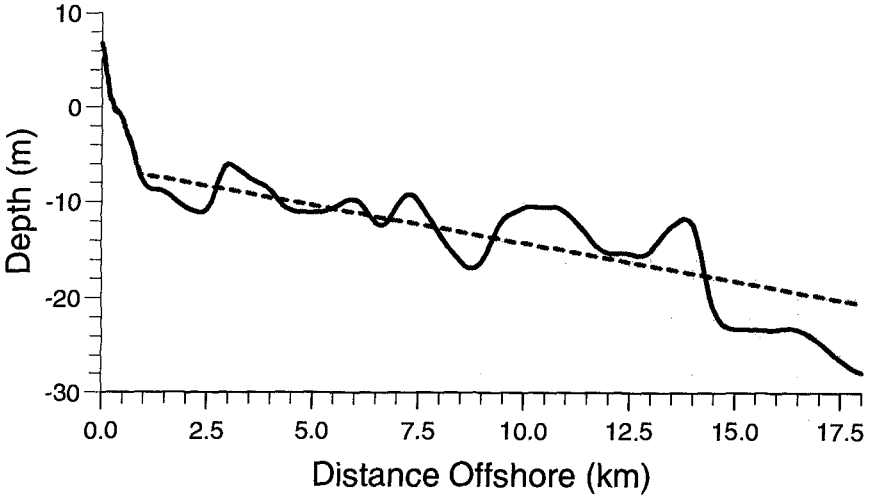

Figure 3 Actual cross-shore bathymetry and equivilent slope.

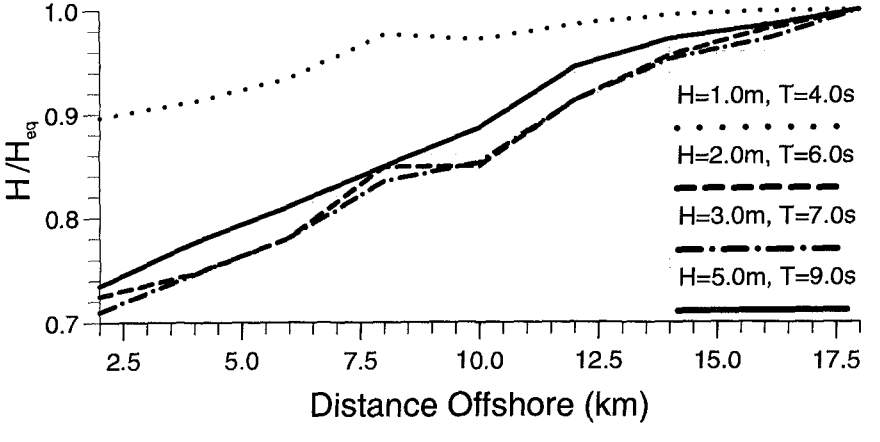

Figure 4 Cross-shore to equivilent slope wave height ratio.

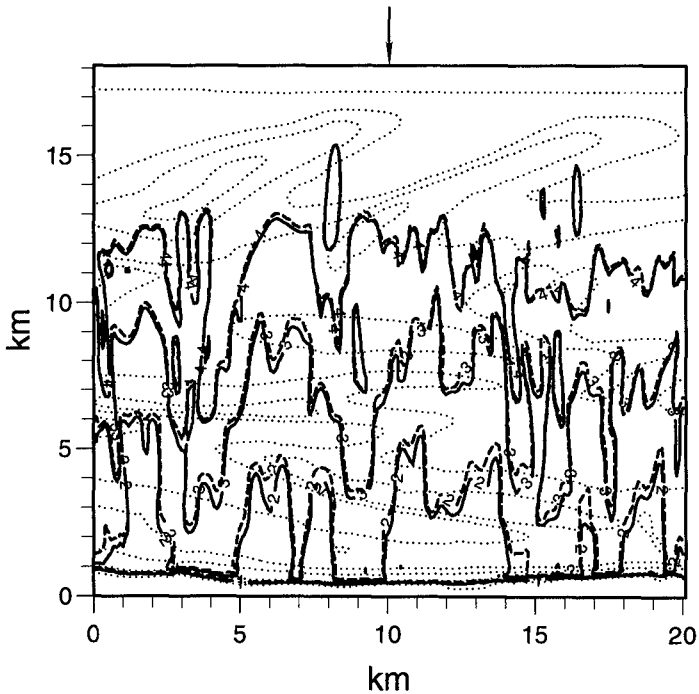

Figure 5 Wave height (m), condition D3. Present-day MSL, - - - - -; MSL+0.5m, ———.

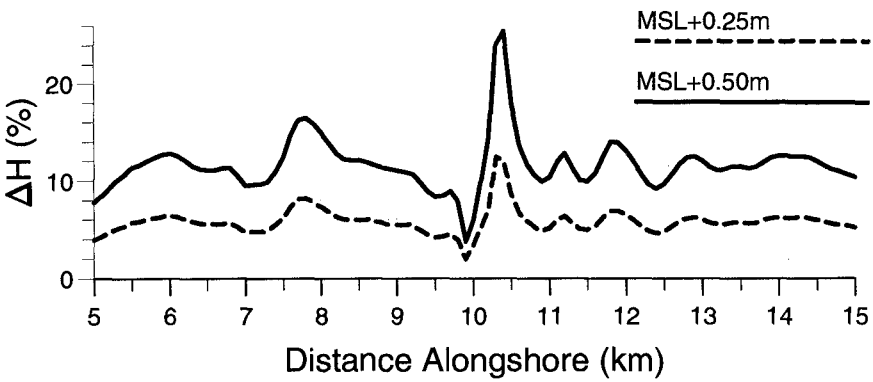

Figure 6 Alongshore wave height change at y=1km, condition 4B.

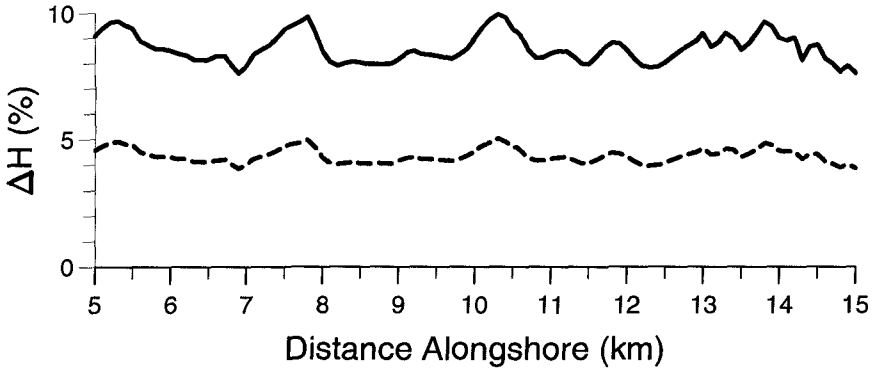

Figure 7 Alongshore wave height change at y=1 km, all conditions MSL+0.5m. (see Fig. 6 for key).

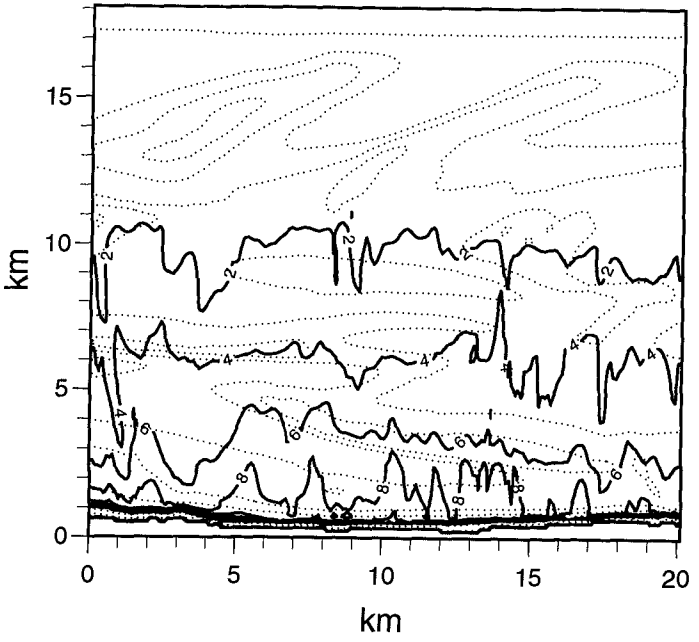

Figure 8 Wave height change (%), all conditions. MSL + 0.5 m.

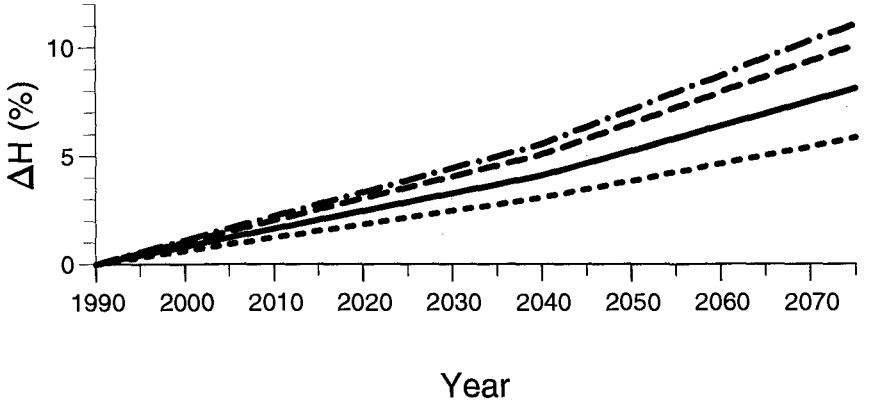

Figure 9 Wave height change at y=1 km, all directions averaged. (see Fig. 4 for key)

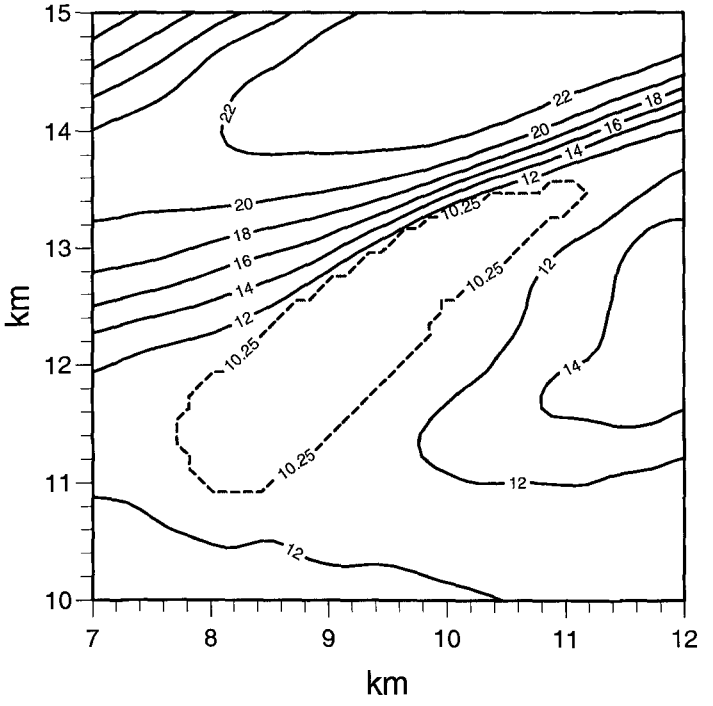

Figure 10 Dredged region of bathymetric grid (m).

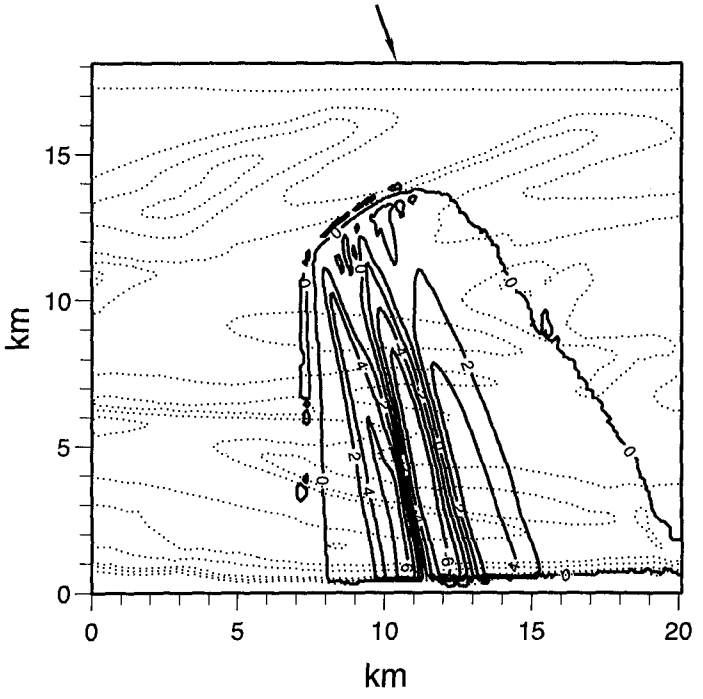

Figure 11 Wave height change (%), condition C5, due to dredging.

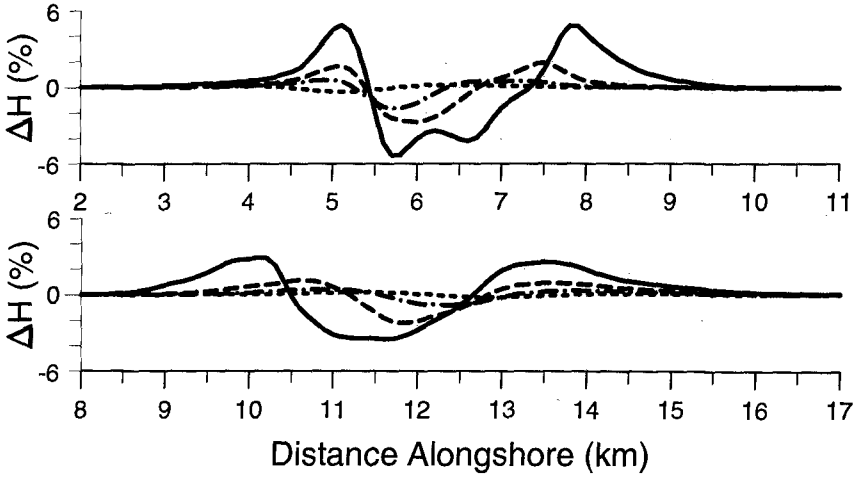

Figure 12a-b Alongshore wave height change at y=1 km. a=347°, b=307°. (see Fig. 4 for key)