PORT EXPANSION PROJECT
PORT OF PHILLIPSBURG
ST. MAARTEN NETHERLANDS ANTILLES

WAVE CLIMATE STUDY

TU Delft
Delft University of Technology

Faculty of Civil Engineering
Hydraulic and Geotechnical Engineering Division
Hydraulic Engineering Group

PORT EXPANSION PROJECT
PORT OF PHILLIPSBURG
ST. MAARTEN NETHERLANDS ANTILLES

WAVE CLIMATE STUDY

V.J.W. Hombergen

Delft, march 1991

Delft University of Technology
Faculty of Civil Engineering
Division: Hydraulic and Geotechnical Engineering
Section: Hydraulics and Off-shore Engineering

Supervised by:
Prof. ir. K. d'Angremond
Dr. ir. L. Holthuijsen
ir. A. Mol

Commissioned by:
Grabowsky&Poort BV
Consulting Engineers
The Hague

ACKNOWLEDGEMENTS

The complete study "PortExpansion Project Port of Phillipsburg, St. Maarten Netherlands Antilles", was under supervision of Prof. ir. K. d'Angremond, Dr. ir. L. Holthuijsen, and ir. A. Mol from Grabowsky&Poort International BV, The Hague.

The present Wave Climate Study has been performed during my work-emplacement at Grabowsky&Poort. I would like to extend my gratitude to all employees at Grabowsky&Poort, The Hague, for the superb atmosphere I was fortunate to work in.

I would also like to thank Delft Hydraulics for their assistance and advise, especially Dr. ir. G. van Vledder and Mr. D. Hurdle.

Vincent Hombergen.

CONTENTS

APPENDICES

LIST OF FIGURES

1.0 SUMMARY WAVE CLIMATE STUDY

The Sint Maarten Ports Authority wishes to expand the present port facilities of the Port of Phillipsburg. They have therefore commissioned Grabowsky&Poort International BV as the main consultants for the port development.
The present wave climate study has been performed, to be used as a tool for preliminary designs and the feasibility study for this project.

The present wave climate study is based on data acquired from the British Meteorological Office (BMO), which were obtained from ship's observations (section 4). The BMO data covers the off-shore wave climate for mainly the normal weather conditions.
The following wave climate has been concluded from the study.

Occurring waves are mainly wind generated waves. The ever present tradewinds blow between the direction North East and South East (80% of the time) and thus the main wave direction is from the East (90°N). The most probable significant wave height for normal weather conditions is 2.0 meter and the corresponding mean wave period approximately 5 seconds. These values are conditions for the off-shore wave climate (see section 5).

The data on severe weather conditions, or hurricane conditions, for the off-shore wave climate, were acquired from a hurricane hindcast study, carried out by Oceanroutes Inc. for Delft Hydraulics, for the jetty at Oranje Baai, St. Eustatius. The design wave height, set as the wave height with a return period of once every 100 years, is estimated as 11,3m. (deep water), with a wave period of 12,5 seconds. For the wave climate reference is made to table 6.1.

The above wave climate (normal weather conditions), is transformed to the proposed site. This transformation was initially carried out, using Snell's law, for refraction. These results were later checked with additional runs performed with a numerical wave model, HISWA (Hindcast Shallow water WAves), accounting for short-crestedness, refraction, shoaling ,breaking, wind and bottom dissipation.

The transformation of the off-shore wave climate for normal weather conditions (H_s=2,0m., T_s=8sec.), resulted in a significant wave height of 1,5m. with a corresponding mean wave period of approximately 5 sec. for the conditions at the 12 meter depth contour (design depth of the port entrance). In the computations a wave period of 8 sec. is used. The reason why is explained in section 8.

The transformation of the deep water design wave height (H_s=11,3m., T_s=12,5 sec.) to the site resulted in a significant wave height of 6,75 meter with a wave period of 12,4 seconds. These last values will be used as design parameters for the constructions. For more information on severe weather conditions reference is made to table 8.4.

Next to wind generated waves, swells occur from various directions. These originate from hurricanes in the vicinity of the island. The amplitude of such swell is approximately 0,5 to 1,0 meter, with a period of roughly 12 seconds [ref.: 1 and 2].

2.0 INTRODUCTION

As a result of a significant increase in cargo throughput and calls of cruise vessels in the Port of Phillipsburg, the St. Maarten Ports Authority (SMPA) is planning to expand the port with a cruise terminal and a multi-purpose container terminal.
The (SMPA) has appointed Grabowsky&Poort International BV as the main consultants for the port development.

For the design of the port, a number of studies are carried out. One of these studies is a wave climate study for the sea region in the vicinity of Great Bay. This report presents the results of this study, which is executed on the basis of data from ships observations, and a hurricane hindcast.

3.0 OBJECTIVE

The objective of this study is to collect and analyze wave data to be used for the lay-out study for the harbour, and to determine the design parameters for the harbour constructions. The development of the port lay-out is strongly determined by the penetration of waves due to the exposed and open portion of the selected location for the port. Resulting data will be used for diffraction (wave penetration) calculations to analyze the wave climate along the berths of the alternative designs. A second report will deal with this specific issue.

4.0 SITUATION SKETCH

4.1 Introduction

St. Maarten is one of the three Windward islands belonging to the Netherlands Antilles in the Caribbean Archipelago (figure 4.1). The island is divided into the Dutch side and the French side. Their capitals are respectively, Phillipsburg and Marigot.
The proposed port is on the Dutch side at Phillipsburg, in Great Bay. Great Bay is a bowl shaped bay with the entrance directed to the South. On the East side of the bay (proposed harbour site), the bay is sheltered against waves and winds by Point Blanche Hill.
Phillipsburg is situated at the Northern edge of the bay. Going further in anti-clockwise direction, the bay is bordered by hotels and a peninsula Point Ouest (Fort Amsterdam). See figure 4.2 and figure 4.3.

4.2 Climatology

The ever present tradewinds bring a mild tropical climate to the leeward islands. Although there is a pronounced dry season (February through April), the rainfall is still reasonably uniform distributed over the whole year providing the island with a tropical vegetation.

The prevailing wind is, for more than 80% of the time, between East Northeast and East Southeast with a fairly constant speed throughout the year reaching a minimum average of 9.7 knots (5.0 m/s) during October, and a maximum of 11.2 knots (5.8 m/s) in the months June and August. A windrose is given in figure 4.3.

During the hurricane season, which lasts from June through November, St. Maarten, located within the hurricane belt, is occasionally effected by a hurricane or storm. Almost every year one tropical storm cyclone occurs within the range of 100 miles and the average of once every 4-5 years hurricane conditions are experienced. [ref: 1]

4.3 Waves and tide

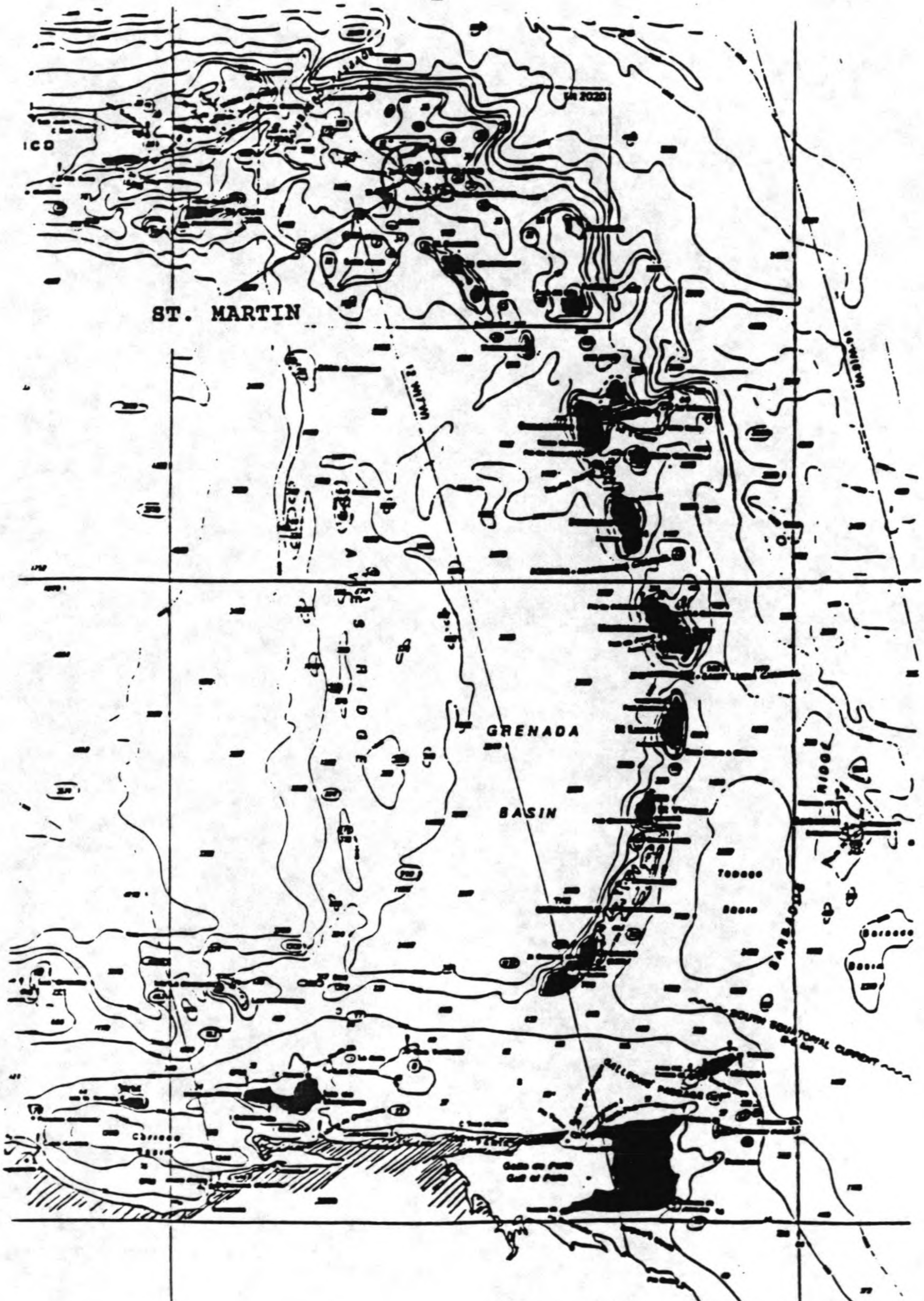
The Tradewinds generate waves at open sea, with a significant wave height generally between 1 and 2 m. For some directions, fetch is limited and wave generation is reduced. The wave directions are typically between NE and SE and periods range between 4 and 8 seconds. This is illustrated by the tables in Appendix A.

Hurricanes in the region of St. Maarten will cause storm waves up to values of 8 meter significant wave height at open sea. All directions are possible. Wave periods range up to 12 seconds. Distant Hurricanes will cause swell action at St. Maarten. The swell amplitude can range between 0,5 and 1,0 meter with periods of 12 seconds. Such swell come in from all directions to which Great Bay is open (East through West) and may cause a significant hindrance to berthed vessels. The occurrences are rather scarce, as also Hurricanes in the region particularly South of St. Maarten. Ships observations give only a slight indication, as they tend to avoid hazardous areas.

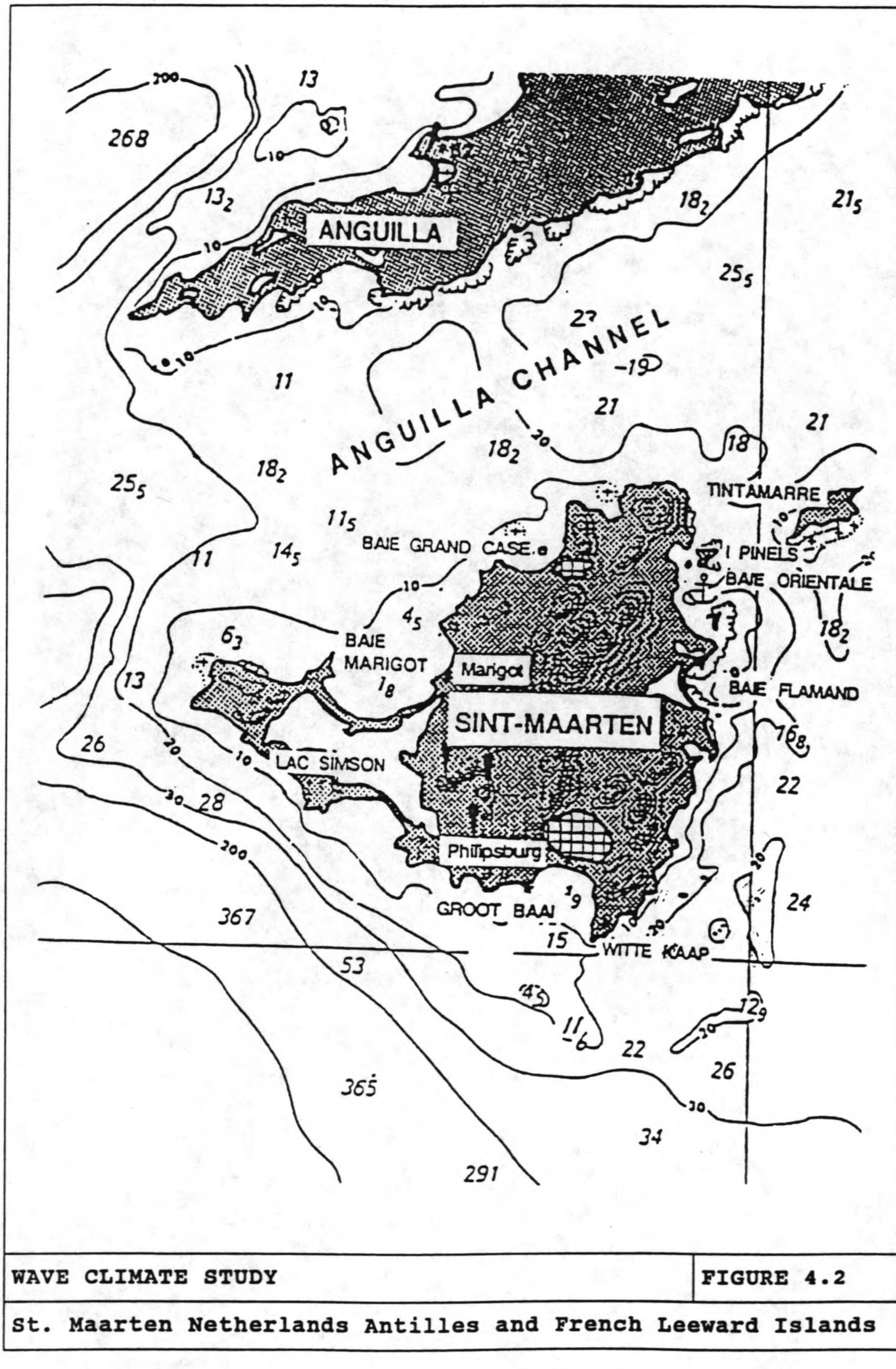
The tidal movement in the bay, has been measured during the preliminary environmental study [ref: 2]. The tidal range (from LLW to HHW) is 0,3 meter.

The present study accounts for the transformation of wave data from deep water, where the wave is generated, to the area at the 12 meter depth line in Great bay, which is the design depth and the location of the proposed port.
This transformation is influenced by:

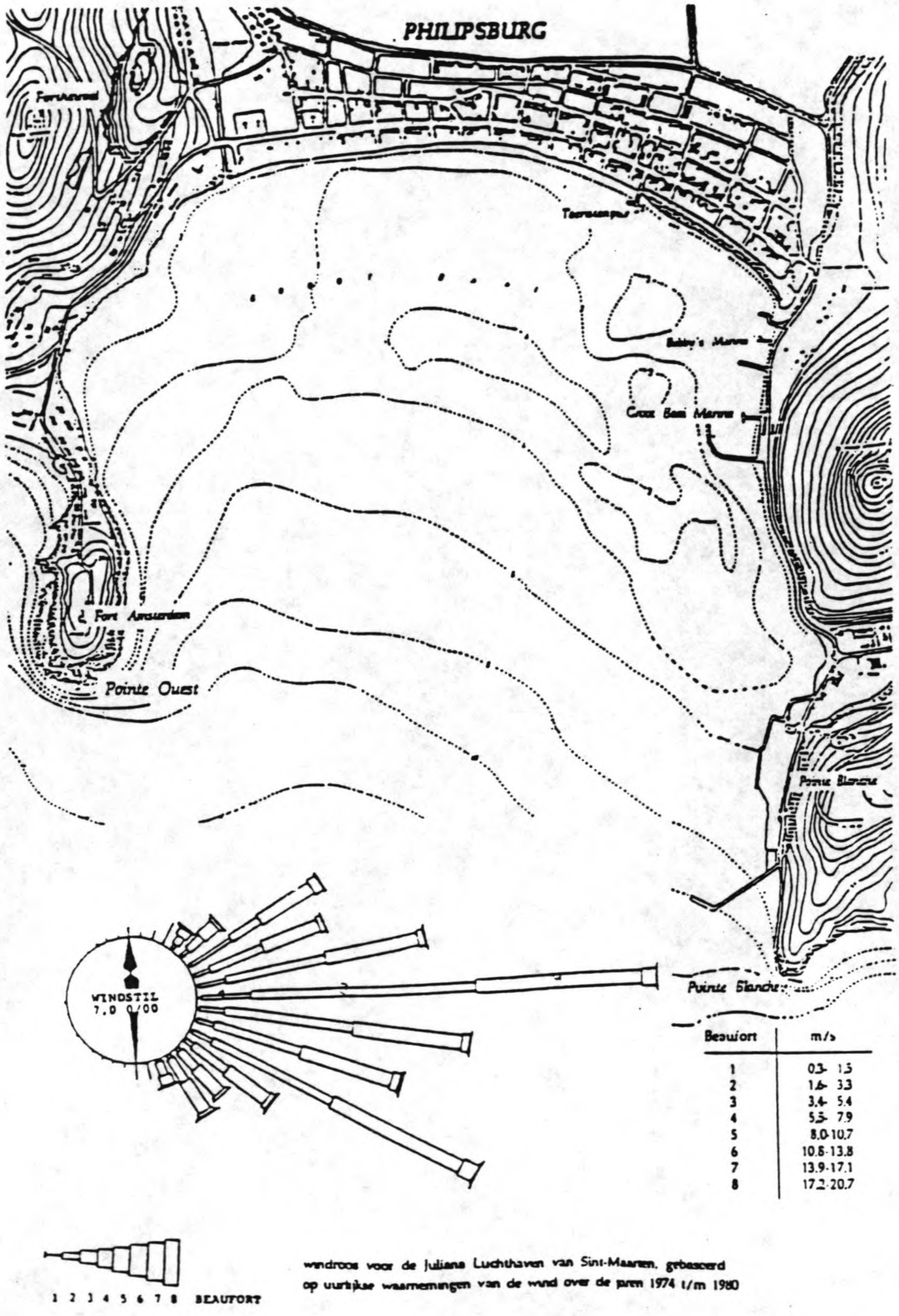
- bottom friction and wave breaking due to shoaling;
- rotation of wave crests (refraction) giving a reduction of the wave height.



WAVE CLIMATE STUDY	FIGURE 4.1
St. Maarten's position in the Caribbean Archipelago	



WAVE CLIMATE STUDY	FIGURE 4.2
St. Maarten Netherlands Antilles and French Leeward Islands	



WAVE CLIMATE STUDY	FIGURE 4.3
Phillipsburg with proposed site and windrose	

5.0 OFF-SHORE WAVE CLIMATE (normal weather conditions)

5.1 Waves

Data for wave climate analysis were obtained from the Royal Dutch Meteorological Institute (KNMI), the British Meteorological Office (BMO). The area covered for the collection of data was 17.0N to 19.0N and 62.0W to 64.0W As shown in figure 5.1. The BMO gave the most detailed and elaborated information, and were for this reason selected as the basic data for the present wave climate study. The data presented in these tables must be used with caution. The area covered is very large compared to the area of interest and local effects may cause a change in the wave characteristics. The data presented by the BMO are included in this report in appendix A.

5.2 Wave data

5.2.1 Wave heights

The data is based on visual ship's observations. A deviation is observed when comparing visual observations with the results from a recording wave meter.

Nordenström has found the following relation [ref 3]:

$$H_s=1,68\cdot H_v^{0,75} \quad [m] \tag{5.1}$$

(H_v - visual observed wave height, H_s - recorded wave height or significant wave height).

Great Bay is sheltered by the island of St. Maarten from waves coming in from the directions 60°N to 270°N. Only through a few 'windows' between the neighbouring islands waves reach Great Bay undisturbed, as shown in figure 5.2.

To acquire the significant wave height, the column "Resultant

wave height (meters)" is transformed according to the equation 5.1.
By doing this the intervals of the respective wave heights increases, especially by smaller wave heights (e.g.: interval $0.0 < H_v < 0.5 = 0.5$ which after transformation becomes the interval $0.0 < H_s < 1.0 = 1.0$). For higher waves the opposite occurs (e.g.:$4 < H_v < 5 = 1$ becomes $4.75 < H_s < 5.62 = 0.87$).

Because of this changing of intervals the data in the tables must be corrected. This has been done for the relationship significant wave height - wave direction, and significant wave height - wave period.
The theory supporting this correction is based on a constant value of the area under a probability density function (p.d.f.) which per definition is 1 (one). This is the total of all the values presented in the last BMO table (100%)
The changing of the intervals result in a change in the p.d.f.. A graphical approximation has been used to determine the p.d.f.:
The values in the tables are percentage frequencies: $P(H_v)$.
The p.d.f. is these values divided by their intervals: $p(H_v)$.
It follows that:

$$P(H_v) = p(H_v).dH_v$$

$$P(H_s) = p(H_s).dH_s = P(H_v)$$

and thus

$$p(H_s) = p(H_v).dH_v/dH_s$$

The above is a transformation with the Jacobian (dH_v/dH_s), in which dH_v/dH_s is the ratio of the intervals of observed wave heights and significant wave heights. The transformation is carried out for the whole table. Figure 5.3 illustrates the change in the p.d.f. for the direction 90°. The figure also shows that the area under the curve increases if the probability density is not transformed (Hs d.n.t.). The above is a graphical approximation but suffices it's objective.
Table 5.1 presents the data for the probability density function for H_v in all directions. Table 5.2 the p.d.f. for H_s after the transformation (properly including the Jacobian).

Directions	60	90	120	150	180	210	240	270	rem
Observed Waveheight Hv									
0.05 to 0.55	4.4	8.4	4.4	2.0	0.6	0.0	0.0	0.2	2.4
0.55 to 1.05	**9.6**	**19.0**	**7.4**	**2.4**	**0.6**	0.2	0.0	0.2	3.9
1.05 to 1.55	**13.6**	**21.4**	**8.2**	**2.6**	**0.4**	0.2	0.0	0.2	4.8
1.55 to 2.05	**8.2**	**13.6**	4.0	1.2	0.2	0.2	0.0	0.0	3.0
2.05 to 2.55	6.0	10.4	3.6	0.6	0.0	0.0	0.0	0.0	1.2
2.55 to 3.05	3.0	4.6	1.2	0.2	0.0	0.0	0.0		1.0
3.05 to 4.05	1.7	1.9	0.6	0.1	0.0	0.0	0.0		0.2
4.05 to 5.05	0.3	0.5	0.1	0.0	0.0		0.0		0.0
5.05 to 6.05	0.1	0.1	0.0	0.0					0.0
6.05 to 7.05	0.0								
7.05 to 8.05	0.0								
8.05 to 9.05									
9.05 to 10.0									
10.0 to 12.0									
12.0 to 14.0									

Table 5.1: Probability density function for Ship's observations (Hv). (deep water)

Directions	60	90	120	150	180	210	240	270	rem
Significant Waveheight Hs									
0.18 to 1.07	2.5	4.7	2.5	1.1	0.3	0.0	0.0	0.1	1.3
1.07 to 1.74	**7.2**	**14.9**	**5.5**	**1.8**	**0.5**	0.2	0.0	0.2	2.5
1.74 to 2.33	**11.5**	**18.1**	**6.9**	**2.2**	**0.3**	0.2	0.0	0.2	4.1
2.33 to 2.88	**7.4**	**12.5**	3.7	1.1	0.2	0.2	0.0	0.0	2.8
2.88 to 3.39	5.9	10.2	3.5	0.6	0.0	0.0	0.0	0.0	1.2
3.39 to 3.88	3.1	4.7	1.2	0.2	0.0	0.0	0.0		1.0
3.88 to 4.80	1.9	2.1	0.7	0.1	0.0	0.0	0.0		0.2
4.80 to 5.66	0.4	0.6	0.1	0.0	0.0		0.0		0.0
5.66 to 6.48	0.1	0.1	0.0	0.0					0.0
6.48 to 7.27	0.0								
7.27 to 8.77	0.0								
8.77 to 9.48									
9.49 to 10.9									
10.9 to 12.2									

Table 5.2: Probability density function for the Significant wave height (Hs). (deep water)

Multiplication of each value in the above tables by respectively their H_v-, H_s-interval and totalling them again per table, gives the total of 1 (100%, per definition).

The transformation shows that the most probable significant wave height for this wave field is roughly 2.0 meters, and not as would have been assumed without the transformation, a significant wave height of approximately 1.5 meters. The dominant wave direction remains 90°N.

5.2.2 Wave periods

It is also possible to transform the data for the wave period. The data is also obtained from the BMO-charts. The relationship between measured wave period and observed wave period is [ref: 3]:

$$T_v = 0,9 \cdot T_m \quad [\text{sec.}] \qquad \textbf{(5.2)}$$

The visual wave period can be interpreted as $T_{1/3}$.
The change in the intervals is 10%. According to formula(5.2) the wave heights must be transformed. This is also done with the data for the wave periods, only this time, to preserve the total of 100% (area under curve is 1), the data must also be multiplied by a factor 1,1 (1/0,9).

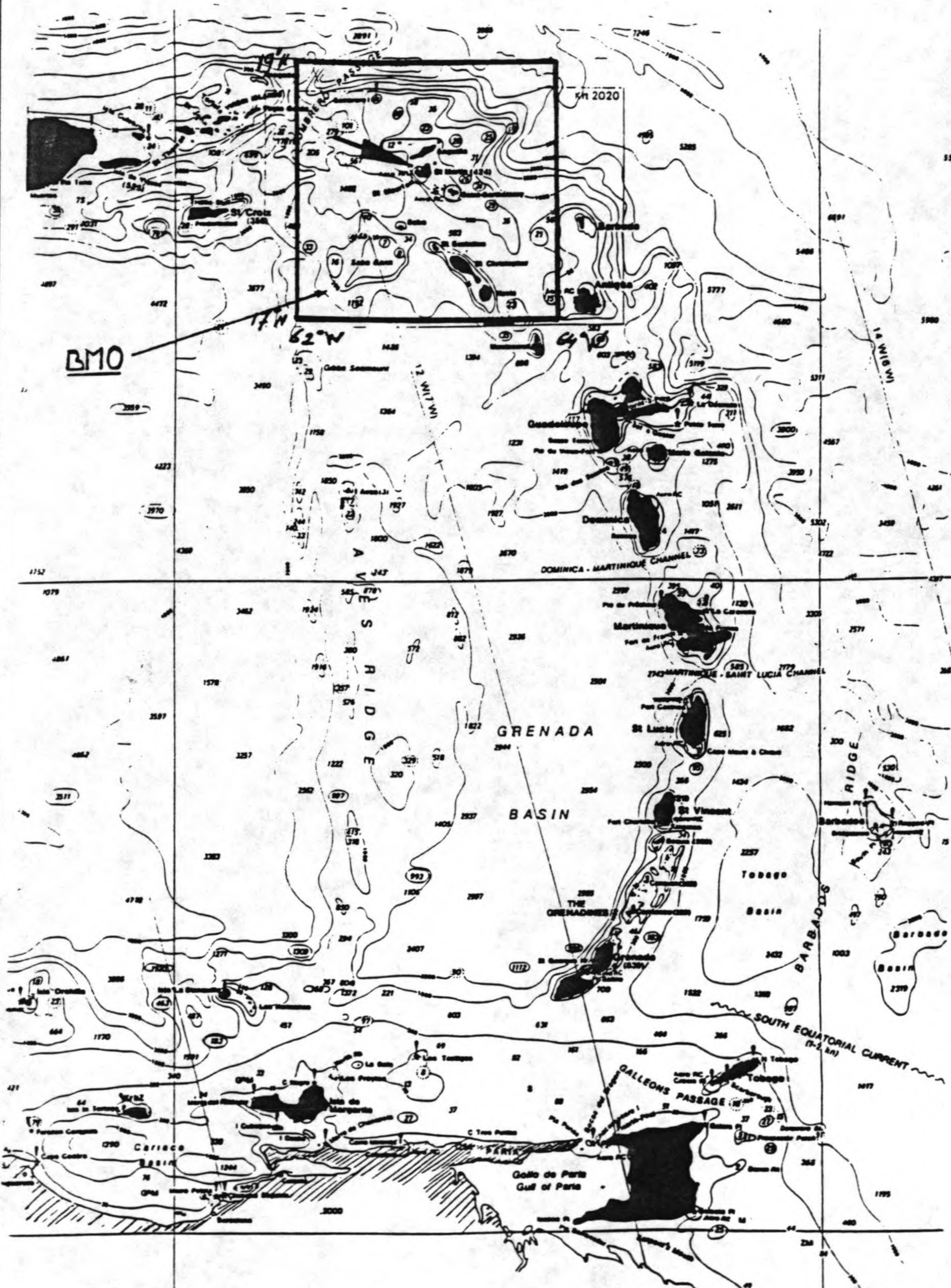
Table 5.3 presents the data for p.d.f for the significant wave height and wave period ($T_{1/3}$).

Wave period	<5*	5/6*	7/8*	10/11*	12/13*	14/15*
Significant Wave height Hs						
0.18 to 1.07	**12.5**	0.9	0.3	0.3	0.1	0.0
1.07 to 1.74	**27.8**	**6.6**	1.0	0.3	0.2	0.0
1.74 to 2.33	**28.3**	**14.7**	**4.0**	**1.1**	**0.6**	**0.4**
2.33 to 2.88	13.5	**11.1**	**4.4**	**1.4**	**0.4**	**0.4**
2.88 to 3.39	9.2	**9.9**	**5.4**	**1.1**	**0.4**	**0.4**
3.39 to 3.88	2.7	5.4	2.5	**0.9**	**0.5**	0.0
3.88 to 4.80	1.4	2.5	1.6	0.4	**0.2**	0.0
4.80 to 5.66	0.3	0.5	0.5	0.3	0.1	0.0
5.66 to 6.48	0.1	0.1	0.1	0.0	0.0	
6.48 to 7.27	0.0	0.0	0.0	0.0		
7.27 to 8.03	0.0					
8.03 to 8.77						
8.77 to 9.48						
9.48 to 10.9						
10.9 to 12.2						

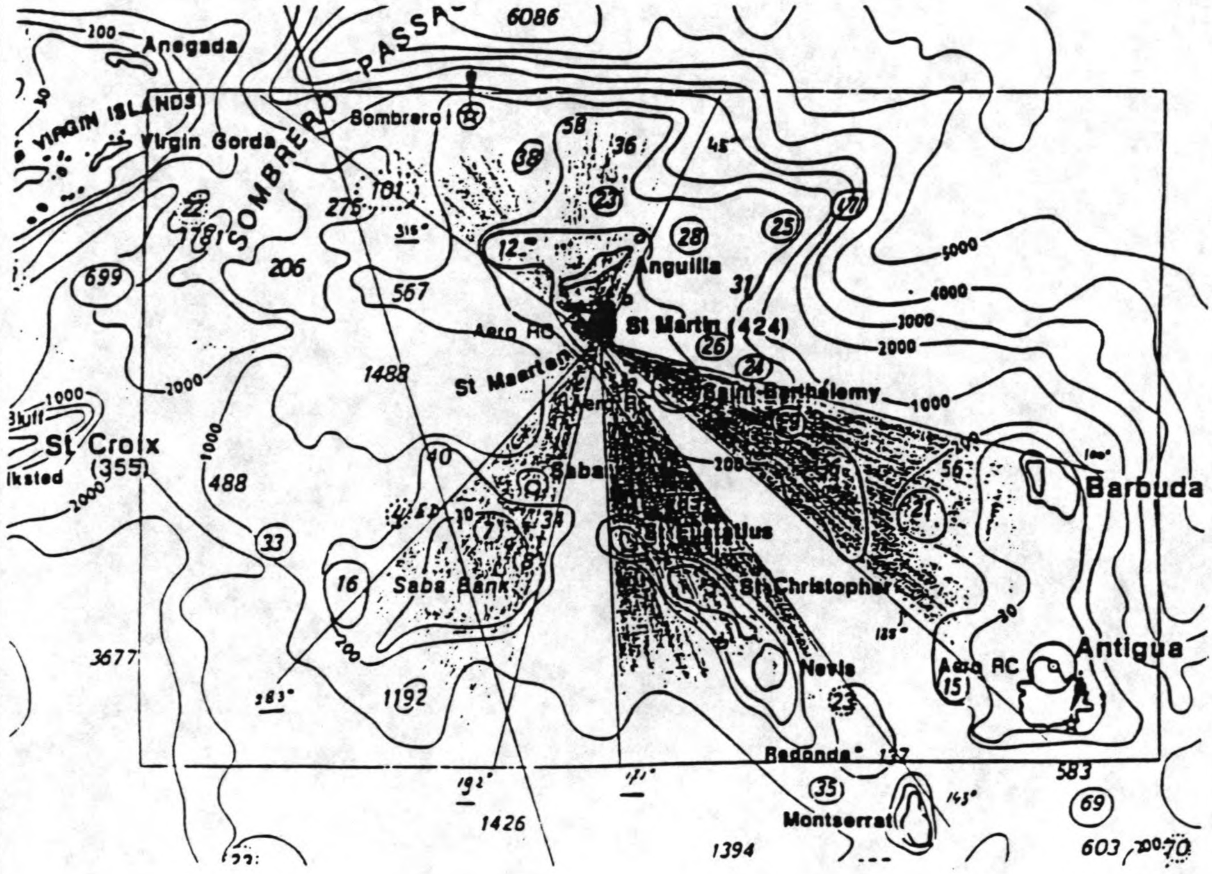
Table 5.2: Joint p.d.f. for significant wave height and wave period.
*Note: <5 means less than 4.5, 6/7=5.4/6.3, 8/9=7.2/8.1, 10/11=9/9.9, 12/13=10.8/11.7, 14/15=12.6/13.5.)

5.3 Comparison of sources

The data presented by the BMO, was checked with the data presented by the KNMI (Royal Dutch Meteorological Institute). They give similar results as to the prevailing wave height and the dominant incident wave direction. The most probable significant deep water wave height (H_s), is 2.0 meters. The most probable wave period is less than 5 sec. Most waves come in from the East, conform the prevailing wind direction. The data from the KNMI is not included in this report as the BMO chart already give sufficient information.
These findings are conform a previous study carried out by the Coastal Environmental Associates (CEA) on the first expansion of the Port of Phillipsburg in 1983 [ref: 1].
The above presented wave climate is for normal weather conditions.

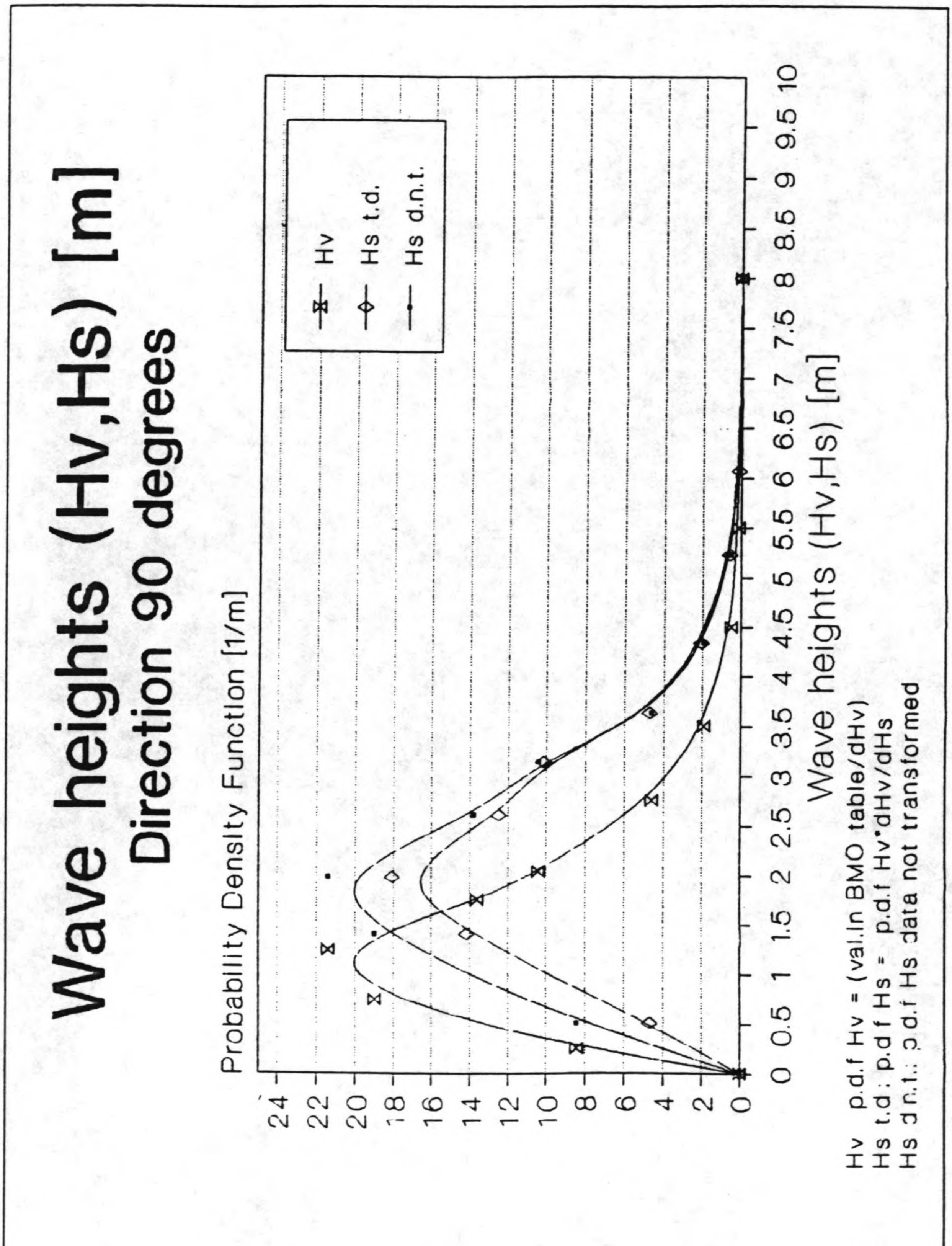


WAVE CLIMATE STUDY	FIGURE 5.1
Area of recorded BMO data (thick marked box).	



WAVE CLIMATE STUDY	FIGURE 5.2

Directions in which St. Maarten is subject to waves



WAVE CLIMATE STUDY	FIGURE 5.3
Probability density function for Hv and Hs for dir. 90°N	

6.0 HURRICANE CONDITIONS

6.1 Introduction

Ships avoid dangerous areas. Therefore data on severe weather conditions are scarce. To obtain information on these conditions, a report from Delft Hydraulics, on a study for Oranje Baai St. Eustatius, is used [ref: 4]. As St. Maarten is situated close to St. Eustatius, the same conditions are expected to occur here (see figure 4.1).

Apart from the general pattern of predominantly easterly waves, of heights up to about 5 meters, higher and longer waves also occur in a scatter of rare observations from all directions. These originate mostly from hurricanes. Figure 6.1 shows this scatter in wave heights observations

For the wave climate study for Oranje Baai, Oceanroutes Inc. [ref.: 4], performed a hurricane hindcast study.
The study covers a hindcast of waves in the 20 most severe of 49 storms, with wind speeds exceeding 25 m/s., passing through a 5° x 5° square centred at 17,5° N and 63,0° W, between 1900 and 1986 (See example figure 6.2).
Hindcasted wave heights, periods and directions, are given at a six hour interval in periods around the maximum of each storm and in the sector of SE through NNW. It is in this directional sector that the 20 most severe storms past trough the 5° x 5° square.

The data presented in the mentioned study, is highly correlated (wave period, significant wave height and wave direction). Care should therefore be taken in the interpretation. In this section the determination of the design parameters, will be based on the (non-)exceedence (or recurrence) of the maximum values for significant wave heights per storm, gathered in the above mentioned data. The data will be transformed to the site with the aid of the numerical HISWA-model (see section 8) and will then be used during the design of the structures for the Port of Phillipsburg (report. "Port Lay-out and Breakwater Design). It is furthermore requested by the commissioner of this study, to determined the design wave parameters, with a return period of once every 100 years.

6.2 Wave heights, severe weather conditions

The data gathered by Oceanroutes Inc., gave 20 different highest registered values for significant wave heights (N = 20), in the period of registration (86 years). P_i is the probability of non-exceedence of a value in N registration and is given by the cumulative probability function [ref.: 11 and 12]:

$$P_i = \frac{i}{N+1} \quad for\ i=1,2,3..N \tag{6.1}$$

In which i is the ranking number (i=1 for the lowest wave height, i=N for the highest wave height).
The recurrence (or return period) of one registered highest value or values lower than this value during the total period of registration can be calculated by using:

$$RP = \frac{1}{(1-P_i)\left(\frac{N}{number\ of\ years}\right)} \tag{6.2}$$

The non-exceedence of these values must be plotted on probability paper, see figure 6.3. The plot is made on a copied graph acquired from literature [ref.: 12]. This allows to draw a fitting straight line through the maximum values. The line can also be extended to higher return periods. From this straight line, the deep water significant wave height for chosen return periods can be attained. The results are shown in table 6.1

6.3 Wave periods

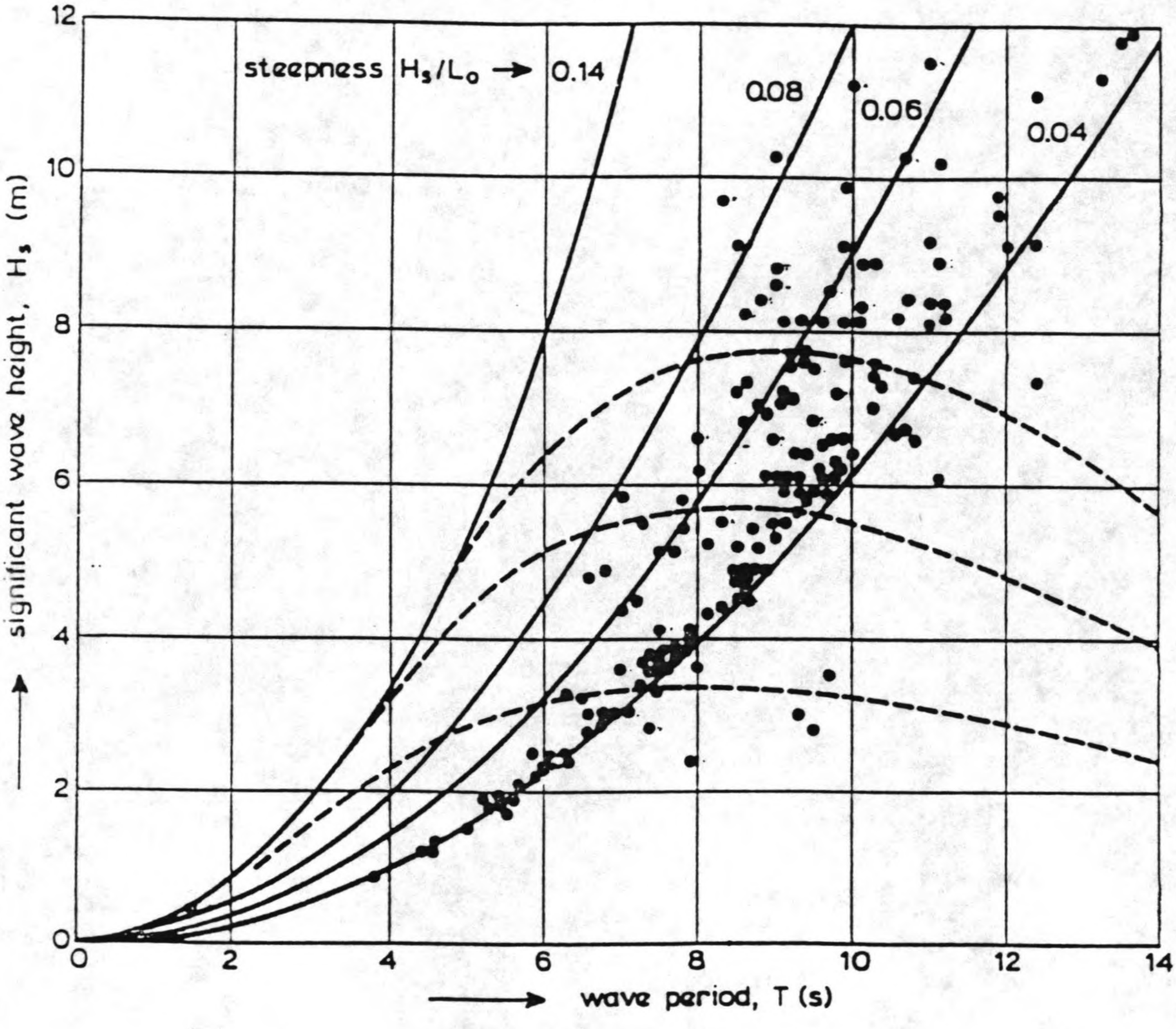
For the determination of the corresponding wave period, the average wave steepness in the wave field is taken. This is done because the data [ref.: 4] gives a whole range of wave height versus wave period relationships (= wave steepness, see figure 6.1). All 196 registered wave heights and their corresponding registered wave periods in the hurricane hindcast are tabulated. The wave periods are converted to wave lengths. Per wave height and corresponding wave length, the wave steepness is determined (H_s/L_0). This results in an average wave steepness of 4,8%. This value corresponds reasonably with figure 6.1.
With the significant wave heights determined from figure 6.3 for a certain return period (table 6.1), the corresponding wave length, and hence the corresponding wave period, can be calculated from the average wave steepness. The corresponding wave periods are also shown in table 6.1.

RP	H_s (FT)	H_s (m)	T_s (sec.)
5	17	5,20	8,5
10	27	8,20	10,5
25	30	9,10	11,0
50	35	10,70	12,0
100	37	11,30	12,5
300	47	14,30	14,0
500	51	15,50	14,5

Table 6.1: Deep water severe weather wave conditions, all directions.

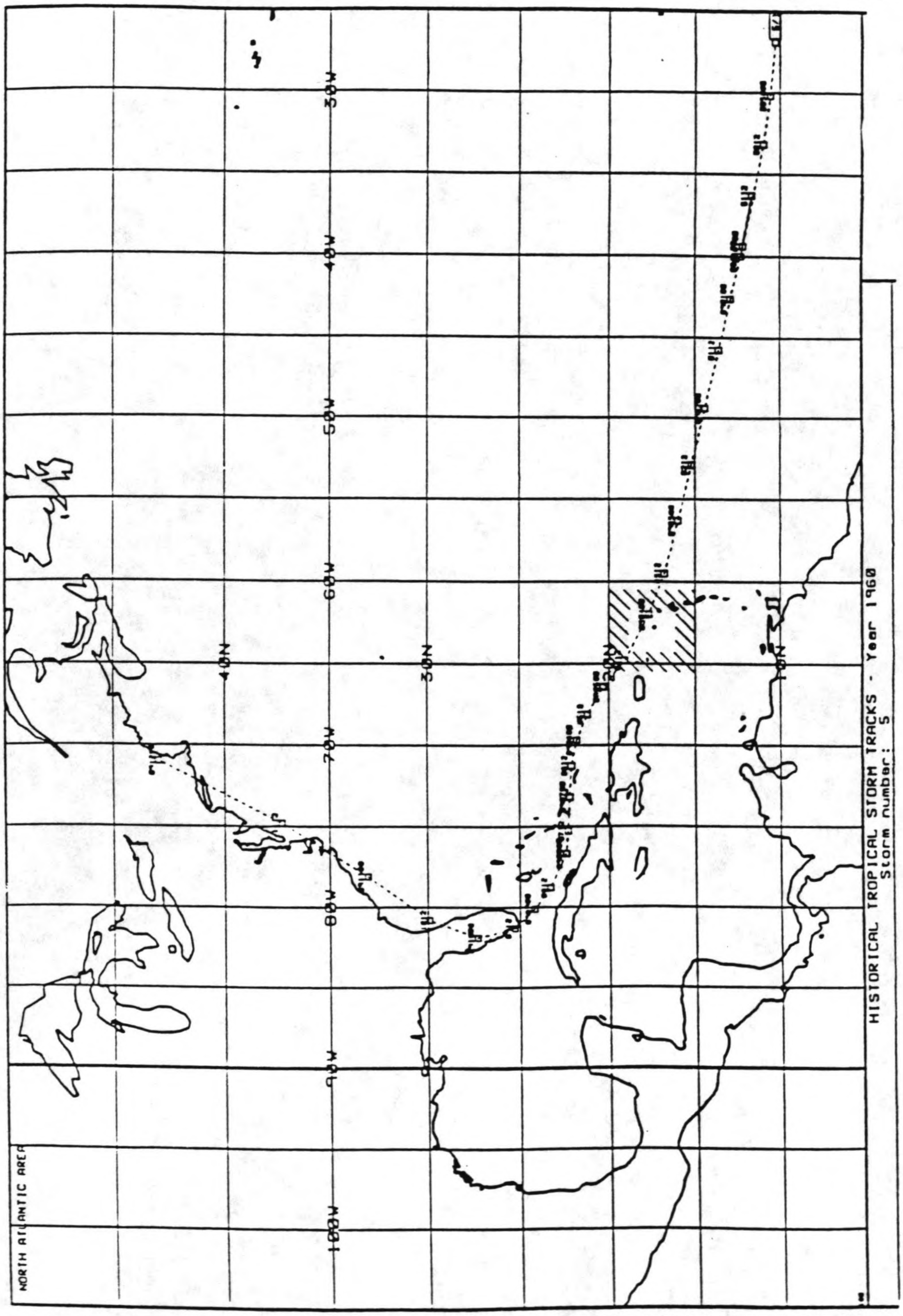
In this stage of the determination of the design conditions, it is not allowed to make a differentiation in wave direction. This would give conditional probabilities.

From figure 6.3 it is concluded that the deep water significant wave height with a return period of once every 100 years is 11,3 meter with a corresponding wave period of 12,5 seconds.



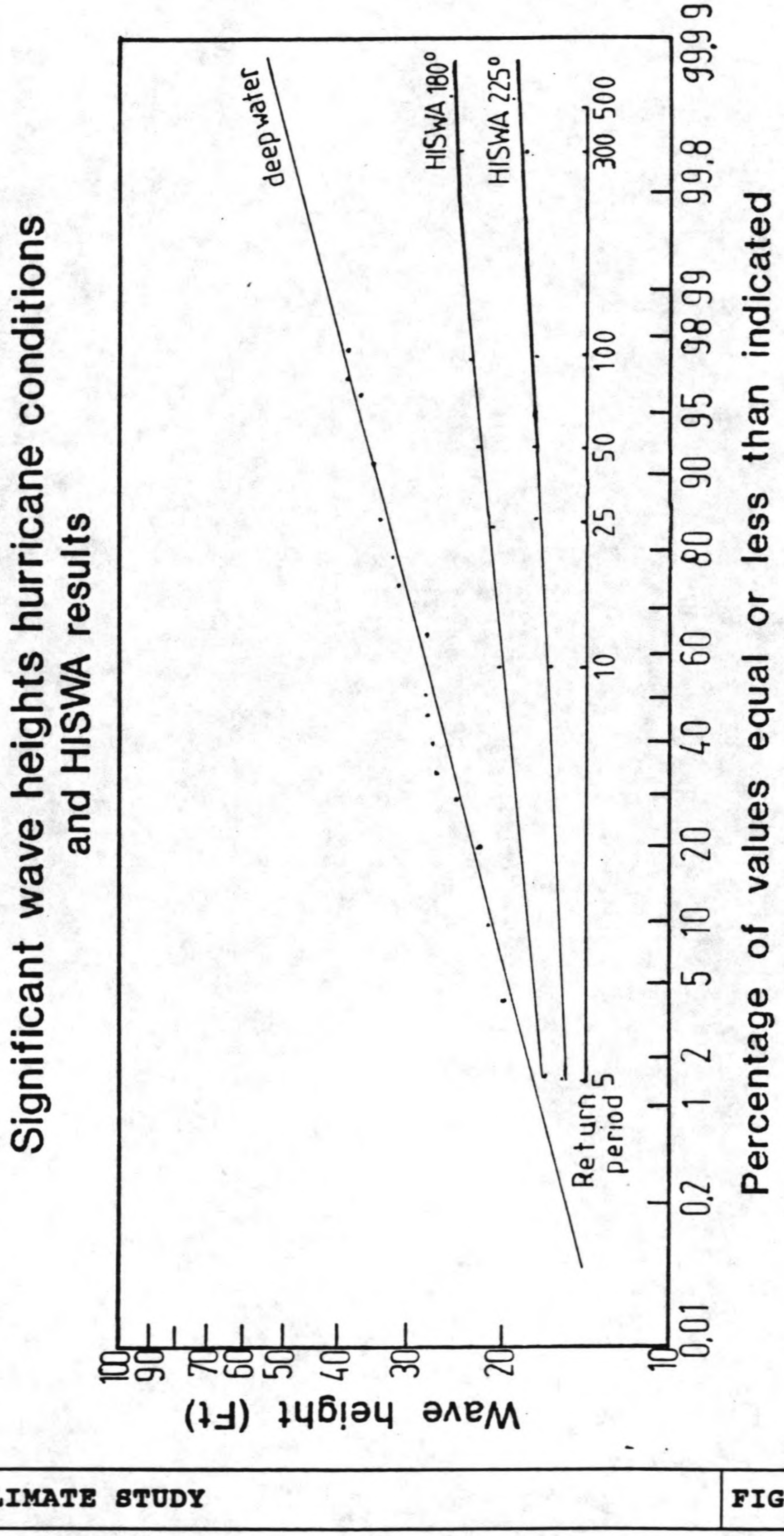
(Ignore the dotted lines, these concern the study for St. Eustatius [ref: 4]).

WAVE CLIMATE STUDY	FIGURE 6.1
Wave height,period and steepness in hurricane waves [ref.4]	



WAVE CLIMATE STUDY — FIGURE 6.2

Example of an Hurricane track near St. Maarten [ref.: 4]



WAVE CLIMATE STUDY	FIGURE 6.3

Wave heights, Percentage of values equal or less than indicated + Return period hurricane conditions + HISWA results

7.0 NEAR-SHORE EFFECTS (REFRACTION AND SHOALING)

7.1 Phenomenon

The data presented in the previous sections 5 and 6 deals with the wave parameters for deep water, observed at some distance from the harbour. These wave parameters change as the waves propagate toward shallow water.

Phenomena are:
- The rotation of wave crests (<u>refraction</u>). Refraction gives an increase or decrease in wave height and a change in wave direction.
- <u>Shoaling</u>, the propagation of waves toward shallower waters causes a reduction and later on an increase of the significant wave height.
- Related to shoaling is <u>breaking of waves</u>. Reduction of wave length (shoaling effect) causes an increase of wave steepness. Wave breaking occurs when steepness criteria are exceeded. Breaking of waves also occurs due to depth limitation.
- <u>Bottom friction</u>, results in a reduction of wave height.
- <u>Wave generation</u>, due to local wind.
- When waves encounter an obstacle on their path <u>diffraction</u> occurs. This phenomenon, the curving of waves around an obstruction, will be dealt with in a second report "Wave Penetration Study"

7.2 Wave propagation to the region South of St. Maarten

The propagation of waves and swells toward Great Bay, can be divided into two stages.
- Propagation up to the deep waters surrounding St. Maarten (SMP -1000 meter to -50 meter).
  (SMP = St. Maarten Peil = Still water level at St. Maarten)
- Further propagation over the shallow area in front of Great Bay (SMP -50 meter to 0 meter).

7.3 Near-shore effects

As now the deep water wave parameters are determined the conditions at the site can be calculated. This section deals with the approximation based on Snell's Law. Later on, these first calculations will be checked with the computer model HISWA (section 8). During this study it showed that Snell's law gives unreliable results for severe weather conditions. It is for this reason that this section deals mainly with normal weather conditions. The transformation of the severe weather conditions to the site will be discussed in section 8. The results in section 7.4 and 7.5 can be used for the feasibility study and the lay-out study.

To transform the waves from the outer region to the 12 meter depth contour, the following phenomena were introduced in the calculation:

- refraction on basis of Snell's law;
- shoaling.
- bottom friction is estimated as a 10% reduction of wave height [ref.: 1] (see appendix B).

The mathematics behind the calculations and the computer output are presented in appendix B. A summary of the results is given in tables 7.1 and 7.2 for the most relevant periods, directions and wave height. In these computations the refraction parameter could not be calculated for the directions smaller than 120° (see appendix B). The refraction parameter (K_r) is therefore set to 1, and the reduction of the wave heights is now only the result of shoaling and friction (section 8 shows the influence of this rough estimate).

T_0 = 5 sec. H_0 = 2.0 meter		
dir.	H12m.	Dir. 12m.
90°	1.80 m.	90.0°
135°	1.58 m.	141.8°
180°	1.88 m.	181.4°
225°	1.89 m.	224.4°
270°	1.80 m.	266.3°

Table 7.1: Wave heights (H12) and directions (Dir12) at 12 meter depth, normal weather conditions.
Note: Right column (dir.) = direction deep water, H_0= deep water significant wave height, T_0 = deep water significant wave period).

T_0 = 8 sec. H_0 = 2.0 meter		
dir.	H12m.	Dir. 12m.
90°	1.66 m.	90.0°
135°	1.01 m.	162.9°
180°	1.60 m.	187.7°
225°	1.65 m.	221.3°
270°	1.34 m.	251.1°

Table 7.2: Wave heights and directions at 12 meter depth, normal weather conditions.

7.4 Near-shore wave climate (normal weather conditions at port entrance)

As demonstrated in section 5 $P(H_s)=P(H_v)$. Using the values in the tables of appendix A ($P(H_v)$ per direction) and the significant wave heights at the site after transformation with Snell's law per direction, results in the following tables 7.4 through 7.7 for $P(H_s)$ at the site. Thus the tables represent the frequency of occurrence of the significant wave height (at the site), and <u>not the p.d.f. of the significant wave height (at the site), with the Jacobean</u>.
These tables do not include the severe weather conditions, discussed in section 6.

Direction 90° (sector 76°-105°)

SIGNIFICANT WAVEHEIGHT	WAVEPERIOD						per mille Hs exceeded
	<5	6/7	8/9	10/11	12/13	14/15	
<0,5	27	3	1	0	0	-	414
0,5 - 1,0	20	10	1	1	0	-	383
1,1 - 1,5	63	10	2	1	1	-	351
1,6 - 2,0	64	31	7	1	0	1	273
2,1 - 2,5	31	25	9	3	1	1	169
2,6 - 3,0	17	21	11	2	1	0	99
3,1 - 3,5	4	12	4	1	0	-	47
3,6 - 4,0	3	8	5	1	-	-	26
4,1 - 4,5	3	2	1	1	-	-	9
4,6 - 5,0	1	1	-	-	-	-	2
5,1 - 5,5	-	-	-	-	-	-	-

Table 7.4: Scatter diagram, H-T (per mille) at . depth contour.
Note: - mean zero, 0 means less then 0,5 per mille.

Direction 135° (sector 106° - 135°)

SIGNIFICANT WAVEHEIGHT	WAVEPERIOD						per mille Hs exceeded
	<5	6/7	8/9	10/11	12/13	14/15	
<0,5	19	1	0	0	0	-	151
0,5 - 1,0	29	5	6	1,5	1,5	0	130
1,1 - 1,5	23	19	2	1,5	0	0	87
1,6 - 2,0	9	9	4	0	0	0	40
2,1 - 2,5	7	3	1	0	0	-	16
2,6 - 3,0	3	0	0	-	0	-	4
3,1 - 3,5	0	-	0	-	-	-	1
3,6 - 4,0	-	-	-	-	-	-	0
4,1 - 4,5	-	-	-	-	-	-	-

Table 7.5: Scatter diagram, H-T (per mille) at 12m. depth contour.
Note: - means zero, 0 means less then 0,5 per mille.

Direction 180° (sector 166° - 195°)

SIGNIFICANT WAVEHEIGHT	WAVEPERIOD						per mille Hs exceeded
	<5	6/7	8/9	10/11	12/13	14/15	
<0,5	3	-	0	-	0	-	11
0,5 - 1,0	1,5	0	0	0	-	-	7
1,1 - 1,5	2,5	0	0	0	-	-	5
1,6 - 2,0	0	1	-	-	0	-	2
2,1 - 2,5	0	1	-	-	0	-	1
2,6 - 3,0	-	-	-	-	-	-	-
3,1 - 3,5	-	0	-	-	-	-	-
3,6 - 4,0	-	-	-	-	-	-	0
4,1 - 4,5	-	-	-	-	-	-	-

Table 7.6: Scatter diagram, H-T(per mille) at 12m. depth contour.
Note: - means zero, 0 means less then 0,5 per mille.

Direction 225° (sector 196° - 225°)

SIGNIFICANT WAVEHEIGHT	WAVEPERIOD						per mille Hs exceeded
	<5	6/7	8/9	10/11	12/13	14/15	
<0,5	0	-	-	-	-	-	4
0,5 - 1,0	1,5	-	-	0	-	-	1
1,1 - 1,5	0	0	0	-	-	-	1
1,6 - 2,0	0	-	0	-	0	-	1
2,1 - 2,5	-	1	-	-	-	-	1
'28' 3,0	-	0	-	-	-	-	-
3,1 - 3,5	-	-	-	-	-	-	-
3,6 - 4,0	-	-	-	-	-	-	-
4,1 - 4,5	-	-	-	-	-	-	-

Table 7.7: Scatter diagram, H-T (per mille) at 12m. depth contour.
Note: - means zero, 0 means less then 0,5 per mille.

7.5 Results Snell's Law normal weather conditions.

The following table shows the results of the study, for significant wave heights at the twelve meter depth contour, based on the approximation with Snell's Law for normal weather conditions. The values in the table are the horizontal totals of the values in the tables 7.4 through 7.7.

SIGNIFICANT WAVEHEIGHT	**WAVEDIRECTION**						**per mille Hs exceeded**
	90	135	180	225	other	total	
<0,5	31	21	4	3	16	75	991
0,5 - 1,0	32	43	2	1	25	103	916
1,1 - 1,5	78	47	3	1	25	154	813
1,6 - 2,0	104	24	1	1	135	265	659
2,1 - 2,5	70	12	-	-	74	156	403
2,6 - 3,0	52	3	0	-	68	123	247
3,1 - 3,5	21	0	-	-	33	54	124
3,6 - 4,0	17	-	-	-	35	52	704
4,1 - 4,5	7	-	-	-	7	14	18
4,6 - 5,0	2	-	-	-	2	4	4
5,1 - 5,5	-	-	-	-	-	-	-
totals	413	150	10	6	423	1002	

Table 7.8: Results for normal weather conditions.

8.0 HISWA COMPUTATIONS

8.1 Introduction

The preceding (section 7) was a study carried out with simple approach based on Snell's Law neglecting or assuming influences of important parameters (bottom friction, wind generation, current), for wave propagation as described in Appendix B. For a more accurate approximation of the wave heights at the twelve meter depth contour, the computer model HISWA is used.

HISWA (HIndcast Shallow water WAves) is a numerical model to obtain realistic estimates of wave parameters in coastal areas, lakes and estuaries from given stationary wind-, bottom- and current conditions. The basis of the model is a parameterized version of the action balance of the waves (or energy balance in the absence of currents) [ref.: 5].

First calculations will be made on the normal weather conditions. followed by a detailed computation on severe weather conditions.

8.2 Physical background

In conventional wave models, one wave component is followed across the area of interest along it's wave path (-ray), as was done in the previous section with Snell's Law. During their journey, the waves are influenced by bottom friction, wind field, depth etc. Hiswa does not compute along the wave ray, but in a grid. In this way the interactions between each individual wave is accounted for. Also by calculating over a larger area irregularities can be included in the calculations such as reefs, banks and islands.

HISWA accounts for:

- Refraction:
  Due to the curving of the wave rays, the direction of energy transport changes as well. HISWA does not deal with refraction along the conventional wave-ray-approach but works on a grid. In this grid refraction can be accounted for by shifting energy from one discrete spectral direction to another during propagation.
- Wind growth:
  Wind induces development of wave energy and wave frequency (wave field). In sheltered areas waves can still be generated due to the wind (depending on the fetch).
- Bottom dissipation:
  In shallow water, wave energy is dissipated by bottom friction which reduces the wave height.
- Surf-dissipation and white-capping:
  In extremely shallow waters or when wave steepness is exceeded waves will break. Breaking in shallow water is referred to as surf dissipation and wave breaking due to exceedance of wave steepness is called white capping.
- Current dissipation:
  In a strong adverse current some wave energy is carried away by the current.

HISWA is therefore far more accurate than the approximation with Snell's law.
For more information on these parameters refer to the HISWA user's manual [ref.: 5].

8.3 The numerical procedure

The computational region is a rectangular grid with an x- and a y-axis. HISWA starts the computation in the upward boundary of this grid (x = 0) and proceeds in the positive x-direction. After all the values on a line in the y-direction are determined the computation proceeds with the next line in the grid (where x = constant).
For the propagation in the x-y space the leap frog scheme (explicit scheme) is used.

8.4 The schematisation

For the calculations with HISWA (normal weather conditions), the bottom profile in and around Great Bay is schematised. For the accuracy desired a very fine grid is made with meshes of 174 meters in the x-and y-direction. In this way small shallows and irregularities can be read by HISWA in the bottom schematisation. A plot of the bottom schematisation can be found in figure 8.1.
For the direction 90°N the influence of St. Barths on the computation was accounted for, by introducing an artificial coastline at the upwave boundary of the grid (representing the island's shadow, illustrated by figure 5.2). For the other directions this island at the Southeast of St. Maarten had no influence on the wave propagation.

For the severe weather conditions two additional bottom grids had to be made. One for the direction 225° and one for the direction 180°. Waves from these two directions are influenced by the Saba Bank and the "window" at the South of St. Maarten between Saba and St. Eustatius (figure 5.2). For these calculations a schematisation of the bottom profile is made with meshes of 1740 m in the x- and y-direction (figure 8.2 for the direction 225° and figure 8.3 for the direction 180°). The schematisation is somewhat rough but with nesting (computation till a downwave boundary, and using the results at this boundary as input for a second computation with a finer schematisation) the accuracy of required bottom resolution seems reasonable. The boundaries were chosen in such a way that these were at the same time the upward boundaries of the finer bottomgrid (figure 8.1), which is used for the normal weather conditions.

For the four directions, four different computation grids had to be defined. The computation grids are situated in such a way that the x-axis was directed in the mean wave direction. The starting boundaries were situated at a depth where the bottom has no influence on the waves (depth > 1/4 deep water wave length (L0)).

For the normal weather conditions a constant wind field is assumed, representing the Tradewinds (u = 5 m/s). The data on hurricane conditions [ref.: 4], gives windspeeds of 20 to 30 m/s, with rare gusts up to 40m/s. HISWA calculates with a constant wind field. A single well-defined windspeed is not present during hurricanes. In the computations the representative windspeed of 20 m/s, blowing in the same direction as the wave propagation, is used.

8.5 Normal weather conditions.

The input for the computations with HISWA in this case are:

Direction	Wave period	Wave height	Wind velocity
90°N	8 sec.	2,0 m.	5 m/s
135°N	8 sec.	2,0 m.	5 m/s
180°N	8 sec.	2,0 m.	5 m/s

Table 8.1 HISWA computations normal weather conditions.

These computations are performed with HISWA to verify the results found in section 7. The wave period of 8 seconds is chosen, to base the calculations on an intermediate wave period for this particular wave field.
There is an other reason why the period of 8 seconds is used. In the diffraction study (following report: Wave Penetration Study), use is made of the DIFFRAC-model. DIFFRAC stands for diffraction, which is the curving of waves around a structure. This model is limited by a maximum number of equations in a matrix (for the methodology reference is made to this report). A wave period of 5 seconds resulted in an exceedence of this limitation. By using a wave period of 8 seconds instead of 5 seconds the number of necessary equations reduces. With additional runs, DIFFRAC showed little difference between the results in diffraction parameters for a wave period of 5 seconds and a wave period of 8 seconds. This allowed the use of a higher wave period to facilitate computations with DIFFRAC.
Additional runs with HISWA, using a wave period of 5 sec.,

gave hardly any difference between the resulting significant wave heights at the 12 meter depth contour, when using a wave period of 8 seconds.
In few of the above the calculations are carried out for a wave period of 8 seconds to meet the DIFFRAC-study.

Table 8.2 gives the values computed by HISWA along a straight line between the tip of Point Blanche (P.B.) and the tip of Point Ouest (P.O.). This line is shown in figure 8.1 (SXM is an abbreviation for St. Maarten). The significant wave height and the depth contour along this line is shown in figure 8.3 for the normal weather conditions.

Normal weather conditions: H0 = 2.0 m. T0 = 8.0 sec.			
Direction	Hs at 12m.	Ts at 12m.	Dir. at 12m.
90°	0,3 - 1,3	2,0 - 5,0	50°- 80°
135°	0,6 - 1,7	6,8 - 8,0	120°-130°
180°	1,4 - 1,9	6,0 - 8,2	180°-185°

Table 8.2: Hiswa results for normal weather conditions.

The significant wave heights at the proposed port entrance are given in table 8.3 (derived from figure 8.4).

Direction (deep water)	Wave height m. 12m. depth
90°	0,75
135°	0,75
180°	1,75

Table 8.3: Approximate wave height at port entrance, normal weather conditions.

8.6 Severe weather conditions

The directions used in the HISWA computations for hurricane conditions were 225° and 180°.
Wave direction 180° is perpendicular to the proposed breakwater. Perpendicular wave attack results in higher wave forces. Direction 225° was found as the most probable direction from where hurricanes occur.

Waves from the directions between 240° and 270° experience such considerable refraction, that they can not reach Great Bay, but end up along the Southern shore between Little Bay and Cupe Coy Beach [ref.: 1].

From the other directions Great Bay is well protected from waves, by islands and reefs. The fetch length is too small, to regenerate excessive wave heights in the shadowed area in the presence of high wind velocities.

Table 6.1 was the input for the computations for both directions.

HISWA provides with the option of plotting the results in the form of contour plots for wave heights. These plots are included in Appendix C.

The results are also shown in table 8.4. Table 8.4 gives the design parameters at the site. The values shown are for a single point located at the centre of the proposed breakwater length. This value lies close to the average wave height at the twelve meter depth contour (variation +/- 4%). The results are also plotted in figure 6.3.

RP	Deep water		Direction 180°		Direction 225°	
	H_s	T_s	H_s12m.	T_s 12m.	H_s 12m.	T_s 12m.
5	5,20	8,50	5,00	8,25	4,30	6,00
10	8,20	10,50	6,20	10,85	4,95	11,10
25	9,10	11,00	6,40	11,25	5,10	11,50
50	10,70	12,00	6,60	11,90	5,15	12,10
100	11,30	12,50	6,75	12,40	5,20	12,60
300	14,30	14,00	7,15	13,90	5,50	14,20
500	15,50	14,50	7,30	14,40	5,70	14,75

Table 8.4: Results HISWA computations, severe weather conditions.

The direction 180° (South to North) was schematised in the computations as the direction making an angle 90° with the x-axis. The direction 225° (SW to NE) makes an angle of 45° with the x-axis. The incoming main direction at the site is given in table 8.5, compared to the computational direction.

	Deep water all directions		comp 90°	comp 45°
RP	H_s	T_s	Dir.$_{12m.}$	Dir.$_{12m.}$
5	5,20	8,50	81,3	61,0
10	8,20	10,50	81,5	62,5
25	9,10	11,00	82,2	61,9
50	10,70	12,00	82,4	62,9
100	11,30	12,50	82,9	62,6
300	14,30	14,00	83,4	64,2
500	15,50	14,50	83,4	65,5

Table 8.5: HISWA results for the directions.

8.6 Comparison HISWA with Snell's Law and conclusions

Comparing the results in table 8.2 and 8.3 with table 7.2 (T0 = 8 sec.), indicates the influence the bottom

irregularities and the estimation of the friction (in Appendix B), has on the calculations.
The values of table 7.2 are in or near the ranges of table 8.2. Refraction at Point Blanche plays a large roll in the wave course. At some distance from Point Blanche (more to the centre of Great Bay) these values may occur but near Point Blanche, at the project site, lower wave heights result. This is due to the steepness of the bottom profile near Point Blanch, which was not accounted for in section 7, (and Appendix B). Note that HISWA does not account for diffraction which results in higher values near Point Blanche than presented here. For more information refer to a second report "Wave Penetration Study".

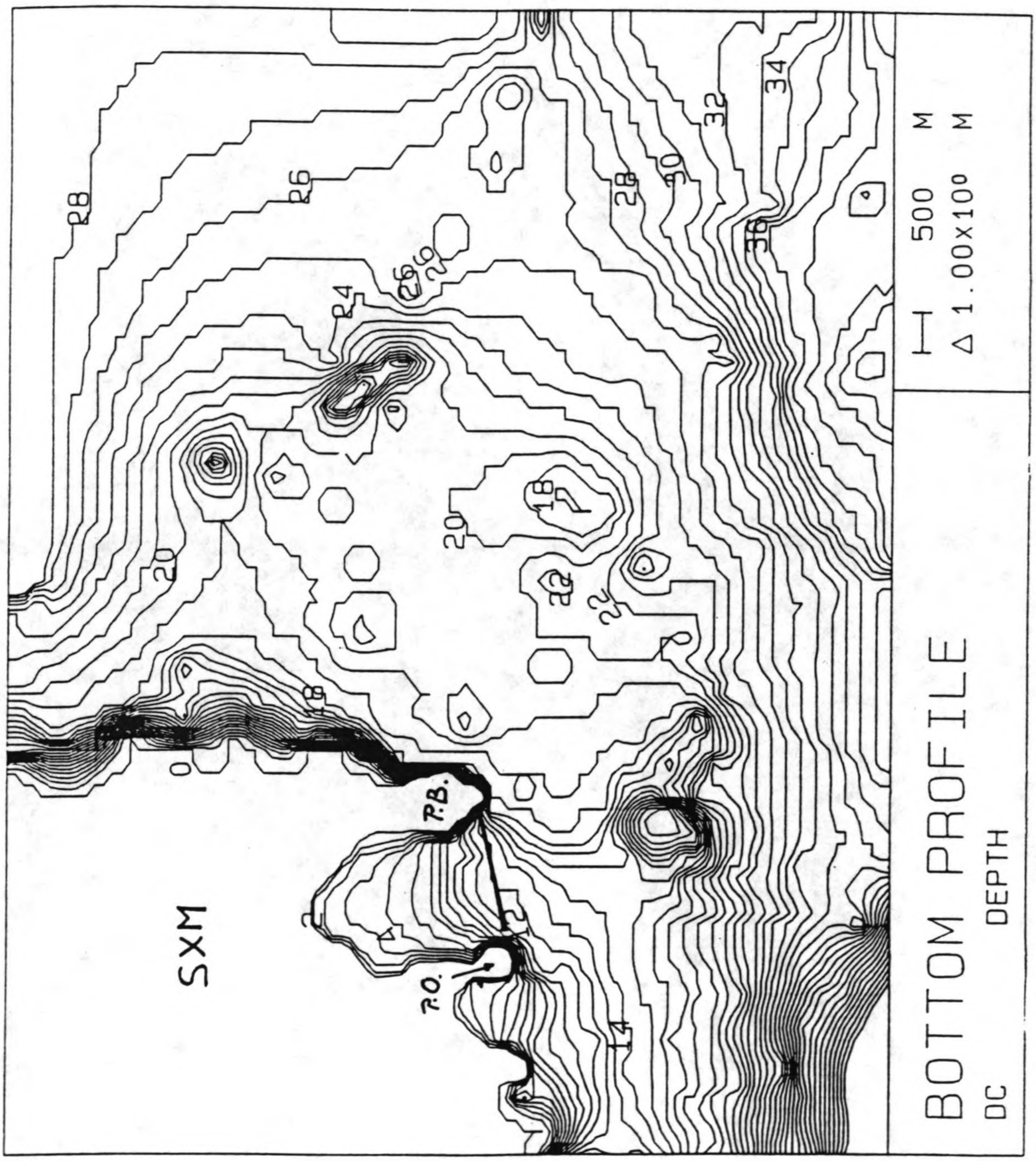
Snell's law gave much less reduction of wave height compared to the HISWA computations on severe weather conditions. The reason is mainly due to the dept at the site. The smaller waves for normal weather conditions, are hardly influenced by the depth at the site, compared to the hurricane waves. The simple approximation for the bottom dissipation is not allowed for the hurricane waves. It can be concluded that for smaller waves, Snell's law may give some indication on wave behaviour, but for severe weather conditions, Snell's law is not suitable.

Significant wave heights from the direction 225° undergo a profound reduction as they travel over the Saba Bank. In this direction, a substantial amount of energy is lost on the Saba Bank, but due to some regeneration by the strong wind (20m/s), waves still reach the site of considerable height. The plots in Appendix C also show how the depth limits the maximum wave height at the site irrespective of the deep water significant wave height. The significant wave heights from the direction 225° result in significant wave heights ranging from 4 to 6 meters, irrespective of the deep water significant wave height. From the direction 180° the range is approximately 5 to 7,5 meters.
From the direction 180°, waves can pass through the "window" between Saba and St. Eustatius, without a meaningful loss of

energy. This is why the resulting significant wave heights for this direction are higher than for the direction 225°.The depth however limits the wave height at the site.
Waves from the South (180°N = 90°N in computations) show a little curving toward the NNE (away from the North). Waves from the direction 225°N (= 45°N in the computations) also show a curving toward the NNE (Toward the North).
The wave periods hardly change. This is the result of the high wind velocity.

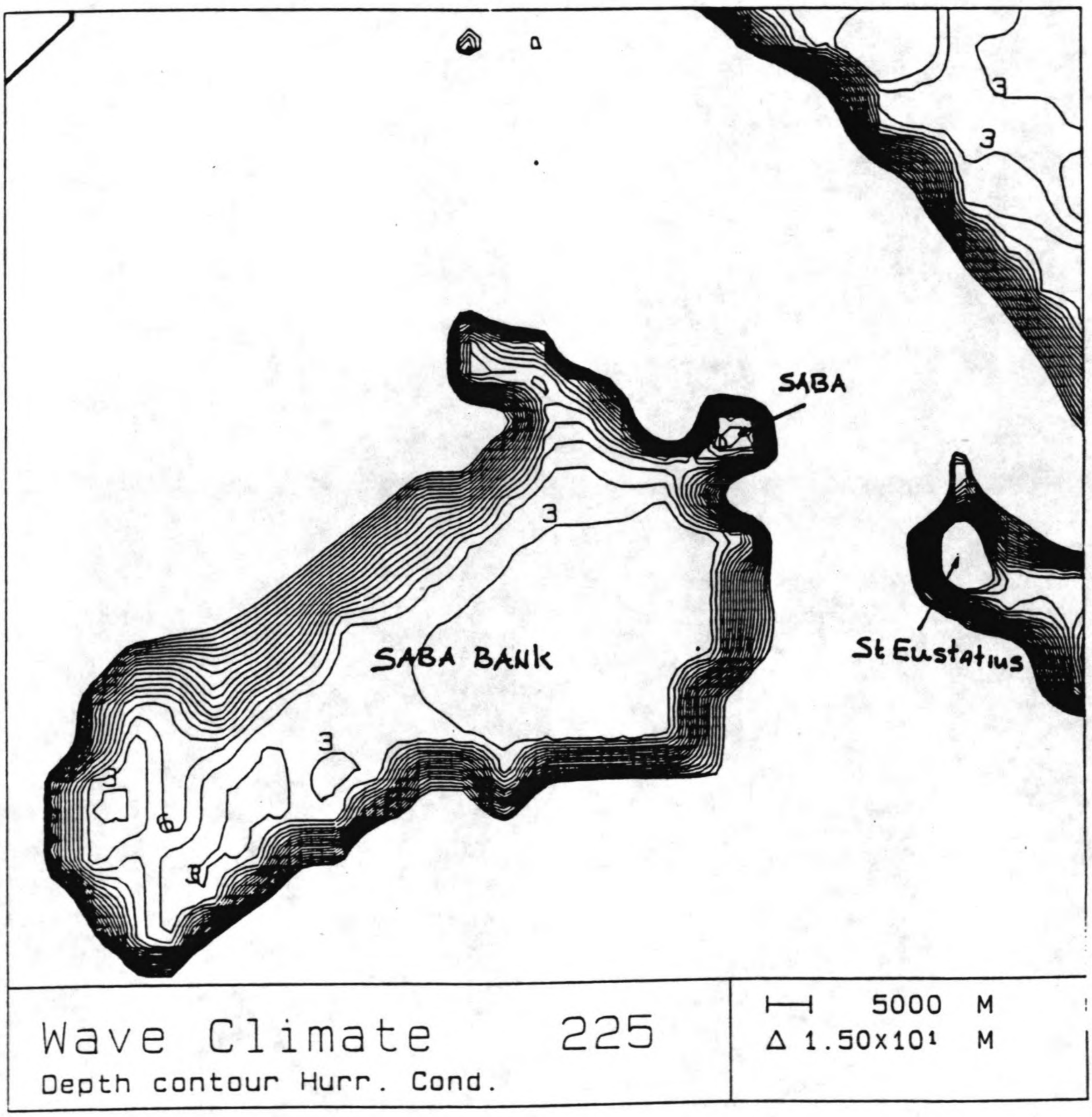
In the following design study, the calculations will be based on the results in table 8.4 and 8.5. The return periods will be used per direction as shown in the tables. It is important to consider that although direction 180°N gives the highest values at the site, does not necessarily mean that these values should indeed be the design parameters. As starting point of the computations, the return period is established based on <u>all directions</u>. The respective wave parameters were then transformed 'as if' coming from the chosen directions 180°N and 225°N. The computations show a profound difference in the results for the significant wave heights. The preceding computations are for the optimisation study for the breakwater, and thus the return period per direction can also play an important role. With other words, if direction 180° would indeed hardly occur, one could consider to design on a direction that has a much larger occurrence but lower wave heights, and in this way minimize construction costs.

It will take an extensive and detailed study to determine the real values.
It is beyond the scope of this thesis to elaborate on this last issue. The optimisation will therefore be based on the maximum values resulting from the direction 180°.



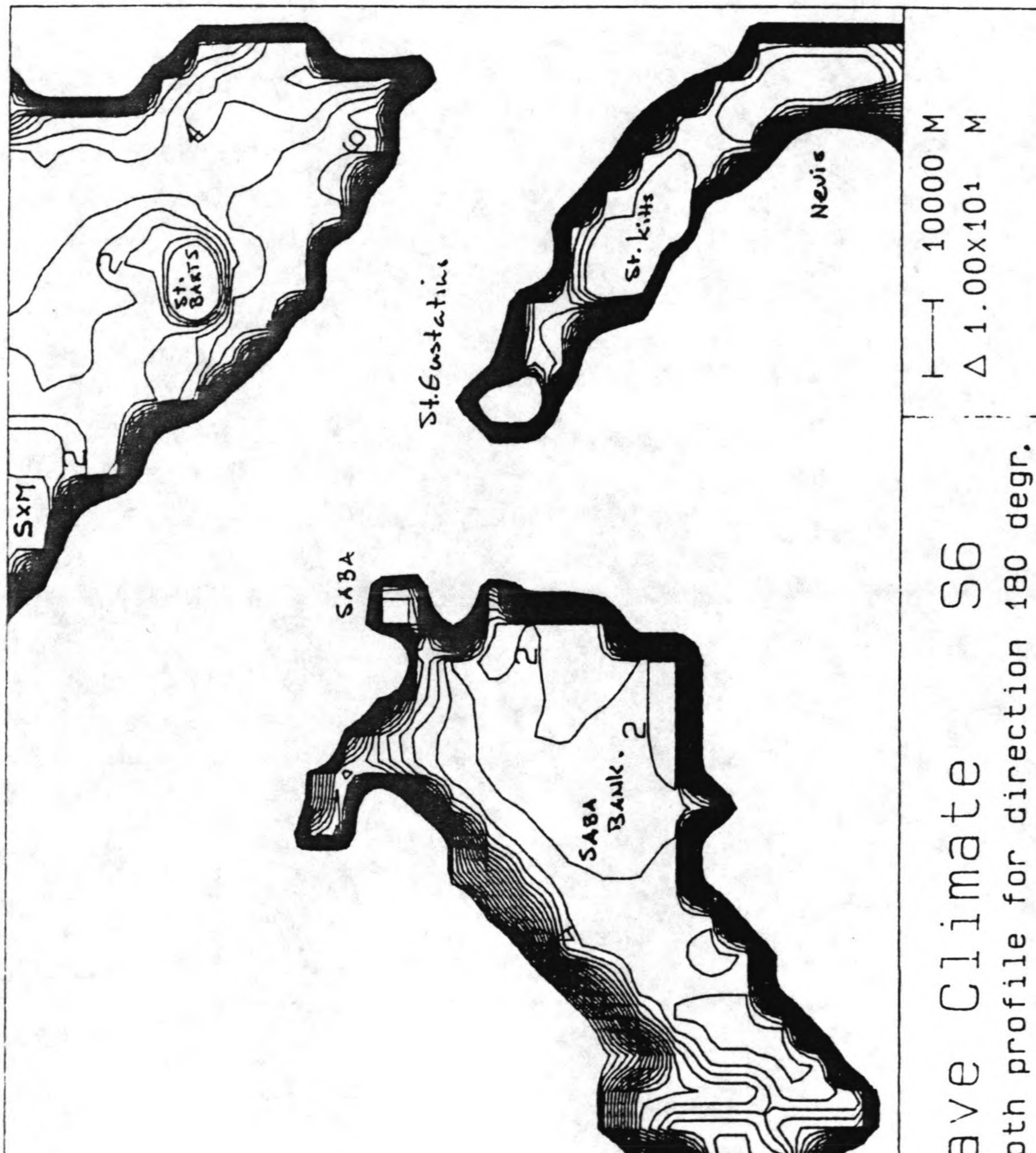
WAVE CLIMATE STUDY	FIGURE 8.1

Bottom profile of the area near St. Maarten

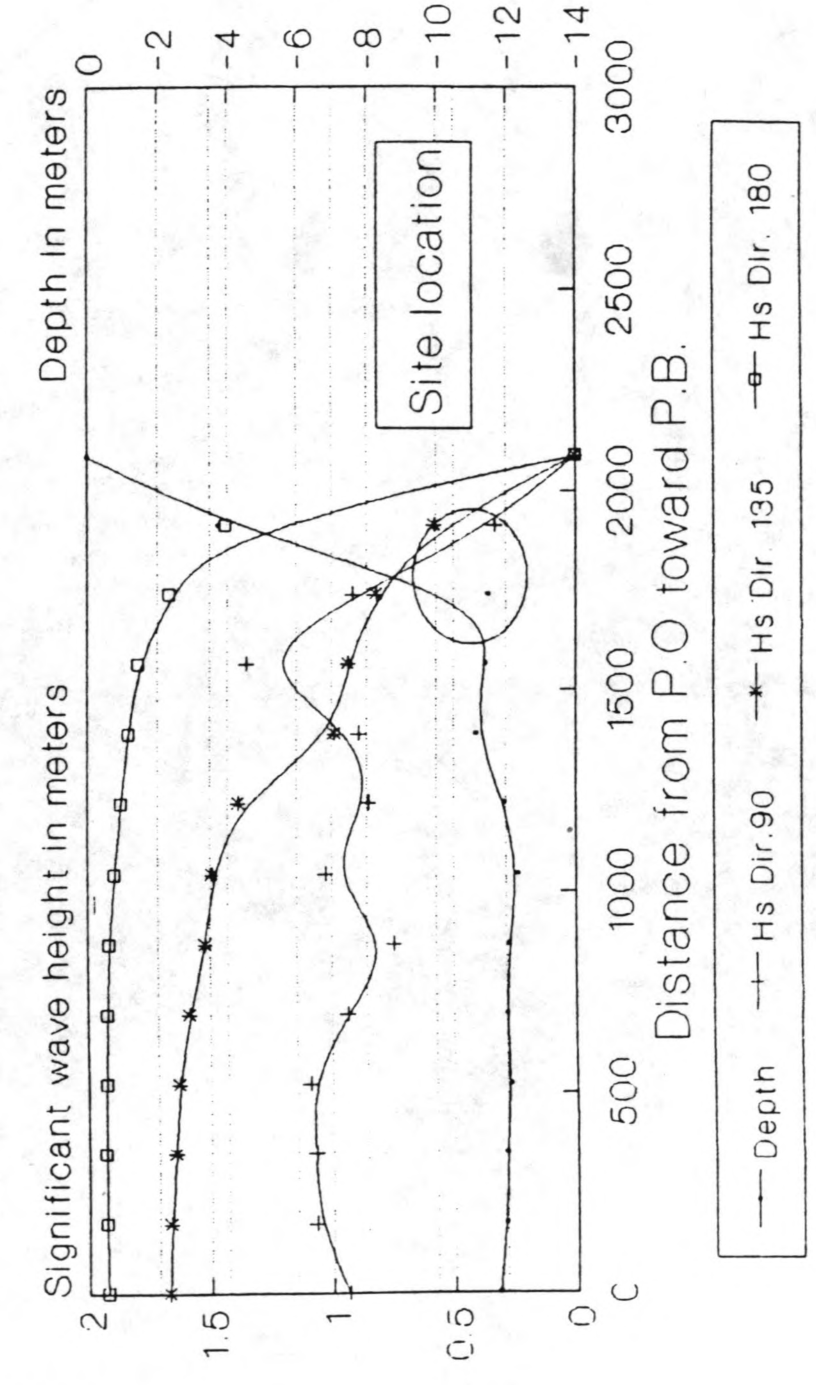


WAVE CLIMATE STUDY **FIGURE 8.2**

Bottom profile Saba Bank (direction 225°)



WAVE CLIMATE STUDY	FIGURE 8.3
Bottom profile used for direction 180° hur. cond.	



WAVE CLIMATE STUDY	FIGURE 8.4
Results HISWA computations,normal weather conditions	

9.0 CONCLUSIONS

The previous wave climate study has lead to the following conclusions for normal weather conditions and for the severe weather (hurricane) conditions.

Great Bay is sheltered by Point Blanche Hill against the most probable wave direction: East (90°N), and is partly sheltered against waves from the direction 90°N through 270°N by neighbouring islands and reefs. The transformation of the off-shore wave climate is therefore carried out in this directional sector. St. Maarten protects Great Bay against waves from the remaining directions (270N° through 90°N).

9.1 Normal weather conditions

- **Off-shore wave climate:**
  The most probable significant wave parameters resulting from the BMO-charts, are a significant wave height of 2,0 meters, with a corresponding wave period of 5 seconds.
- **Wave climate at the site:**
  The numerical wave model HISWA is found to be the appropriate method for estimating the behaviour of the waves as they propagate toward the site, compared to the approximation based on Snell's law. The results calculated by the HISWA model, using the above wave parameters, concluded in an average significant wave height of 1,5 meter (0,3m.-1,9m.), with a corresponding wave period of 5 seconds at the site (table 8.2). Note that a wave period of 8 seconds was used in the model in conjunction with the Wave Penetration Study. Control runs showed hardly any difference in the resulting wave parameters at the site when using a wave period of 5 seconds.

Overall can be stated that Great Bay and especially the site due to it's sheltered position, experience a fairly calm sea throughout most of the year (except then during severe weather conditions).

9.2 Severe weather (hurricane) conditions

St. Maarten experiences hurricane conditions once every 4 to 5 years. Great Bay and the site are not protected against the most probable directions from where the hurricanes occur (180°N through 270°N). Due to strong refraction waves from the direction 240°N through 270°N end up along the southern shore of the island before reaching Great Bay. The direction 225°N is the most probable direction for hurricanes. Waves coming in from the South (180°N) result in perpendicular wave attack on the proposed breakwater. HISWA runs were subsequently carried out for these last two direction.

- **Off-shore hurricane conditions:**
  From the hindcast study, covering 100 years of hurricane data, it is concluded that the deep water significant wave heights range from 5 to 15,5 meters. The corresponding wave periods range from 7 to 14 seconds.
  The design parameters set as the parameters with a return period of once every 100 years, where found as a significant wave height of 11,3 meter with a corresponding wave period of 12,5 seconds.
- **Near-shore hurricane conditions:**
  The off-shore hurricane conditions were also transformed to the site with the aid of HISWA.
  From the direction 180°, waves can pass through the "window" between Saba and St. Eustatius, without a meaningful loss of energy. Significant wave heights from the direction 225° undergo a profound reduction as they travel over the Saba Bank. In this direction, a substantial amount of energy is lost on the Saba Bank, but due to some regeneration by the strong wind (20m/s), waves still reach the site of considerable height.
  This is why the resulting significant wave heights for the direction 180° are higher than for the direction 225°.

Transformation of the design parameters, with a recurrence of once every 100 years, to the proposed site 'as if' coming in from the direction 180° resulted in a significant wave height of 6,75 meters and a corresponding wave period of 12,4 seconds.

Appendix A:

Summary BMO charts for the relevant direction.

DATE OF PRINTOUT: 3/ [illegible]/197[illegible] ** CROWN COPYRIGHT. DO NOT REPRODUCE WITHOUT METEOROLOGICAL OFFICE PERMISSION

FREQUENCIES FOR SEA AREA: 17.0N 19. N 062.0W 064.0W PERIOD OF DAT[illegible]

MONTHS: JANUARY TO DECEMBER

WAVE DIRECTION (DEGREES TRUE) FOR HIGHER OF SEA/SWELL HEIGHT : 046 TO 075

LOWER LIMIT / UPPER LIMIT	WAVE PERIOD (SECONDS) FOR HIGHER OF SEA/SWELL HEIGHT										
LOWER LIMIT	0	6	8	10	12	14	16	18	20	22	TOTAL
UPPER LIMIT	5	7	9	11	13	15	17	19	21		
RESULTANT WAVE HEIGHT (METRES)											
0.0 TO 0.5	171	1[illegible]	2	1	..	..	..	..	..	..	184
.6 TO 1.0	30[illegible]	7[illegible]	11	2	4	..	..	1	..	..	399
1.1 TO 1.5	337	174	41	7	3	4	1	..	..	..	567
1.6 TO 2.0	161	117	45	10	2	4	..	..	..	..	339
2.1 TO 2.5	91	95	45	9	3	3	..	..	..	..	246
2.6 TO 3.0	3[illegible]	55	24	6	[illegible]	..	..	1	..	..	122
3.1 TO 4.0	3[illegible]	57	37	9	5	1	..	..	..	..	139
4.1 TO 5.0	3	[illegible]	14	4	..	..	..	..	..	..	29
5.1 TO 6.0	2	5	4	..	..	..	..	..	..	..	11
6.1 TO 7.0	..	1	..	..	..	..	..	..	..	..	1
7.1 TO 8.0	1	..	..	..	..	..	..	..	..	..	1
8.1 TO 9.0	..	..	..	..	..	..	..	..	..	..	..
9.1 TO 10.0	..	..	..	..	..	..	..	..	..	..	..
10.1 TO 12.0	..	..	..	..	..	..	..	..	..	..	..
[illegible]	..	..	..	..	..	..	..	..	..	..	..
[illegible]	..	..	..	..	..						
16.1 TO 18.0	..	..	..	..	..	..	..	..	..	..	..
18.1 TO 20.0	..	..	..	..	..	..	..	..	..	..	..
20.1 OR MORE	..	..	..	..	..	..	..	..	..	..	..
TOTAL	2133	598	223	49	21	12	1	2	..	..	2038

NOTE:- .. INDICATES ZERO FREQUENCY

PERCENTAGE FREQUENCIES FOR SEA AREA: 17.0N 19.0N 062.0W 064.0W PERIOD OF [

MONTHS: JANUARY TO DECEMBER

WAVE DIRECTION (DEGREES TRUE) FOR HIGHER OF SEA/SWELL HEIGHT : 076 TO 105

	WAVE PERIOD (SECONDS) FOR HIGHER OF SEA/SWELL HEIGHT										
LOWER LIMIT	0	6	8	10	12	14	16	18	20	22	
UPPER LIMIT	5	7	9	11	13	15	17	19	21		TOTAL
RESULTANT WAVE HEIGHT (METRES)											
0.0 TO 0.5	3.7	0.3	0.1	0.0	0.0	..	..	..	0.0	..	4.2
0.6 TO 1.0	7.3	1.9	0.3	0.1	0.0	..	..	..	..	..	9.5
1.1 TO 1.5	6.4	3.2	0.7	0.2	0.1	0.1	..	..	0.0	..	10.7
1.6 TO 2.0	3.1	2.5	0.9	0.3	0.0	0.1	..	..	..	..	6.8
2.1 TO 2.5	1.7	2.1	1.1	0.2	0.1	0.1	..	..	..	..	5.2
2.6 TO 3.0	0.5	1.2	0.4	0.1	0.1	0.0	..	..	..	..	2.3
3.1 TO 4.0	0.5	0.8	0.5	0.1	0.0	..	..	..	..	..	1.9
4.1 TO 5.0	0.1	0.2	0.1	0.1	..	0.0	..	..	..	..	0.5
5.1 TO 6.0	0.0	0.1	0.0	..	..	..	..	..	..	..	0.1
6.1 TO 7.0	..	..	..	..	..	..	..	..	..	..	..
7.1 TO 8.0	..	..	..	..	..	..	..	..	..	..	..
8.1 TO 9.0	..	..	..	..	..	..	..	..	..	..	..
9.1 TO 10.0	..	..	..	..	..	..	..	..	..	..	..
10.1 TO 12.0	..	..	..	..	..	..	..	..	..	..	..
12.1 TO 14.0	..	..	..	..	..	..	..	..	..	..	..
14.1 TO 16.0	..	..	..	..	..	..	..	..	..	..	..
16.1 TO 18.0	..	..	..	..	..	..	..	..	..	..	..
18.1 TO 20.0	..	..	..	..	..	..	..	..	..	..	..
20.1 OR MORE	..	..	..	..	..	..	..	..	..	..	..
TOTAL	23.3	12.2	4.2	1.1	0.3	0.3	..	..	0.0	..	41.4

NOTE:- .. INDICATES ZERO FREQUENCY WHILST 0.0 INDICATES LESS THAN 0.05 PER CENT
TABLE TOTAL NUMBER OF OBSERVATIONS IS 3444

PERCENTAGE FREQUENCIES FOR SEA AREA: 17.0N 19.0N 062.0W 064.0W PERIOD OF

MONTHS: JANUARY TO DECEMBER

WAVE DIRECTION (DEGREES TRUE) FOR HIGHER OF SEA/SWELL HEIGHT : 106 TO 135

WAVE PERIOD (SECONDS) FOR HIGHER OF SEA/SWELL HEIGHT — LOWER LIMIT	0	6	8	10	12	14	16	18	20	22	
UPPER LIMIT	5	7	9	11	13	15	17	19	21		TOTAL
RESULTANT WAVE HEIGHT (METRES)											
0.0 TO 0.5	1.9	0.1	0.2	0.0	0.0	..	..	..	..	..	2.2
0.6 TO 1.0	3.0	0.5	0.1	0.0	0.0	0.0	..	..	..	..	3.7
1.1 TO 1.5	2.3	1.1	0.5	0.1	0.1	0.0	..	..	0.0	..	4.1
1.6 TO 2.0	0.9	0.8	0.2	0.1	0.0	0.0	..	..	..	..	2.0
2.1 TO 2.5	0.7	0.6	0.3	0.0	0.0	0.0	..	..	..	..	1.8
2.6 TO 3.0	0.2	0.3	0.1	0.0	0.0	..	..	..	..	..	0.6
3.1 TO 4.0	0.1	0.3	0.1	0.0	0.0	..	..	..	..	..	0.5
4.1 TO 5.0	0.0	0.0	0.0	..	0.0	..	..	..	..	..	0.1
5.1 TO 6.0	..	..	0.0	..	..	..	..	..	..	..	0.0
6.1 TO 7.0	..	..	..	..	..	..	..	..	..	..	..
7.1 TO 8.0	..	..	..	..	..	..	..	..	..	..	..
8.1 TO 9.0	..	..	..	..	..	..	..	..	..	..	..
9.1 TO 10.0	..	..	..	..	..	..	..	..	..	..	..
10.1 TO 12.0	..	..	..	..	..	..	..	..	..	..	..
12.1 TO 14.0	..	..	..	..	..	..	..	..	..	..	..
14.1 TO 16.0	..	..	..	..	..	..	..	..	..	..	..
16.1 TO 18.0	..	..	..	..	..	..	..	..	..	..	..
18.1 TO 20.0	..	..	..	..	..	..	..	..	..	..	..
20.1 OR MORE	..	..	..	..	..	..	..	..	..	..	..
TOTAL	9.1	3.8	1.4	0.4	0.3	0.1	..	..	0.0	..	15.1

NOTE:- .. INDICATES ZERO FREQUENCY WHILST 0.0 INDICATES LESS THAN 0.05 PER CENT
TABLE TOTAL NUMBER OF OBSERVATIONS IS 1257

DATE OF PRINTOUT: 3/ 9/19[illegible] ** CROWN COPYRIGHT. DO NOT REPRODUCE WITHOUT METEOROLOGICAL OFFICE PERMISSI

PERCENTAGE FREQUENCIES FOR SEA AREA: 17.0N 19.0N 062.0W 064.0W PERIOD OF DA

MONTHS: JANUARY TO DECEMBER

WAVE DIRECTION (DEGREES TRUE) FOR HIGHER OF SEA/SWELL HEIGHT : 136 TO 165

WAVE PERIOD (SECONDS) FOR HIGHER OF SEA/SWELL HEIGHT											
LOWER LIMIT	0	6	8	10	12	14	16	18	20	22	
UPPER LIMIT	5	7	9	11	13	15	17	19	21		TOTAL
RESULTANT WAVE HEIGHT (METRES)											
0.0 TO 0.5	0.8	0.1	0.0	0.0	..	..	..	..	..	..	1.0
0.6 TO 1.0	1.0	0.2	0.0	..	..	..	0.0	..	..	..	1.2
1.1 TO 1.5	0.8	0.3	0.1	..	0.0	..	..	..	..	..	1.3
1.6 TO 2.0	0.3	0.2	0.1	0.0	..	..	..	..	..	..	0.6
2.1 TO 2.5	0.1	0.1	0.0	0.0	..	..	..	..	..	..	0.3
2.6 TO 3.0	..	0.1	..	..	..	..	..	..	..	..	0.1
3.1 TO 4.0	0.0	0.1	0.0	..	..	0.0	..	..	..	..	0.1
4.1 TO 5.0	..	..	..	..	..	..	..	..	..	..	..
5.1 TO 6.0	0.0	..	..	..	0.0	..	..	..	..	..	0.0
6.1 TO 7.0	..	..	..	..	..	..	..	..	..	..	..
7.1 TO 8.0	..	..	..	..	..	..	..	..	..	..	..
8.1 TO 9.0	..	..	..	..	..	..	..	..	..	..	..
9.1 TO 10.0	..	..	..	..	..	..	..	..	..	..	..
10.1 TO 12.0	..	..	..	..	..	..	..	..	..	..	..
12.1 TO 14.0	..	..	..	..	..	..	..	..	..	..	..
14.1 TO 16.0	..	..	..	..	..	..	..	..	..	..	..
16.1 TO 18.0	..	..	..	..	..	..	..	..	..	..	..
18.1 TO 20.0	..	..	..	..	..	..	..	..	..	..	..
20.1 OR MORE	..	..	..	..	..	..	..	..	..	..	..
TOTAL	3.1	1.0	0.3	0.1	0.0	0.0	0.0	..	..	..	4.5

NOTE:- .. INDICATES ZERO FREQUENCY WHILST 0.0 INDICATES LESS THAN 0.05 PER CENT
TABLE TOTAL NUMBER OF OBSERVATIONS IS 374

PERCENTAGE FREQUENCIES FOR SEA AREA: 17.0N 19.0N 062.0W 064.0W

PERIOD OF DA

MONTHS: JANUARY TO DECEMBER

WAVE DIRECTION (DEGREES TRUE) FOR HIGHER OF SEA/SWELL HEIGHT : 166 TO 195

WAVE PERIOD (SECONDS) FOR HIGHER OF SEA/SWELL HEIGHT — LOWER LIMIT	0	6	8	10	12	14	16	18	20	22	
UPPER LIMIT	5	7	9	11	13	15	17	19	21		TOTAL
RESULTANT WAVE HEIGHT (METRES)											
0.0 TO 0.5	0.3	..	0.0	..	0.0	..	..	..	..	..	0.3
0.6 TO 1.0	0.3	0.0	..	0.0	..	..	..	..	..	..	0.3
1.1 TO 1.5	0.1	0.1	0.0	..	..	..	..	..	..	..	0.2
1.6 TO 2.0	0.0	0.1	..	..	..	..	..	..	..	..	0.1
2.1 TO 2.5	0.0	..	..	..	0.0	..	..	..	..	..	0.0
2.6 TO 3.0	..	..	0.0	0.0	..	..	..	..	..	..	0.0
3.1 TO 4.0	0.0	0.0	..	..	..	..	..	..	..	..	0.1
4.1 TO 5.0	..	0.0	..	..	..	..	..	..	..	..	0.0
5.1 TO 6.0	..	..	..	..	..	..	..	..	..	..	..
6.1 TO 7.0	..	..	..	..	..	..	..	..	..	..	..
7.1 TO 8.0	..	..	..	..	..	..	..	..	..	..	..
8.1 TO 9.0	..	..	..	..	..	..	..	..	..	..	..
9.1 TO 10.0	..	..	..	..	..	..	..	..	..	..	..
10.1 TO 12.0	..	..	..	..	..	..	..	..	..	..	..
12.1 TO 14.0	..	..	..	..	..	..	..	..	..	..	..
14.1 TO 16.0	..	..	..	..	..	..	..	..	..	..	..
16.1 TO 18.0	..	..	..	..	..	..	..	..	..	..	..
18.1 TO 20.0	..	..	..	..	..	..	..	..	..	..	..
20.1 OR MORE	..	..	..	..	..	..	..	..	..	..	..
TOTAL	0.7	0.2	0.1	0.0	0.0	..	..	..	..	..	1.1

NOTE:- .. INDICATES ZERO FREQUENCY WHILST 0.0 INDICATES LESS THAN 0.05 PER CENT
(2) THE TOTAL NUMBER OF OBSERVATIONS IS [illegible]

PERCENTAGE FREQUENCIES FOR SEA AREA: 17.0N 19.0N 06[illegible].0W 06[illegible].0W PERIOD OF DAT

MONTHS: JANUARY TO DECEMBER

WAVE DIRECTION (DEGREES TRUE) FOR HIGHER OF SEA/SWELL HEIGHT : 195 TO 225

WAVE PERIOD (SECONDS) FOR HIGHER OF SEA/SWELL HEIGHT — LOWER LIMIT	0	6	8	10	12	14	16	18	20	22	
UPPER LIMIT	5	7	9	11	13	15	17	19	21		TOTAL
RESULTANT WAVE HEIGHT (METRES)											
0.0 TO 0.5	0.0	..	..	..	..	..	..	..	..	..	0.0
0.6 TO 1.0	0.0	0.0	0.0	0.0	..	..	..	..	..	..	0.1
1.1 TO 1.5	0.1	..	0.0	..	..	..	..	..	..	..	0.1
1.6 TO 2.0	0.0	0.1	..	..	..	..	..	..	..	..	0.1
2.1 TO 2.5	..	..	..	..	..	..	..	..	..	..	..
2.6 TO 3.0	0.0	0.0	..	..	..	..	..	..	..	..	0.0
3.1 TO 4.0	0.0	..	..	..	..	..	..	..	..	..	0.0
4.1 TO 5.0	..	..	..	..	..	..	..	..	..	..	..
5.1 TO 6.0	..	..	..	..	..	..	..	..	..	..	..
6.1 TO 7.0	..	..	..	..	..	..	..	..	..	..	..
7.1 TO 8.0	..	..	..	..	..	..	..	..	..	..	..
8.1 TO 9.0	..	..	..	..	..	..	..	..	..	..	..
9.1 TO 10.0	..	..	..	..	..	..	..	..	..	..	..
10.1 TO 12.0	..	..	..	..	..	..	..	..	..	..	..
12.1 TO 14.0	..	..	..	..	..	..	..	..	..	..	..
14.1 TO 16.0	..	..	..	..	..	..	..	..	..	..	..
16.1 TO 18.0	..	..	..	..	..	..	..	..	..	..	..
18.1 TO 20.0	..	..	..	..	..	..	..	..	..	..	..
20.1 OR MORE	..	..	..	..	..	..	..	..	..	..	..
TOTAL	0.3	0.1	0.0	0.0	..	..	..	..	..	..	0.4

NOTE:- .. INDICATES ZERO FREQUENCY WHILST 0.0 INDICATES LESS THAN 0.05 PER CENT
TABLE TOTAL NUMBER OF OBSERVATIONS IS 35

PERCENTAGE FREQUENCIES FOR SEA AREA: 17.0N 19.0N 062.0W 05[illegible]

MONTHS: JANUARY TO DECEMBER

WAVE DIRECTION (DEGREES TRUE) FOR HIGHER OF SEA/SWELL HEIGHT : 226 TO 255

WAVE PERIOD (SECONDS) FOR HIGHER OF SEA/SWELL HEIGHT — LOWER LIMIT / UPPER LIMIT	0 / 5	6 / 7	8 / 9	10 / 11	12 / 13	14 / 15	16 / 17	18 / 19	20 / 21	22	TOTAL
RESULTANT WAVE HEIGHT (METRES)											
0.0 TO 0.5	0.0	0.0	..	..	..	..	..	..	..	..	0.0
.6 TO 1.0	0.0	0.0	..	..	..	..	..	..	..	..	0.0
1.1 TO 1.5	0.0	0.0	..	..	..	..	..	..	..	..	0.0
1.6 TO 2.0	0.0	..	..	..	..	..	..	..	..	..	0.0
2.1 TO 2.5	0.0	..	..	..	..	..	..	..	..	..	0.0
2.6 TO 3.0	..	..	..	..	..	..	..	..	..	..	..
3.1 TO 4.0	0.0	..	..	0.0	..	..	..	..	..	..	0.0
4.1 TO 5.0	..	..	..	..	..	..	..	..	..	..	..
5.1 TO 6.0	..	..	..	..	..	..	..	..	..	..	..
6.1 TO 7.0	..	..	..	..	..	..	..	..	..	..	..
7.1 TO 8.0	..	..	..	..	..	..	..	..	..	..	..
8.1 TO 9.0	..	..	..	..	..	..	..	..	..	..	..
9.1 TO 10.0	..	..	..	..	..	..	..	..	..	..	..
10.1 TO 12.0	..	..	..	..	..	..	..	..	..	..	..
12.1 TO 14.0	..	..	..	..	..	..	..	..	..	..	..
14.1 TO 16.0	..	..	..	..	..	..	..	..	..	..	..
16.1 TO 18.0	..	..	..	..	..	..	..	..	..	..	..
18.1 TO 20.0	..	..	..	..	..	..	..	..	..	..	..
20.1 OR MORE	..	..	..	..	..	..	..	..	..	..	..
TOTAL	0.1	0.0	..	0.0	..	..	..	..	..	..	0.2

NOTE:- .. INDICATES ZERO FREQUENCY WHILST 0.0 INDICATES LESS THAN 0.05 PER CENT
TABLE TOTAL NUMBER OF OBSERVATIONS IS 15

DATE OF PRINTOUT: 3/ 9/199[illegible] ** CROWN COPYRIGHT. DO NOT REPRODUCE WITHOUT METEOROLOGICAL OFFICE PERMISS

PERCENTAGE FREQUENCIES FOR SEA AREA: 17.0N 19.0N 062.0W 064.[illegible] PERIOD OF D

MONTHS: JANUARY TO DECEMBER

WAVE DIRECTION (DEGREES TRUE) FOR HIGHER OF SEA/SWELL HEIGHT : TOTAL

	WAVE PERIOD (SECONDS) FOR HIGHER OF SEA/SWELL HEIGHT										
LOWER LIMIT	0	6	8	10	12	14	16	18	20	22	
UPPER LIMIT	5	7	9	11	13	15	17	19	21		TOTAL
RESULTANT WAVE HEIGHT (METRES)											
0.0 TO 0.5	10.[illegible]	0.7	0.3	0.2	0.1	0.0	..	..	0.0	..	11.4
0.6 TO 1.0	[illegible]	4.0	0.6	0.2	0.1	0.0	0.0	0.0	..	..	21.3
1.1 TO 1.5	15.2	7.9	2.2	0.5	0.3	0.2	0.0	..	0.0	..	26.5
1.6 TO 2.0	6.7	5.6	2.2	0.7	0.2	0.2	..	..	..	..	15.6
2.1 TO 2.5	4.3	4.6	2.5	0.5	0.2	0.2	0.0	..	..	..	12.3
2.6 TO 3.0	1.2	2.4	1.2	0.4	0.2	0.0	0.0	0.0	..	..	5.4
3.1 TO 4.0	1.[illegible]	2.1	1.3	0.3	0.2	0.0	..	..	0.0	..	5.2
4.1 TO 5.0	0.2	0.3	0.[illegible]	0.2	0.1	0.0	..	..	..	..	1.4
5.1 TO 6.0	0.1	0.1	0.1	0.0	0.0	..	..	..	..	..	0.4
6.1 TO 7.0	..	0.0	0.0	0.0	..	..	..	..	..	..	0.0
7.1 TO 8.0	0.0	..	..	..	..	..	..	..	..	..	0.0
8.1 TO 9.0	..	..	..	..	0.0	..	..	..	..	..	0.0
9.1 TO 10.0	..	..	..	..	..	..	..	..	..	..	..
10.1 TO 12.0	..	..	..	..	..	..	..	..	..	..	..
12.1 TO 14.0	..	..	..	..	..	..	..	..	..	..	..
14.1 TO 16.0	..	..	..	..	..	..	..	..	..	..	..
16.1 TO 18.0	..	..	..	..	..	..	..	..	..	..	..
18.1 TO 20.0	..	..	..	..	..	..	..	..	..	..	..
20.1 [illegible]	..	..	..	..	..	..	..	..	..	..	..
TOTAL	56.1	27.8	10.[illegible]	3.2	1.3	0.7	0.0	0.0	0.1	..	100.[illegible]

NOTE:- .. INDICATES ZERO FREQUENCY WHILST 0.0 INDICATES LESS THAN 0.05 PER CENT
[illegible] TOTAL NUMBER OF OBSERVATIONS IS 9324

Appendix B:

Calculations.

Snell's Law

B.0 NEAR-SHORE EFFECTS.

The area in which the waves propagate is subject to refraction and shoaling. They have an effect on wave height and incident wave angle.
In the deep ocean the depth changing (even by a few hundreds of meters), doesn't influence the short surface waves. It is not for the near-coastal zone, where the shallower water depth begins to effect the propagation speed. Since the phase velocity decreases with the decreasing of the local water depth, the parts of the wave crest lying over deeper water travel faster than the parts of the same wave crest lying over shallower water. In the course of it's propagation, such a wave front therefore turns gradually toward the shallows. This is a common observation on beaches that the crests end up almost parallel to the shoreline even when they were approaching the coast at an oblique angle from the sea [ref.: 6].

B.1 MATHEMATICAL DESCRIPTION.

B.1.1 Wave rays.

Consider the (x,y)-plane filled with k-vectors varying in magnitude and direction from point to point. Wave rays are always orthogonal to the wave crest or constant phase lines. The wave frequency is given by:

$$\omega = -\frac{\delta\chi}{\delta t} \tag{B1}$$

where chi is the wave phase as function of x,t,k and omega. In each point of the wave field the frequency omega and the wave number k ($=2\pi/L$), are related by the dispersion relation:

$$\omega^2 = gk \cdot \tanh(kh) \tag{B2}$$

which depends only on the local wave number, but also on the local properties as the water depth, current velocity or the ambient density gradient:

$$\omega=\Omega\,[k,f(x,t,h,\rho,\ldots)] \tag{B3}$$

Assumed that function Ω is not depending on time, and taking the square of (1) we get a non-linear differential equation for chi (wave phase):

$$\left(\frac{\delta\chi}{\delta x}\right)^2+\left(\frac{\delta\chi}{\delta y}\right)^2=k^2 \tag{B4}$$

If the angle of incidence Θ is defined as the angle made between depth contour-normals (the x-direction) and the wave direction, then:

$$k=k_{xi}+k_{yj}=k\cos\theta_i+k\sin\theta_j \tag{B5}$$

The local wave number vector (k) is irrotational, resulting in:

$$\frac{\delta k_i}{\delta\chi_j}-\frac{\delta k_j}{\delta\chi_i}=0 \tag{B6}$$

Substitution of $k = k_{xi}$+..etc. in (B6) results in:

$$\frac{\delta(k\cdot\sin\theta)}{\delta x}-\frac{\delta(k\cdot\cos\theta)}{\delta y}=0 \tag{B7}$$

For a shoreline where the alongshore variation in y-direction of all variables are zero, equation B7 reduces to:

$$\frac{\delta(k\cdot\sin\theta)}{\delta x}=0 \Rightarrow k\cdot\sin\theta=const. \tag{B8}$$

and thus $\sin(\Theta)/c$ = const.
The constant value is given through the boundary condition at the given initial point, i.e.:

$$\frac{\sin\theta_0}{c_0}=\frac{\sin\theta_1}{c_1} \tag{B9}$$

Equation (B9) is known as Snell's law for refraction. According to this law the angle of the wave ray of the incident wave with the normal of the depth contour decreases as the waves travel towards the shore, with the result that the wave rays are perpendicular at the shoreline.

In general cases when the bottom contours are irregular and varying along a coast there is a variation in the y-direction and (B7) must be used as:

$$k\cdot\cos\theta\frac{\delta\theta}{\delta x}+k\cdot\sin\theta\frac{\delta\theta}{\delta y}=\cos\theta\frac{\delta k}{\delta y}-\sin\theta\frac{\delta k}{\delta x} \quad \textbf{(B10)}$$

B.1.2 Shoaling.

Wave action in a wave train is transported in the direction of wave propagation with a group velocity c_g:

$$c_g=\frac{\delta\omega}{\delta k} \quad \textbf{(B11)}$$

where $c_g=nc$, with:

$$n=\frac{1}{2}+\frac{kh}{\sinh(2kh)} \quad \textbf{(B12)}$$

In general:

$$c_1=c_0\tanh(kh) \quad \textbf{(B13)}$$

In deep water tanh(kh)=1 thus: $c = c_0$.
When waves travel towards shallow water their velocity decreases. The total energy is assumed to remain constant (no dissipation due to bottom friction as yet).

$$P=E_0\cdot n_0\cdot c_0=E_1\cdot n_1\cdot c_1 \quad \textbf{(B14)}$$

If c_1 decreases and P remains constant, E must increase.

$$E=\frac{1}{8}\cdot\rho\cdot g\cdot H^2 \quad \textbf{(B15)}$$

This means that while the group velocity of the waves decreases, the wave height increases as:

$$\frac{H_1}{H_0}=\sqrt{\frac{c_{g_1}}{c_{g_0}}} \quad \textbf{(B16)}$$

Using the assumption P = constant:

$$E \cdot c_g \cos\theta = const. \qquad \textbf{(B17)}$$

Which yields:

$$\frac{H_1}{H_0} = \sqrt{\frac{c_{g_0}}{c_{g_1}}} \cdot \sqrt{\frac{\cos\theta_0}{\cos\theta_1}} \qquad \textbf{(B18)}$$

The equation gives the variation of the wave height while the wave travels towards a shore due to shoaling and refraction. The first factor on the right side of the equation is the shoaling factor (Ks), the second factor is the refraction factor (Kr).

B.2 WAVE HEIGHTS AT THE 12 METER DEPTH CONTOUR.

To get an impression of the behaviour of the incident wave crests as the wave field travels toward Great Bay the above is applied. A spreadsheet program was made and tables for short waves on mildly sloping bottoms were used [ref.: 7]. Assumptions made here are that the depth decreases gradually and that no unevenness occurs. The depth contours are schematised as parallel straight lines.

The calculation was carried out for waves coming in from various directions between 90 degrees to 270 degrees. The normal on the depth contours make an angle of about 60 degrees with the South.

The theory is only valid outside of the breaking zone. Two limitations were checked for when breaking would occur. One was that H_{max}/h should be smaller than 0,6 (for bottom slopes of approximately 1%). The other was that H_{max} = 0,14*tanh(kh)^2*L_0 (Miche). The numerical output, enclosed at the end of this appendix, shows the maximum wave height before breaking per wave period ("Maximum wave height according to Miche").
The tables presented by the BMO were used as starting point for the calculations.

B.2.1 Shoaling parameters:

With the aid of tables presented in the Shore Protection Manual Volume 2, [ref.: 7]. values of the following parameters, as function of the h/l_0 ratio, are determined:

K_s = Shoaling parameter.
tanh(kh), where k is the wave number ($2\pi/L$).

For equation (17), a spreadsheet program is generated, using the parameters from the Shore Protection Manual, valid for the 12 meter depth contour.
Waves with an incident angle larger than 90 degrees with the normal on the depth contour can not be calculated with this program (This would give a negative square root). They are however the important dominant wave direction.
In this case the refraction parameter K_r is set to 1 (one). The reduction of wave height in this case, will only result from shoaling and friction (rough estimate, see section 7).

In the calculation also a constant friction parameter was introduced with a maximum value of 90% (reduction 10%, as shown in tables), for the longest waves. For the smaller waves, the reduction due to friction, is set to zero percent, as the depth (12 meter) over wave length ratio is larger than 1/4. With a wave period of 6 to 7 sec., bottom friction starts to influence the waves. A friction parameter of 95% (reduction 5%) is used. The friction parameters are also rough estimates. These values are estimated on basis of a report carried out by the CEA [ref.: 1], which showed reductions in the range mentioned above.

The calculations are inclosed in this appendix.

What can be concluded from these calculations, is that the mean off-shore significant wave height of 2.0 meter, results in a 1.5 meter wave height at the 12 meter depth contour, with only a slight curving toward the North for all wave directions.

B.3 TRANSITION OF WAVES FROM DEEP WATER TO THE SHORE-LINE.

An additional computation is carried out to give an illustration of the behaviour of the wave field as it travels from deep water to the shore-line.

The depth contours in the bay, are also schematised as parallel, making an angle of 60 degrees with the South-North-axis.

Parameters used were:

Deep water wave height (H0)	: 2 meters.
Direction deep water	:180 degrees
Wave period (T0)	: 8 seconds.
Wave length (L0)	:100 meters.

The results are shown in the following graphs:

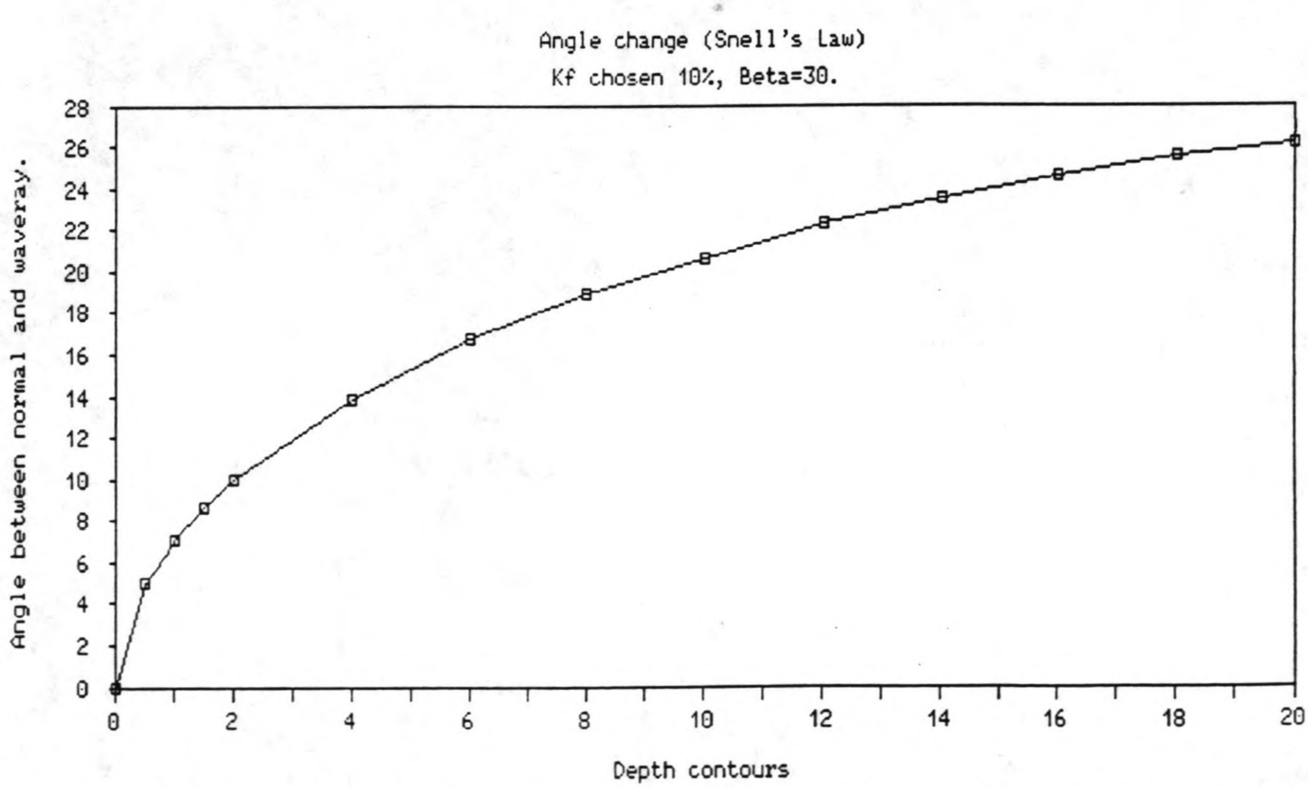


Figure B1: Angle change between the normal of the depth contour and wave ray.

Figure 1 shows the curving of the wave rays as they travel over a bottom with decreasing depth, ending perpendicular to the shoreline (0°).

Figure 2 shows the change in wave height as the wave progresses toward the shore-line. Due to shoaling the wave height increases. When the wave reaches it's maximum steepness, breaking occurs. The breaker depth can be read from the graph, 2.4 meter. From here on Snell's law is no longer valid. In fact the peak in the left hand side of the figure does not occur.

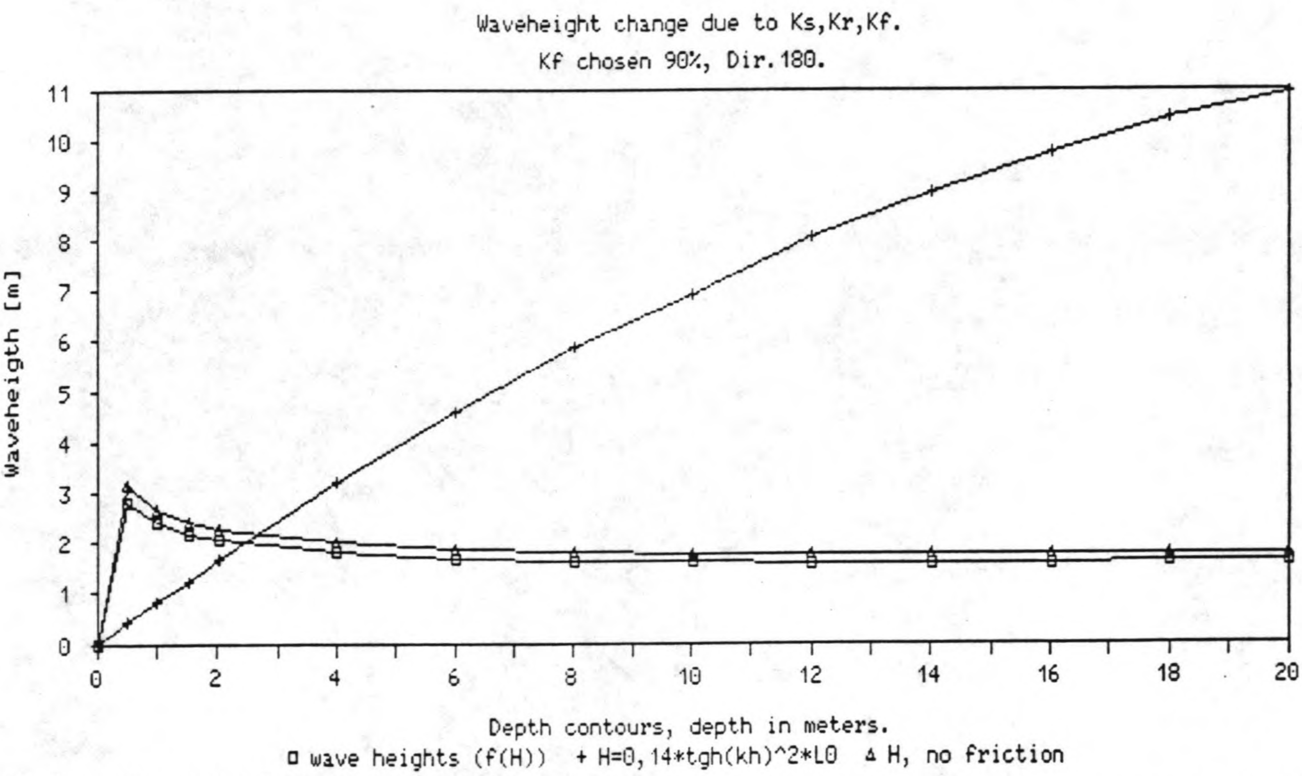


Figure B2: Wave height change with Snell's Law, and approximation breaker depth.

In this example T = 8 sec. is used.
The actual breaker line commonly observed is situated much closer to the shore-line. This is because the prevailing wave period is 5 sec, giving a lower breaker depth.

These computations were carried out as an indication of the wave behaviour in Great Bay. The proposed site for the new port of Phillipsburg is not influenced by the wave activities at the shore line during normal weather conditions.

The wave height value at the 12 meter depth contour can also be found in the computations made in the Appendix B, direction 180 degrees, column T = 8/9 sec.. This deep water wave height results in a wave height at the 12 meter depth contour of 1.6 meter.

TRANSFORMATION DEEPWATER WAVE CONDITONS TO
12 METER DEPTH CONTOUR.

approximated angle depth contour with S-N axis: 60 degrees
approach angle on 360° compass: 90.0000 degrees
Betha0 =120.0000 degrees = 2.0944 rad.

ship's observ.
deep water SIGNIFICANT WAVE HEIGHT AT 12 METER.
wave height

0.5000	0.4745	0.4372	0.4166	0.4331	0.4545	0.4788
1.4000	1.3286	1.2243	1.1664	1.2126	1.2726	1.3406
2.0000	1.8980	1.7489	1.6663	1.7323	1.8180	1.9152
2.6000	2.4674	2.2736	2.1661	2.2520	2.3634	2.4898
3.1300	2.9704	2.7371	2.6077	2.7111	2.8452	2.9973
3.6300	3.4449	3.1743	3.0243	3.1442	3.2997	3.4761
4.3400	4.1187	3.7952	3.6158	3.7591	3.9451	4.1560
5.2400	4.9728	4.5822	4.3656	4.5387	4.7632	5.0178
6.1000	5.7889	5.3343	5.0821	5.2836	5.5449	
6.9000	6.5481	6.0339	5.7486	5.9765		
7.6500						
9.5000						
9.1500	friction parameter estimated per wave length					
9.8500	0.0000	0.0500	0.1000	0.1000	0.1000	0.1000
10.5000						
	5.0580	5.3668	7.5769	8.7596	9.2722	9.8992
	Maximum wave height according to Miche					
	T<5(T=5)	T=6/7	T=8/9	T=10/11	T=12/13	T=14/15

Friction parameter used: 0,9
Used parameters per wave length:

T0=5 :L0= 39.1123	,h/L0	= 0.3068	,tanhkh	=	0.9611
	,Ks	= 0.9490	,Betha1	=	0.9833
	,Kr	= 1.0000			
T0=6 :L0= 56.3218	,h/L0	= 0.2131	,tanhkh	=	0.8250
	,Ks	= 0.9205	,Betha1	=	0.7959
	,Kr	= 1.0000			
T0=8 :L0=100.1276	,h/L0	= 0.1198	,tanhkh	=	0.7352
	,Ks	= 0.9257	,Betha1	=	0.6902
	,Kr	= 1.0000			
T0=10:L0=156.4493	,h/L0	= 0.0767	,tanhkh	=	0.6324
	,Ks	= 0.9624	,Betha1	=	0.5796
	,Kr	= 1.0000			
T0=12:L0=225.2870	,h/L0	= 0.0533	,tanhkh	=	0.5422
	,Ks	= 1.0100	,Betha1	=	0.4888
	,Kr	= 1.0000			
T0=14:L0=306.6406	,h/L0	= 0.0391	,tanhkh	=	0.4802
	,Ks	= 1.0640	,Betha1	=	0.4289
	,Kr	= 1.0000			

TRANSFORMATION DEEPWATER WAVE CONDITONS TO
12 METER DEPTH CONTOUR.

approximated angle depth contour with S-N axis: 60 degrees
approach angle on 360° compass: 135.0000 degrees
Betha0 = 75.0000 degrees = 1.3090 rad.

ship's observ.
deep water SIGNIFICANT WAVE HEIGHT AT 12 METER.
wave height

0.5000	0.3959	0.2862	0.2526	0.2476	0.2505	0.2588
1.4000	1.1086	0.8013	0.7072	0.6933	0.7015	0.7246
2.0000	1.5838	1.1448	1.0103	0.9905	1.0021	1.0352
2.6000	2.0589	1.4882	1.3134	1.2876	1.3027	1.3457
3.1300	2.4786	1.7915	1.5811	1.5501	1.5682	1.6201
3.6300	2.8746	2.0777	1.8336	1.7977	1.8188	1.8788
4.3400	3.4368	2.4841	2.1923	2.1493	2.1745	2.2463
5.2400	4.1495	2.9993	2.6469	2.5950	2.6254	2.7122
6.1000	4.8305	3.4915	3.0813	3.0209	3.0563	
6.9000	5.4641	3.9494	3.4854	3.4171		
7.6500						
9.5000						
9.1500	friction parameter estimated per wave length					
9.8500	0.0000	0.0500	0.1000	0.1000	0.1000	0.1000
10.5000						
	5.0580	5.3668	7.5769	8.7596	9.2722	9.8992
	Maximum wave height according to Miche					
	T<5(T=5)	T=6/7	T=8/9	T=10/11	T=12/13	T=14/15

Friction parameter used: 0,9
Used parameters per wave length:

T0=5 :L0= 39.1123	,h/L0	= 0.3068	,tanhkh =	0.9611
	,Ks	= 0.9490	,Betha1 =	1.1900
	,Kr	= 0.8344		
T0=6 :L0= 56.3218	,h/L0	= 0.2131	,tanhkh =	0.8250
	,Ks	= 0.9205	,Betha1 =	0.9221
	,Kr	= 0.6545		
T0=8 :L0=100.1276	,h/L0	= 0.1198	,tanhkh =	0.7352
	,Ks	= 0.9257	,Betha1 =	0.7897
	,Kr	= 0.6063		
T0=10:L0=156.4493	,h/L0	= 0.0767	,tanhkh =	0.6324
	,Ks	= 0.9624	,Betha1 =	0.6571
	,Kr	= 0.5717		
T0=12:L0=225.2870	,h/L0	= 0.0533	,tanhkh =	0.5422
	,Ks	= 1.0100	,Betha1 =	0.5512
	,Kr	= 0.5512		
T0=14:L0=306.6406	,h/L0	= 0.0391	,tanhkh =	0.4802
	,Ks	= 1.0640	,Betha1 =	0.4823
	,Kr	= 0.5405		

TRANSFORMATION DEEPWATER WAVE CONDITONS TO
12 METER DEPTH CONTOUR.

approximated angle depth contour with S-N axis: 60 degrees
approach angle on 360° compass: 180.0000 degrees
Betha0 = 30.0000 degrees = 0.5236 rad.

ship's observ.
deep water SIGNIFICANT WAVE HEIGHT AT 12 METER.
wave height

0.5000	0.4715	0.4263	0.4020	0.4138	0.4311	0.4522
1.4000	1.3203	1.1937	1.1256	1.1586	1.2071	1.2663
2.0000	1.8861	1.7053	1.6079	1.6551	1.7244	1.8089
2.6000	2.4520	2.2169	2.0903	2.1517	2.2418	2.3516
3.1300	2.9518	2.6688	2.5164	2.5903	2.6987	2.8310
3.6300	3.4233	3.0951	2.9184	3.0041	3.1299	3.2832
4.3400	4.0929	3.7004	3.4892	3.5916	3.7420	3.9254
5.2400	4.9416	4.4678	4.2128	4.3364	4.5180	4.7394
6.1000	5.7527	5.2011	4.9042	5.0481	5.2595	
6.9000	6.5071	5.8832	5.5474	5.7102		
7.6500						
9.5000						
9.1500	friction parameter estimated per wave length					
9.8500	0.0000	0.0500	0.1000	0.1000	0.1000	0.1000
10.5000						
	5.0580	5.3668	7.5769	8.7596	9.2722	9.8992
	Maximum wave height according to Miche					
	T<5(T=5)	T=6/7	T=8/9	T=10/11	T=12/13	T=14/15

Friction parameter used: 0,9
Used parameters per wave length:

T0=5 :L0= 39.1123	,h/L0	= 0.3068	,tanhkh =	0.9611
	,Ks	= 0.9490	,Betha1 =	0.5013
	,Kr	= 0.9937		
T0=6 :L0= 56.3218	,h/L0	= 0.2131	,tanhkh =	0.8250
	,Ks	= 0.9205	,Betha1 =	0.4252
	,Kr	= 0.9750		
T0=8 :L0=100.1276	,h/L0	= 0.1198	,tanhkh =	0.7352
	,Ks	= 0.9257	,Betha1 =	0.3764
	,Kr	= 0.9650		
T0=10:L0=156.4493	,h/L0	= 0.0767	,tanhkh =	0.6324
	,Ks	= 0.9624	,Betha1 =	0.3217
	,Kr	= 0.9554		
T0=12:L0=225.2870	,h/L0	= 0.0533	,tanhkh =	0.5422
	,Ks	= 1.0100	,Betha1 =	0.2745
	,Kr	= 0.9485		
T0=14:L0=306.6406	,h/L0	= 0.0391	,tanhkh =	0.4802
	,Ks	= 1.0640	,Betha1 =	0.2425
	,Kr	= 0.9445		

TRANSFORMATION DEEPWATER WAVE CONDITONS TO
12 METER DEPTH CONTOUR.

approximated angle depth contour with S-N axis: 60 degrees
approach angle on 360° compass: 225.0000 degrees
Betha0 =-15.0000 degrees = -0.2618 rad.

ship's observ.
deep water   SIGNIFICANT WAVE HEIGHT AT 12 METER.
wave height

0.5000	0.4739	0.4348	0.4132	0.4285	0.4489	0.4724
1.4000	1.3268	1.2173	1.1570	1.1999	1.2570	1.3227
2.0000	1.8954	1.7391	1.6528	1.7141	1.7957	1.8896
2.6000	2.4640	2.2608	2.1486	2.2284	2.3344	2.4565
3.1300	2.9663	2.7216	2.5866	2.6826	2.8102	2.9573
3.6300	3.4402	3.1564	2.9998	3.1112	3.2591	3.4297
4.3400	4.1130	3.7738	3.5866	3.7197	3.8966	4.1005
5.2400	4.9660	4.5564	4.3303	4.4911	4.7046	4.9508
6.1000	5.7810	5.3041	5.0410	5.2282	5.4768	
6.9000	6.5392	5.9998	5.7021	5.9138	6.1950	
7.6500					6.8684	
9.5000					8.5294	
9.1500	friction parameter estimated per wave length					
9.8500	0.0000	0.0500	0.1000	0.1000	0.1000	0.1000
10.5000						
	5.0580	5.3668	7.5769	8.7596	9.2722	9.9992
	Maximum wave height according to Miche					
	T<5(T=5)	T=6/7	T=8/9	T=10/11	T=12/13	T=14/15

Friction parameter used: 0,9
Used parameters per wave length:

```
TO=5 :LO= 39.1123 ,h/LO   =  0.3068 ,tanhkh =  0.9611
                  ,Ks     =  0.9490 ,Betha1 = -0.2514
                  ,Kr     =  0.9986
TO=6 :LO= 56.3218 ,h/LO   =  0.2131 ,tanhkh =  0.8250
                  ,Ks     =  0.9205 ,Betha1 = -0.2152
                  ,Kr     =  0.9943
TO=8 :LO=100.1276 ,h/LO   =  0.1198 ,tanhkh =  0.7352
                  ,Ks     =  0.9257 ,Betha1 = -0.1915
                  ,Kr     =  0.9919
TO=10:LO=156.4493 ,h/LO   =  0.0767 ,tanhkh =  0.6324
                  ,Ks     =  0.9624 ,Betha1 = -0.1644
                  ,Kr     =  0.9895
TO=12:LO=225.2870 ,h/LO   =  0.0533 ,tanhkh =  0.5422
                  ,Ks     =  1.0100 ,Betha1 = -0.1408
                  ,Kr     =  0.9877
TO=14:LO=306.6406 ,h/LO   =  0.0391 ,tanhkh =  0.4802
                  ,Ks     =  1.0640 ,Betha1 = -0.1246
                  ,Kr     =  0.9866
```

TRANSFORMATION DEEPWATER WAVE CONDITONS TO
12 METER DEPTH CONTOUR.

approximated angle depth contour with S-N axis: 60 degrees
approach angle on 360° compass: 270.0000 degrees
Betha0 =-60.0000 degrees = -1.0472 rad.

ship's observ. deep water wave height	SIGNIFICANT WAVE HEIGHT AT 12 METER.					
0.5000	0.4507	0.3696	0.3354	0.3348	0.3420	0.3550
1.4000	1.2619	1.0349	0.9392	0.9374	0.9577	0.9941
2.0000	1.8027	1.4785	1.3417	1.3392	1.3681	1.4201
2.6000	2.3435	1.9220	1.7443	1.7409	1.7786	1.8461
3.1300	2.8212	2.3138	2.0998	2.0958	2.1411	2.2224
3.6300	3.2719	2.6835	2.4353	2.4306	2.4831	2.5775
4.3400	3.9118	3.2083	2.9116	2.9060	2.9688	3.0816
5.2400	4.7230	3.8736	3.5154	3.5086	3.5845	3.7206
6.1000	5.4982	4.5094	4.0923	4.0844	4.1728	
6.9000	6.2193	5.1008	4.6290	4.6201		
7.6500						
9.5000						
9.1500	friction parameter estimated per wave length					
9.8500	0.0000	0.0500	0.1000	0.1000	0.1000	0.1000
10.5000						
	5.0580	5.3668	7.5769	8.7596	9.2722	9.8992
	Maximum wave height according to Miche					
	T<5(T=5)	T=6/7	T=8/9	T=10/11	T=12/13	T=14/15

Friction parameter used: 0,9
Used parameters per wave length:

```
T0=5 :L0= 39.1123 ,h/L0 = 0.3068 ,tanhkh =  0.9611
                  ,Ks   = 0.9490 ,Betha1 = -0.9833
                  ,Kr   = 0.9498
T0=6 :L0= 56.3218 ,h/L0 = 0.2131 ,tanhkh =  0.8250
                  ,Ks   = 0.9205 ,Betha1 = -0.7959
                  ,Kr   = 0.8454
T0=8 :L0=100.1276 ,h/L0 = 0.1198 ,tanhkh =  0.7352
                  ,Ks   = 0.9257 ,Betha1 = -0.6902
                  ,Kr   = 0.8052
T0=10:L0=156.4493 ,h/L0 = 0.0767 ,tanhkh =  0.6324
                  ,Ks   = 0.9624 ,Betha1 = -0.5796
                  ,Kr   = 0.7730
T0=12:L0=225.2870 ,h/L0 = 0.0533 ,tanhkh =  0.5422
                  ,Ks   = 1.0100 ,Betha1 = -0.4888
                  ,Kr   = 0.7525
T0=14:L0=306.6406 ,h/L0 = 0.0391 ,tanhkh =  0.4802
                  ,Ks   = 1.0640 ,Betha1 = -0.4289
                  ,Kr   = 0.7415
```

Appendix C.

Results HISWA Computations

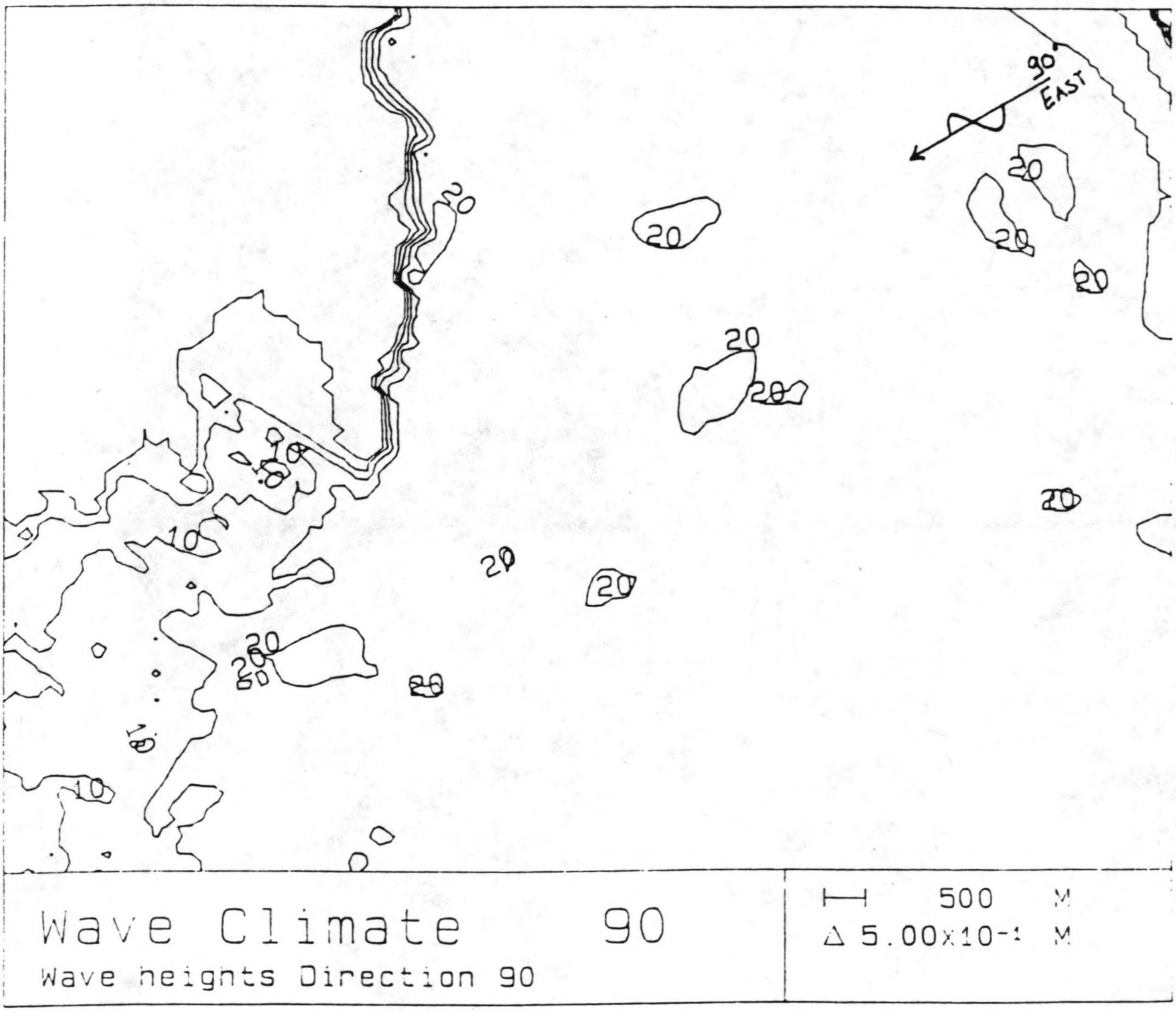


Figure C1: HISWA results significant wave heights for waves coming in from the East (90°). H0 = 2,0 m., T0 = 8 sec.

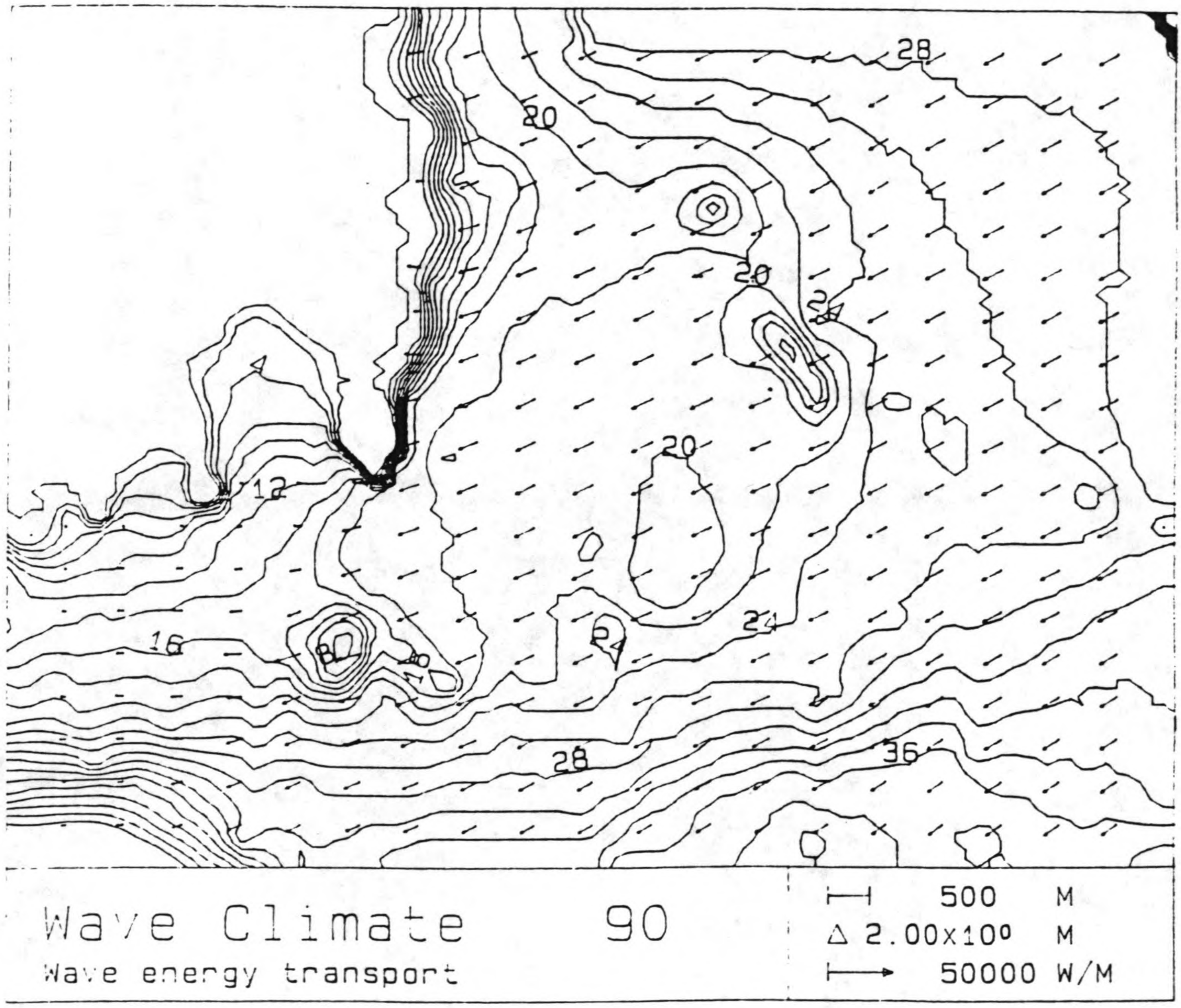


Figure C2: HISWA results for waves coming in from the East (90°). H0 = 2,0 m., T0 = 8 sec. Arrows indicate the decrease of wave energy and direction of propagation.

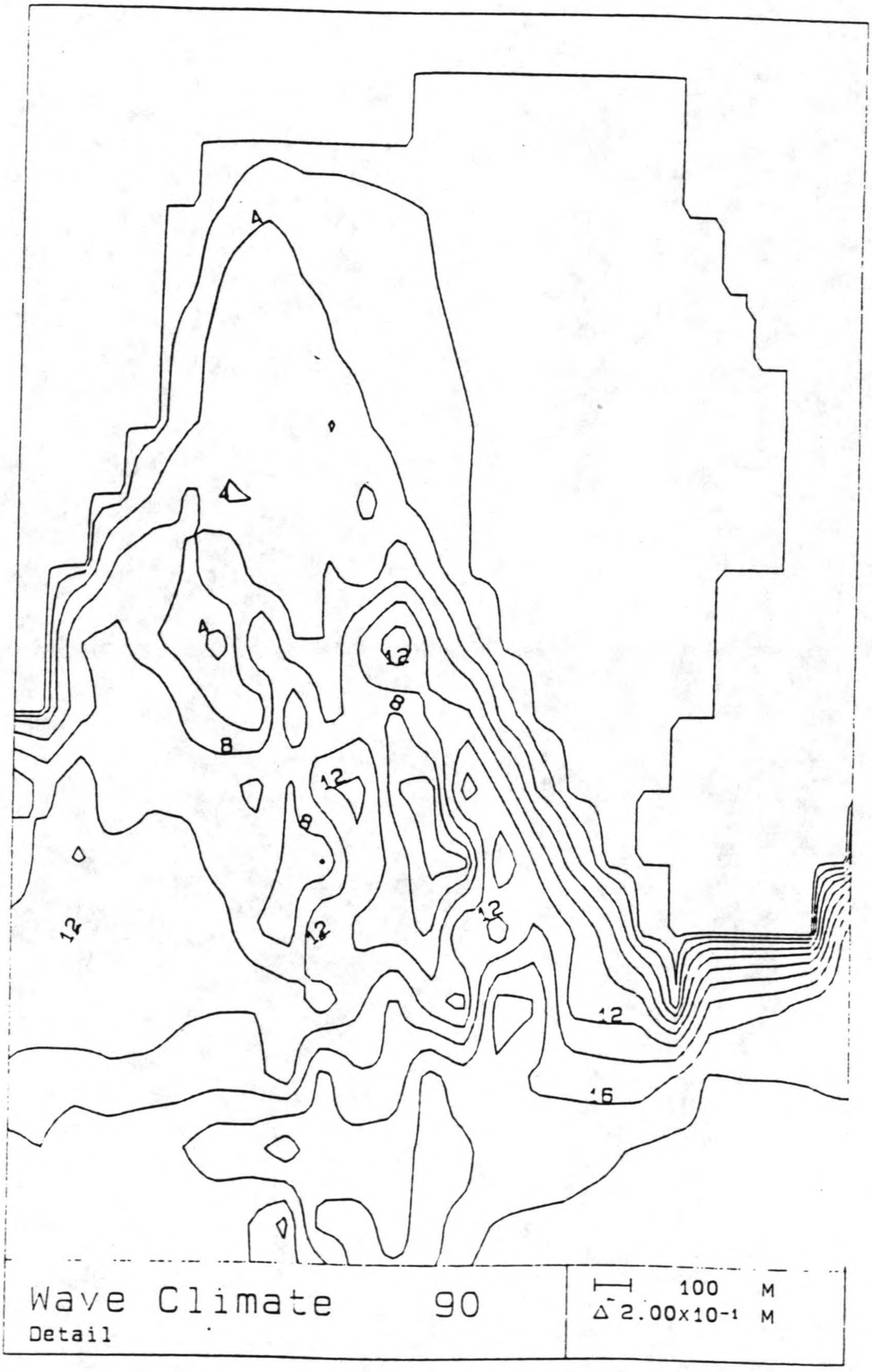


Figure C3: HISWA results significant wave heights for waves coming in from the East (90°). H0 = 2,0 m., T0 = 8 sec. Plot shows schematised Great Bay.

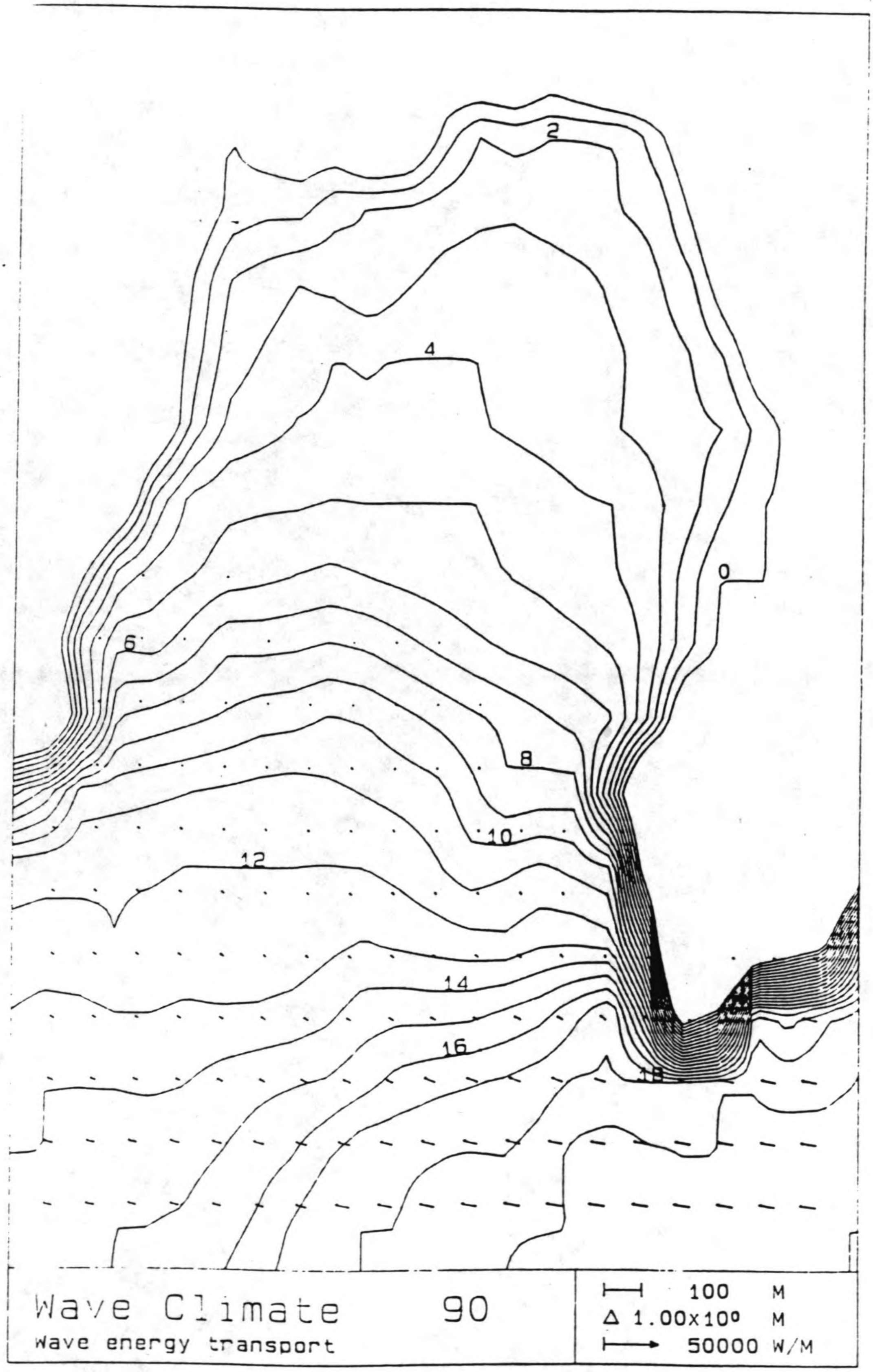


Figure C4: HISWA results for waves coming in from the East (90°). H0 = 2,0 m., T0 = 8 sec. Arrows indicate the decrease of wave energy and direction of propagation. Detail of Great Bay.

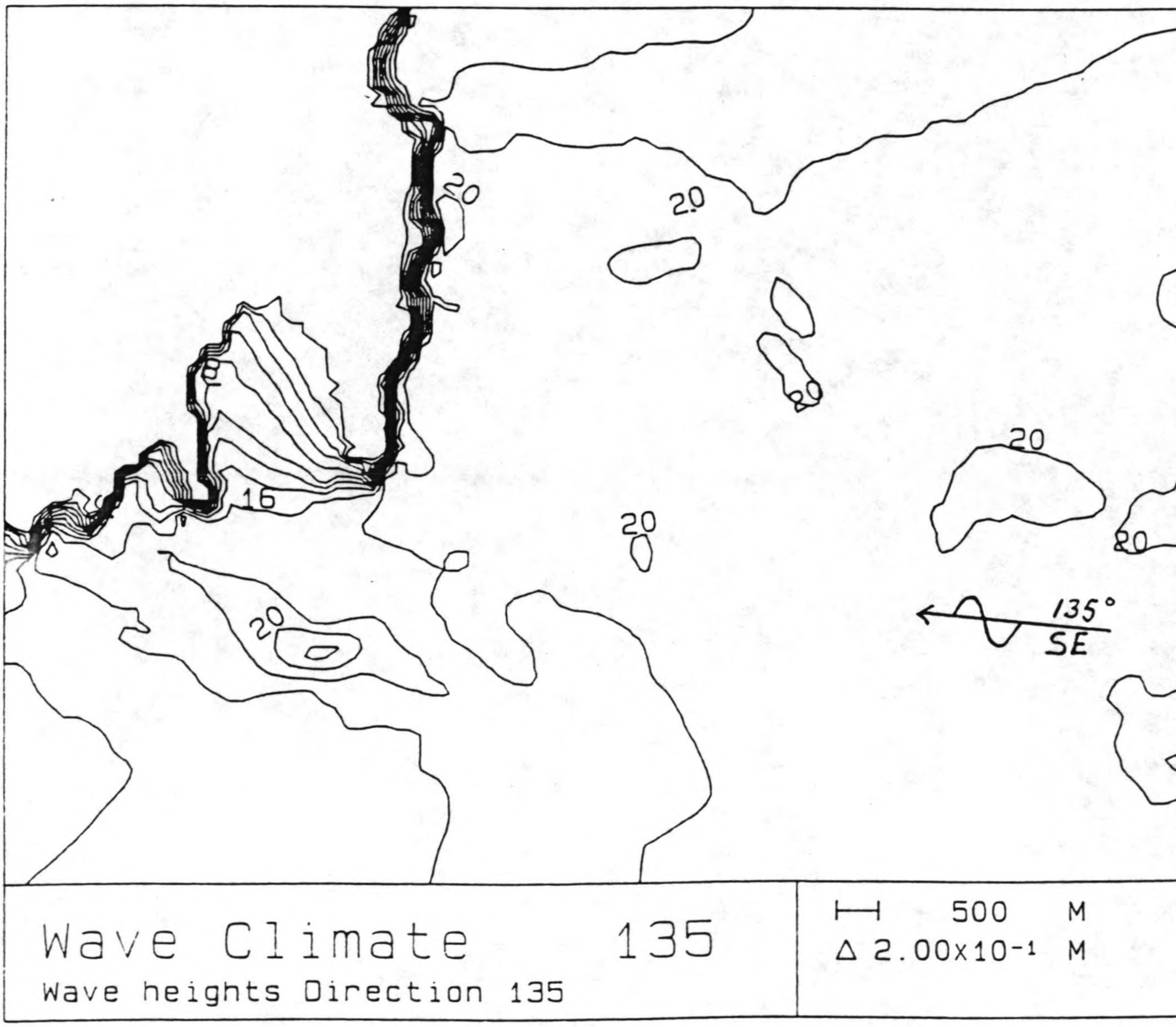


Figure C5: HISWA results significant wave heights for waves coming in from the Sotheast (135°). H0 = 2,0 m., T0 = 8 sec.

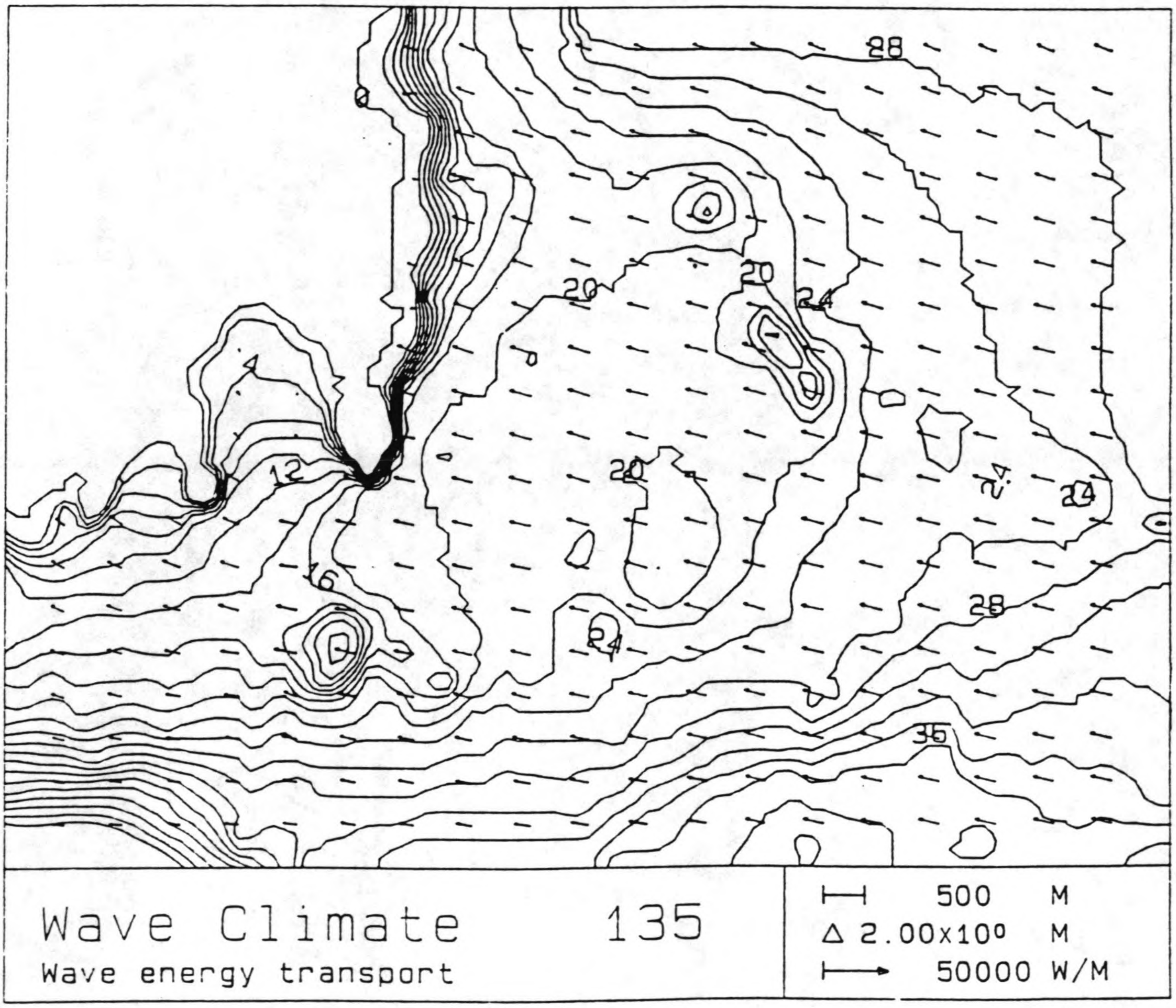


Figure C6: HISWA results for waves coming in from the Southeast (135°). H0 = 2,0 m., T0 = 8 sec. Arrows indicate the decrease of wave energy and direction of propagation.

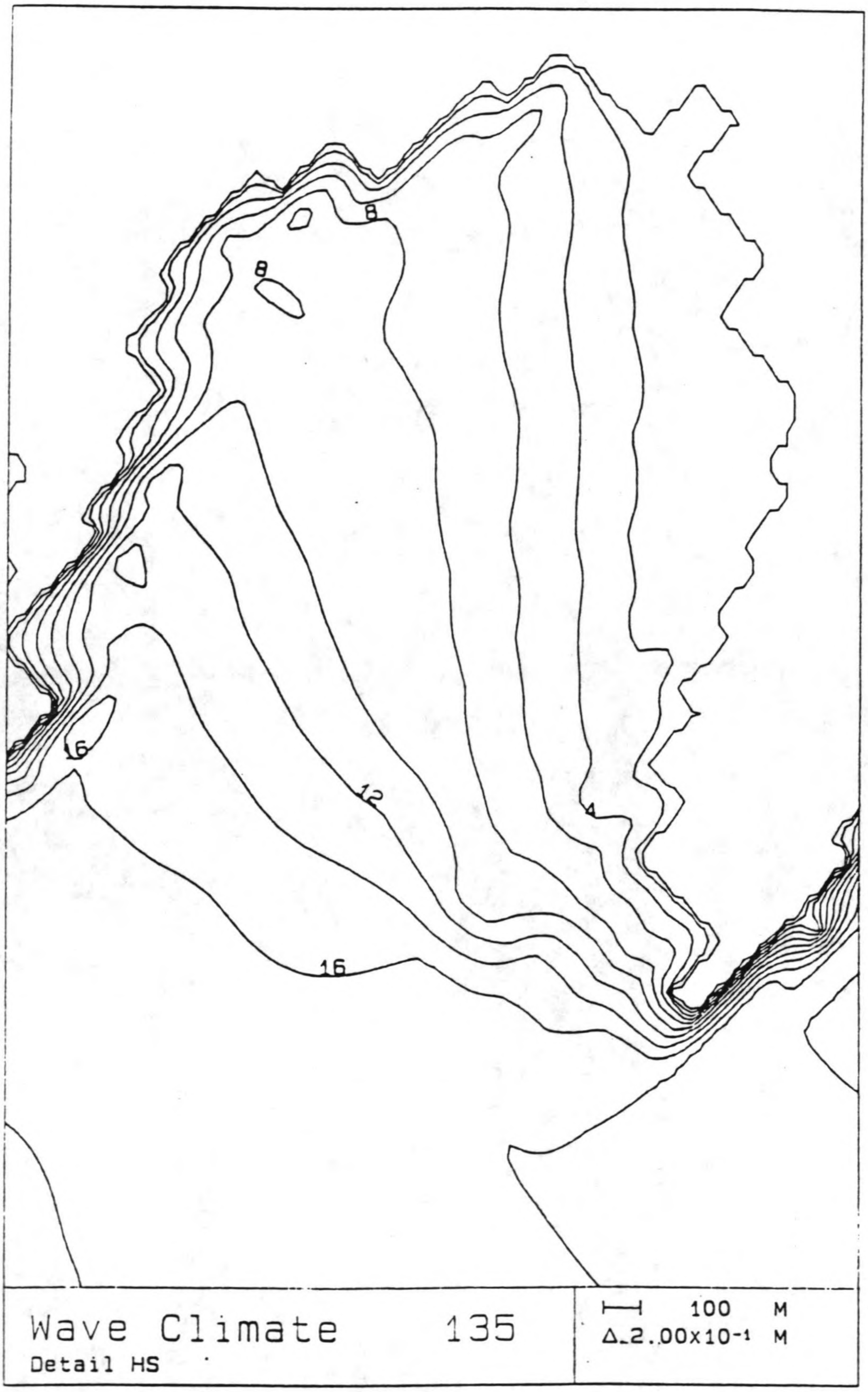


Figure C7: HISWA results significant wave heights for waves coming in from the Southeast (135°). H0 = 2,0 m., T0 = 8 sec. Plot shows schematised Great Bay.

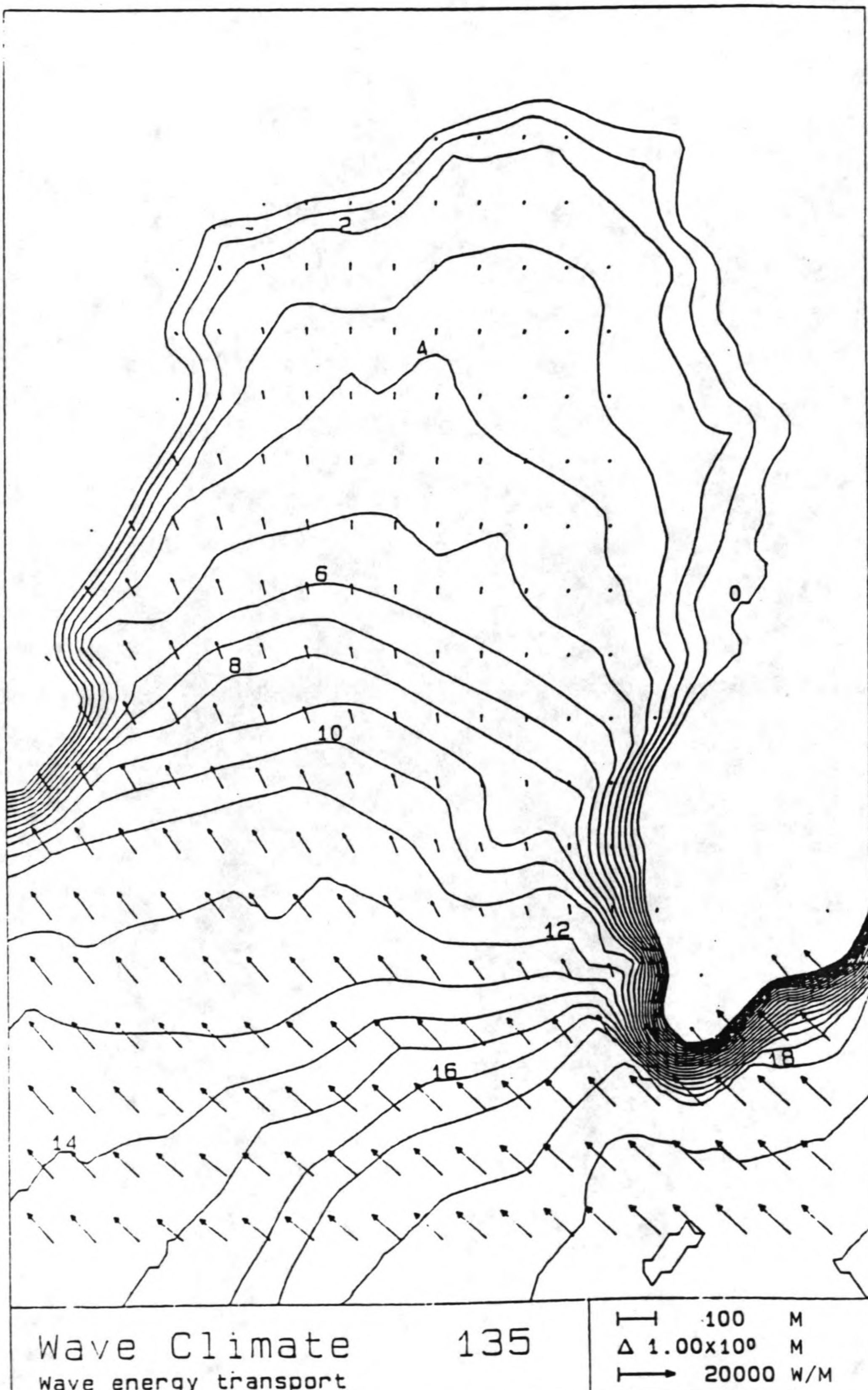


Figure C8: HISWA results for waves coming in from the Southeast (135°). H0 = 2,0 m., T0 = 8 sec. Arrows indicate the decrease of wave energy and direction of propagation. Detail of Great Bay.

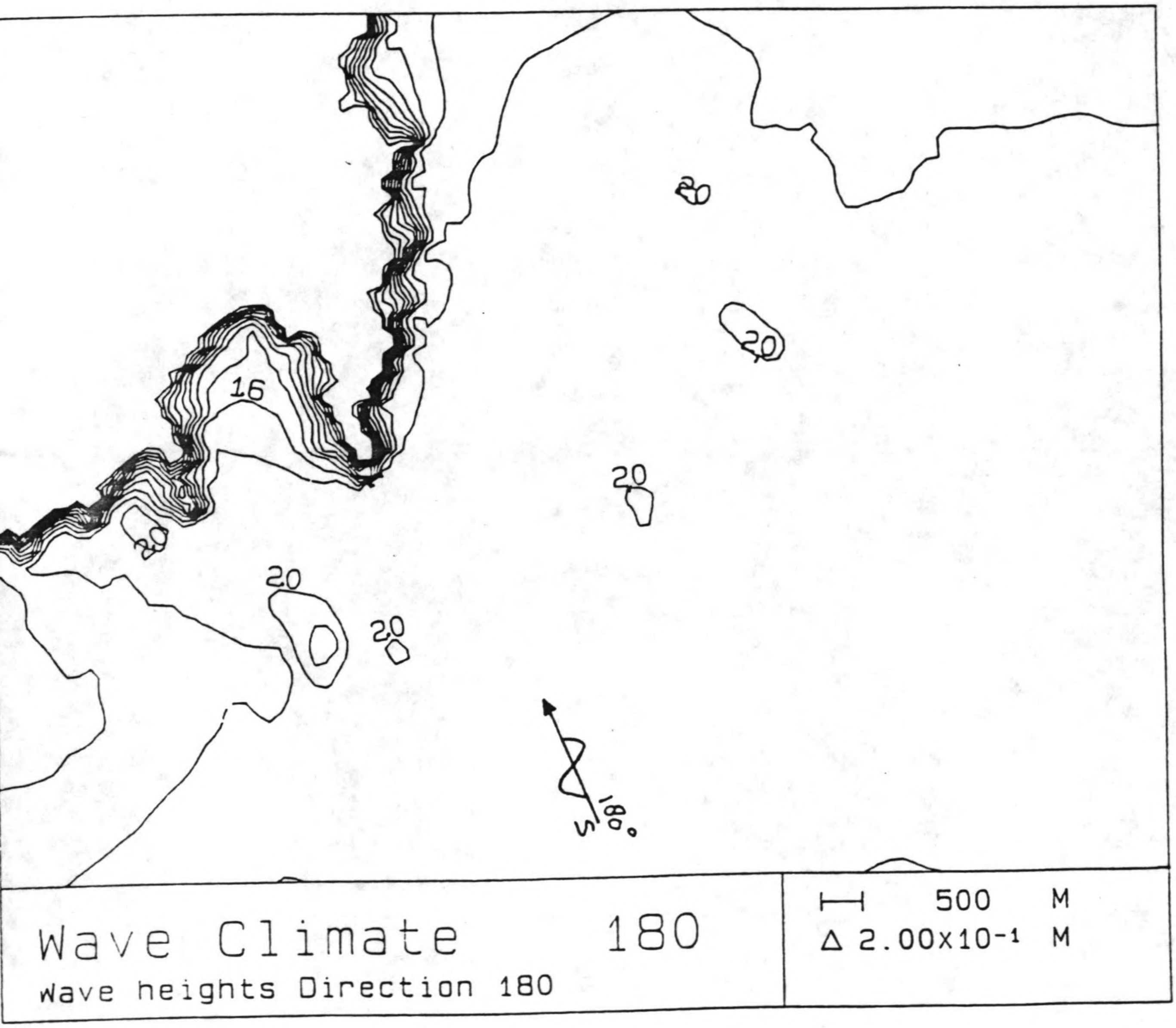


Figure C9: HISWA results significant wave heights for waves coming in from the South (180°). H0 = 2,0 m., T0 = 8 sec.

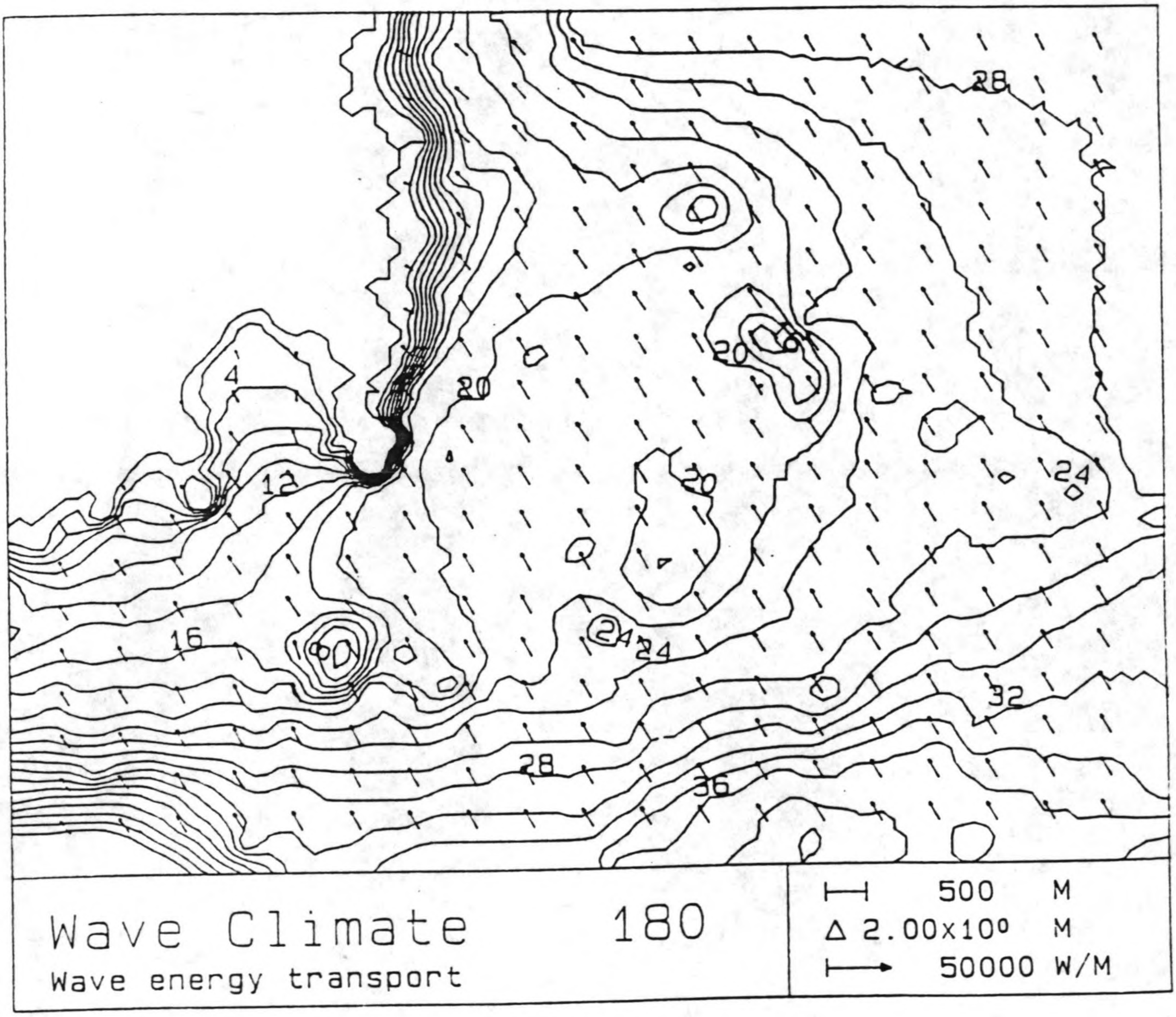


Figure C10: HISWA results for waves coming in from the South (180°). H0 = 2,0 m., T0 = 8 sec. Arrows indicate the decrease of wave energy and direction of propagation.

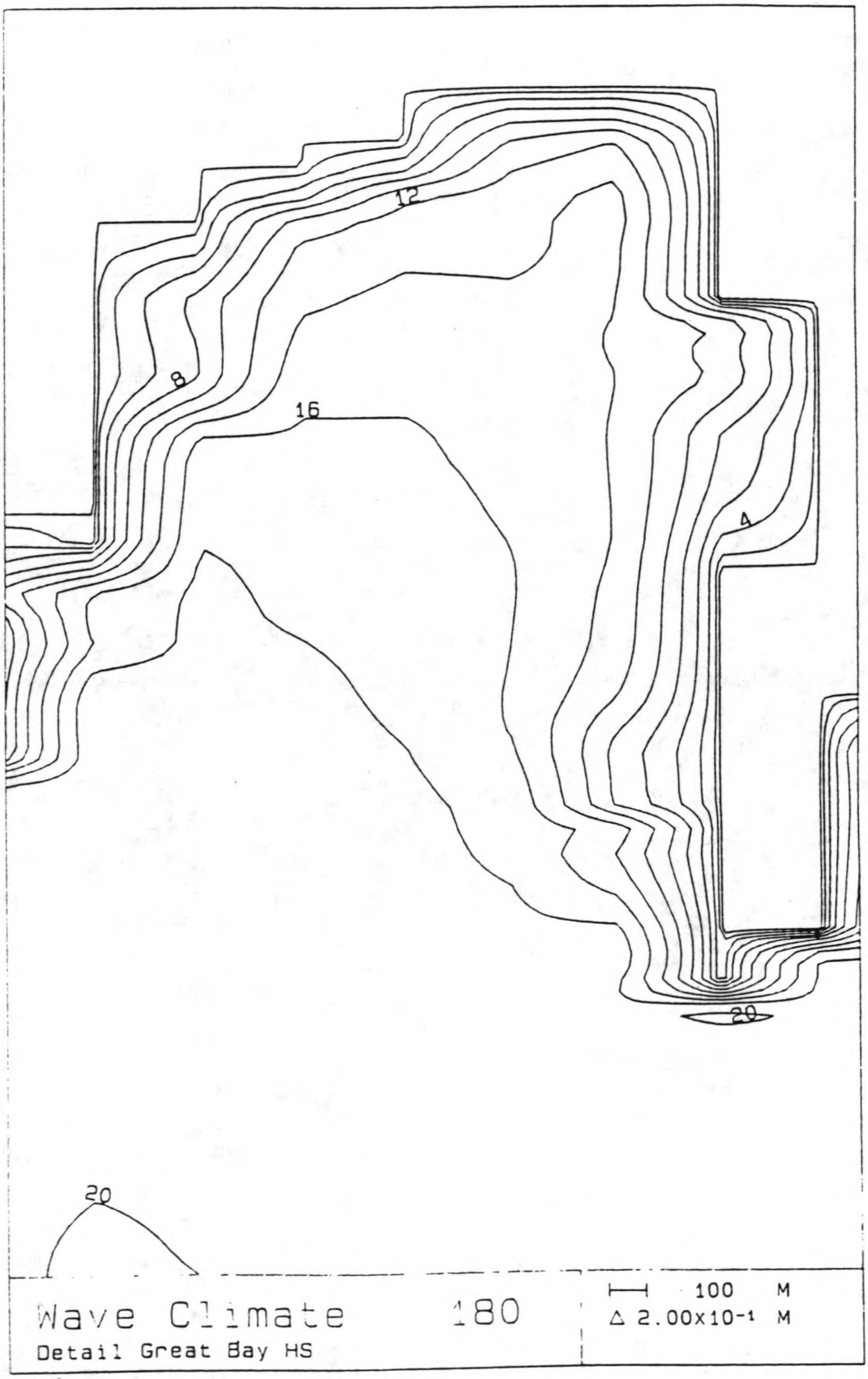


Figure C11: HISWA results significant wave heights for waves coming in from the South (180°). H0 = 2,0 m., T0 = 8 sec. Plot shows schematised Great Bay.

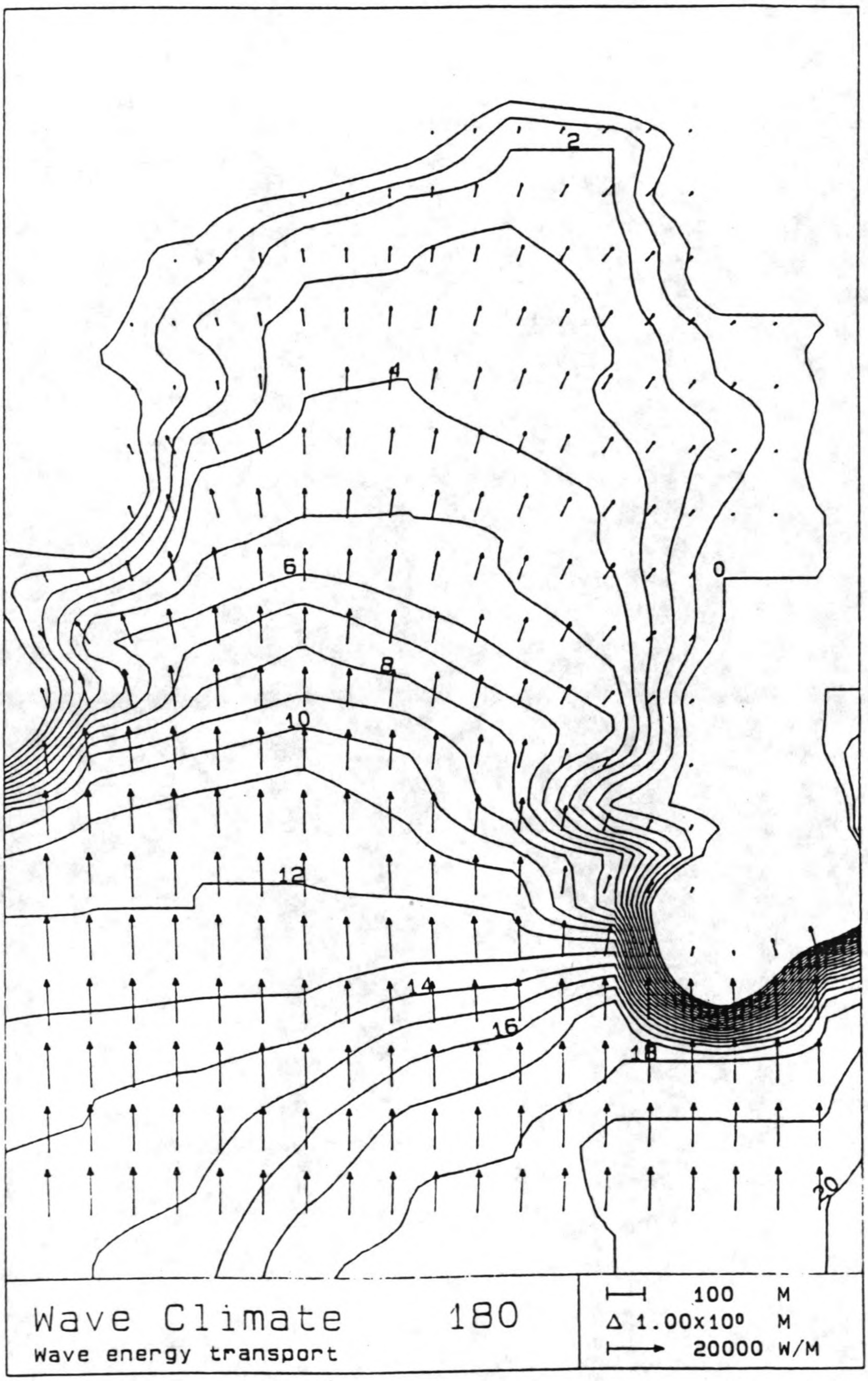


Figure C12: HISWA results for waves coming in from the East (90°). H0 = 2,0 m., T0 = 8 sec. Arrows indicate the decrease of wave energy and direction of propagation. Detail of Great Bay.

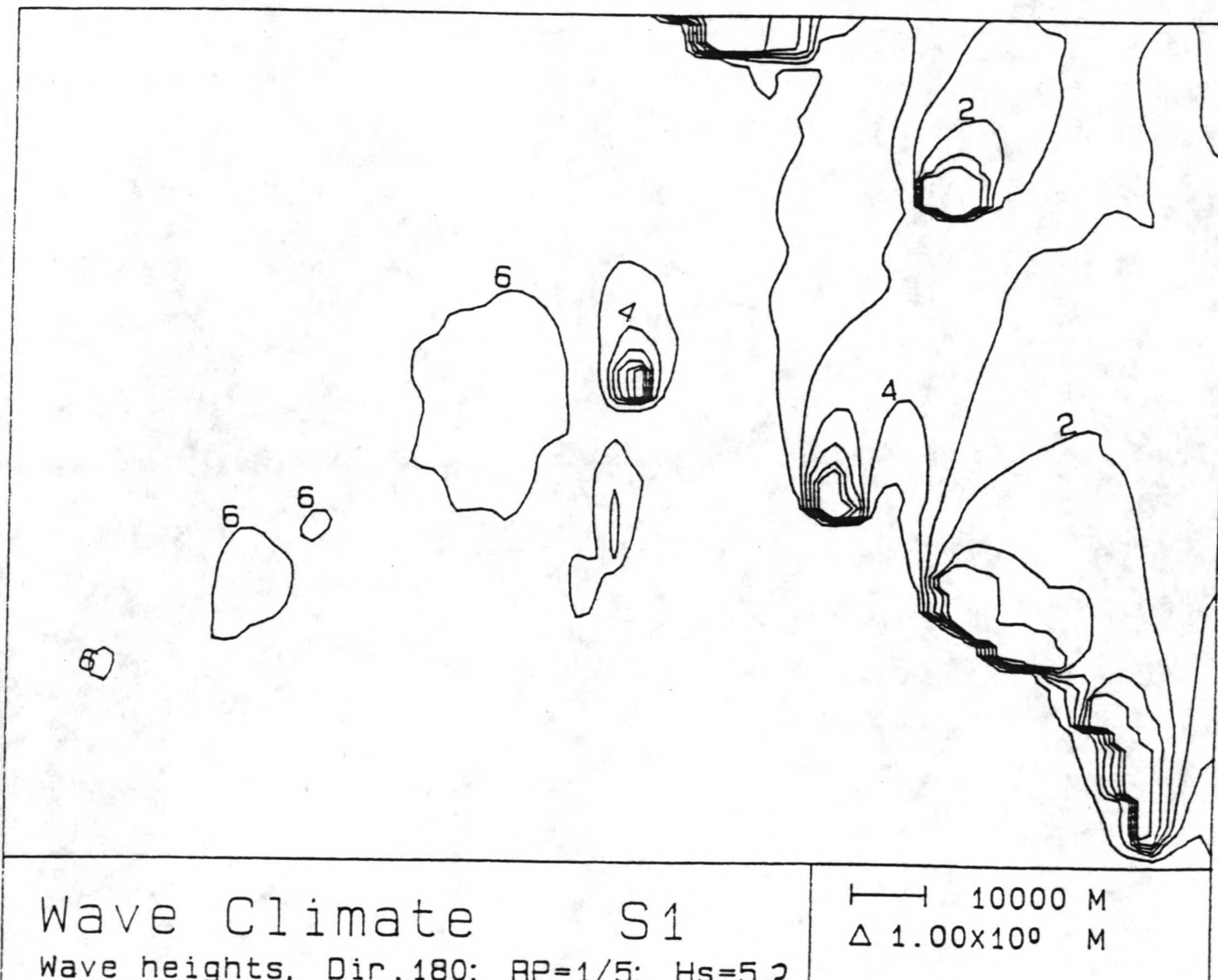


Figure C13: HISWA results, Hurricane Conditions. Return period once every 5 years. Direction 180° H_s = 5,2 meter, T_s = 8,5 seconds. Wave behaviour through window.

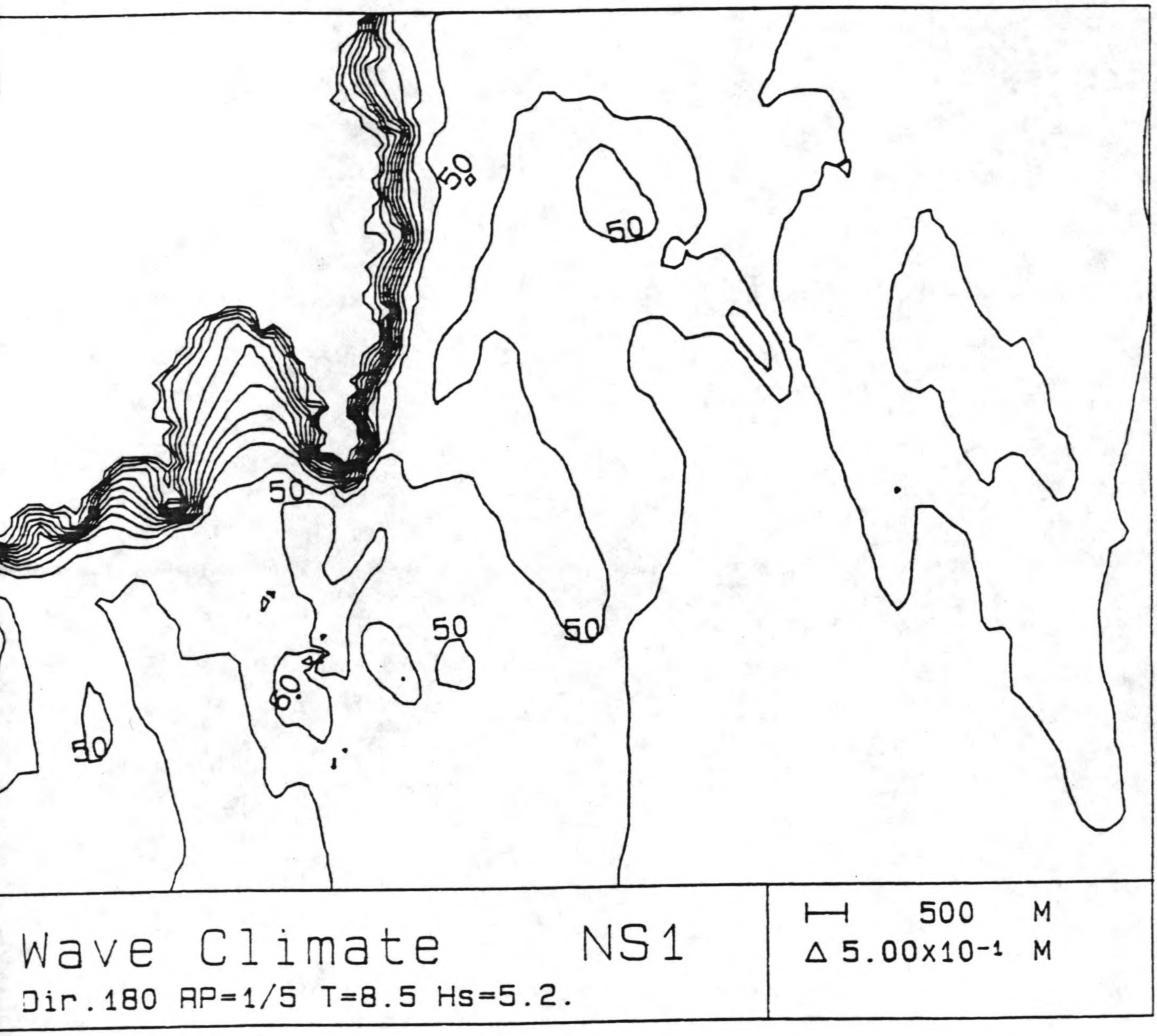


Figure C14: HISWA results, Hurricane Conditions. Return period once every 5 years. Direction 180° H_s = 5,2 meter, T_s = 8,5 seconds. Wave heights near St. Maarten.

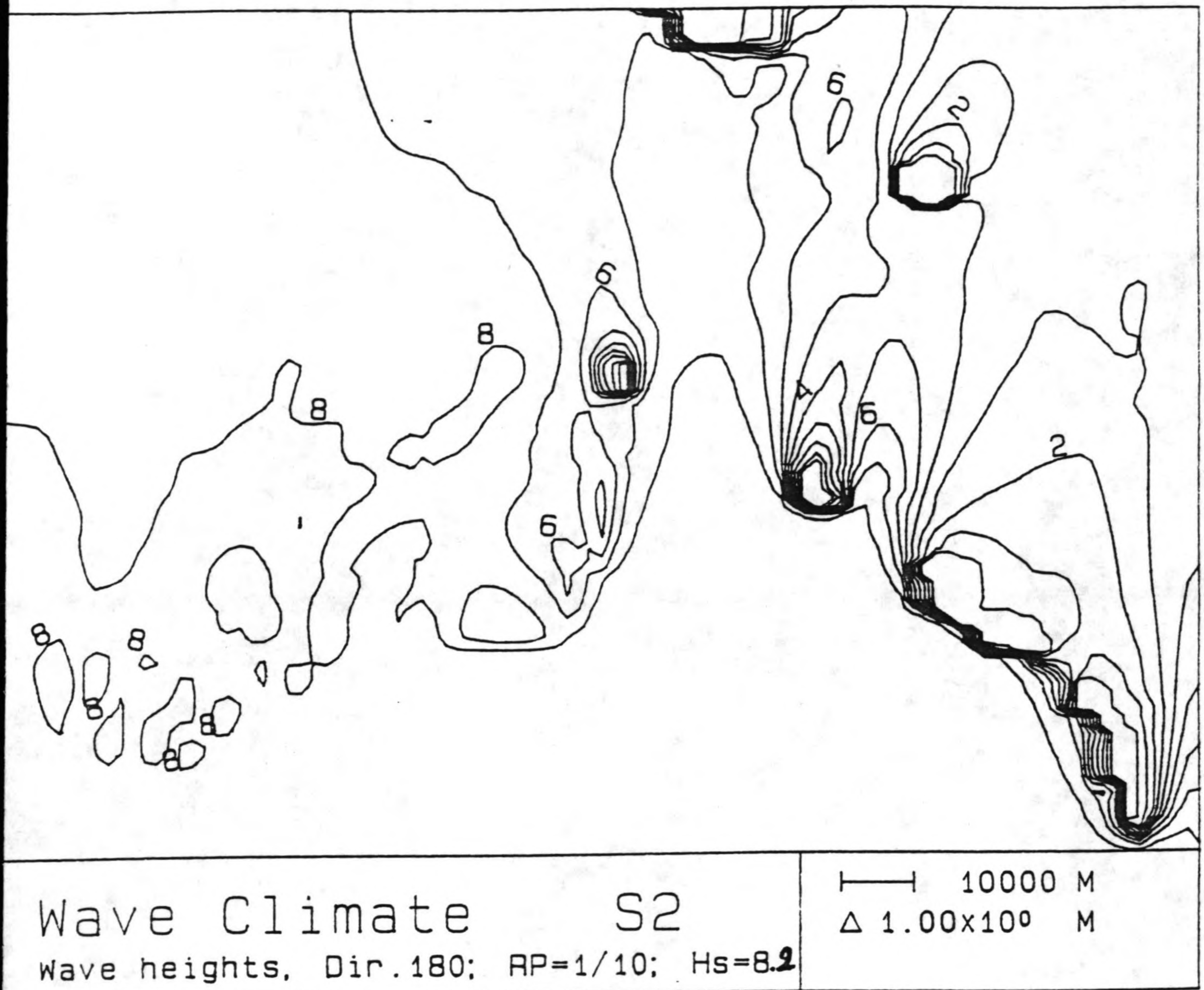


Figure C15: HISWA results, Hurricane Conditions. Return period once every 10 years. Direction 180° H_s = 8,2 meter, T_s = 10,5 seconds. Wave behaviour through window.

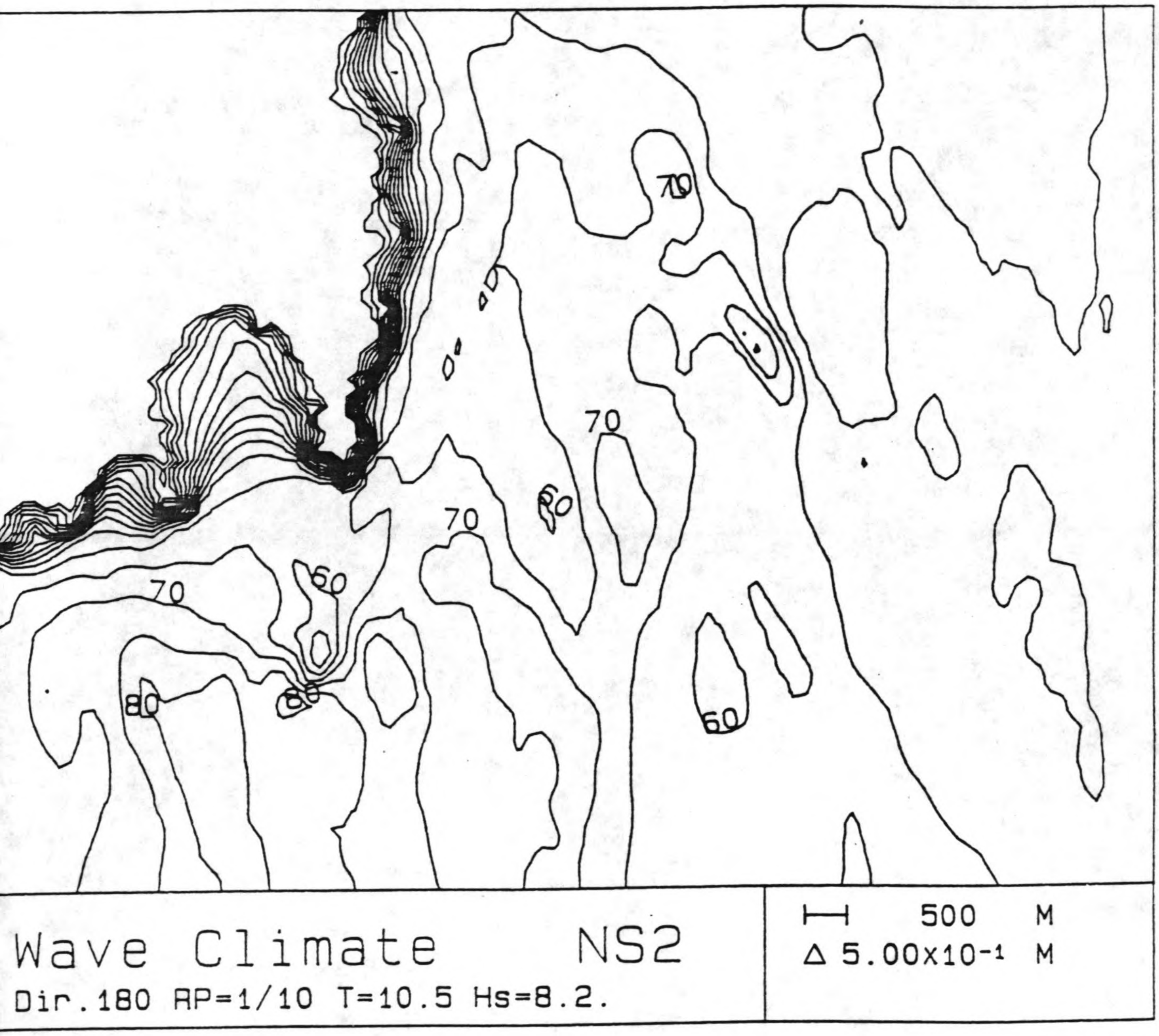


Figure C16: HISWA results, Hurricane Conditions. Return period once every 10 years. Direction 180° H_s = 8,2 meter, T_s = 10,5 seconds. Wave heights near St. Maarten.

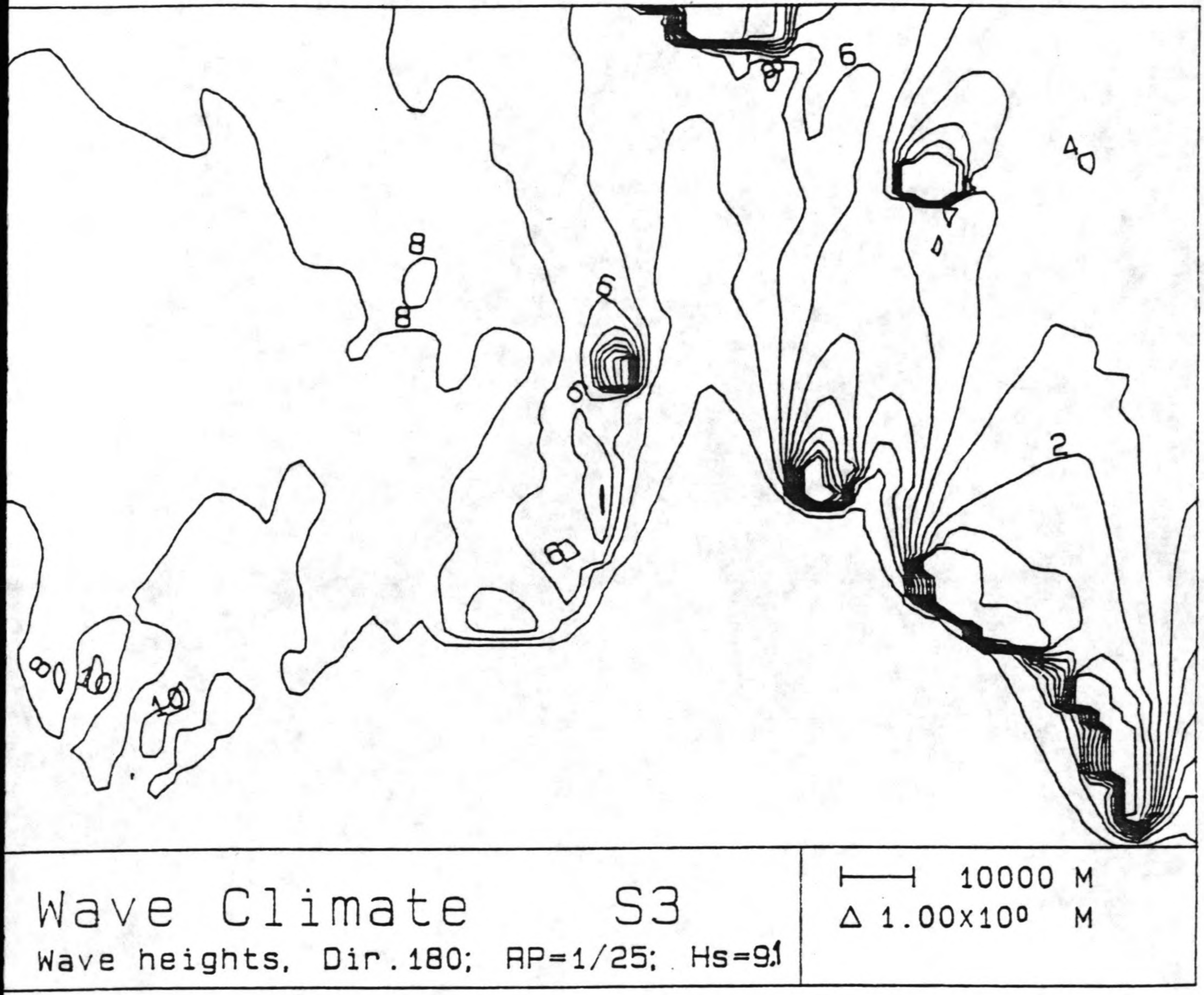


Figure C17: HISWA results, Hurricane Conditions. Return period once every 25 years. Direction 180° H_s = 9,1 meter, T_s = 11,0 seconds. Wave behaviour through window.

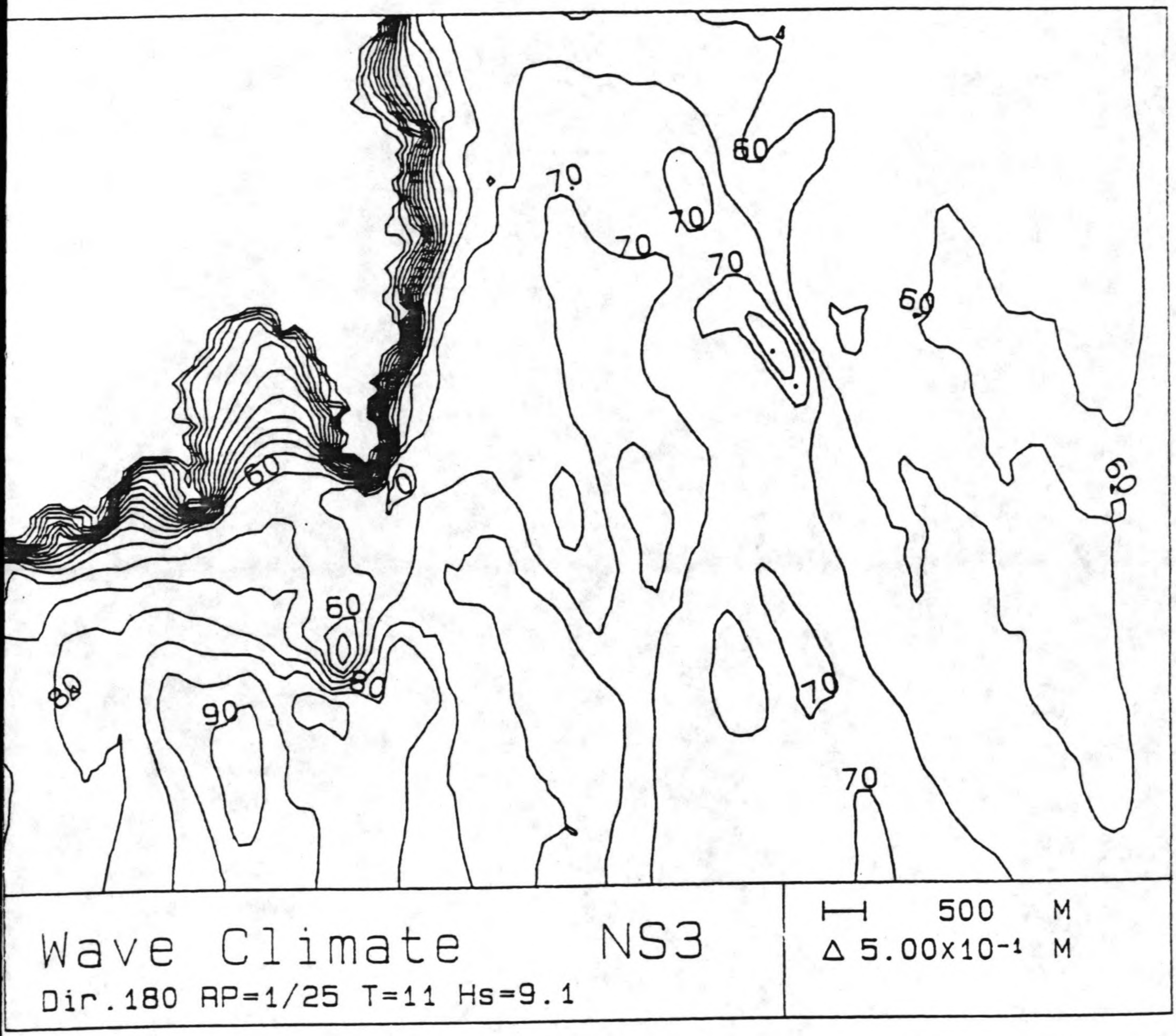


Figure C18: HISWA results, Hurricane Conditions. Return period once every 25 years. Direction 180° H_s = 9,1 meter, T_s = 11,0 seconds. Wave heights near St. Maarten.

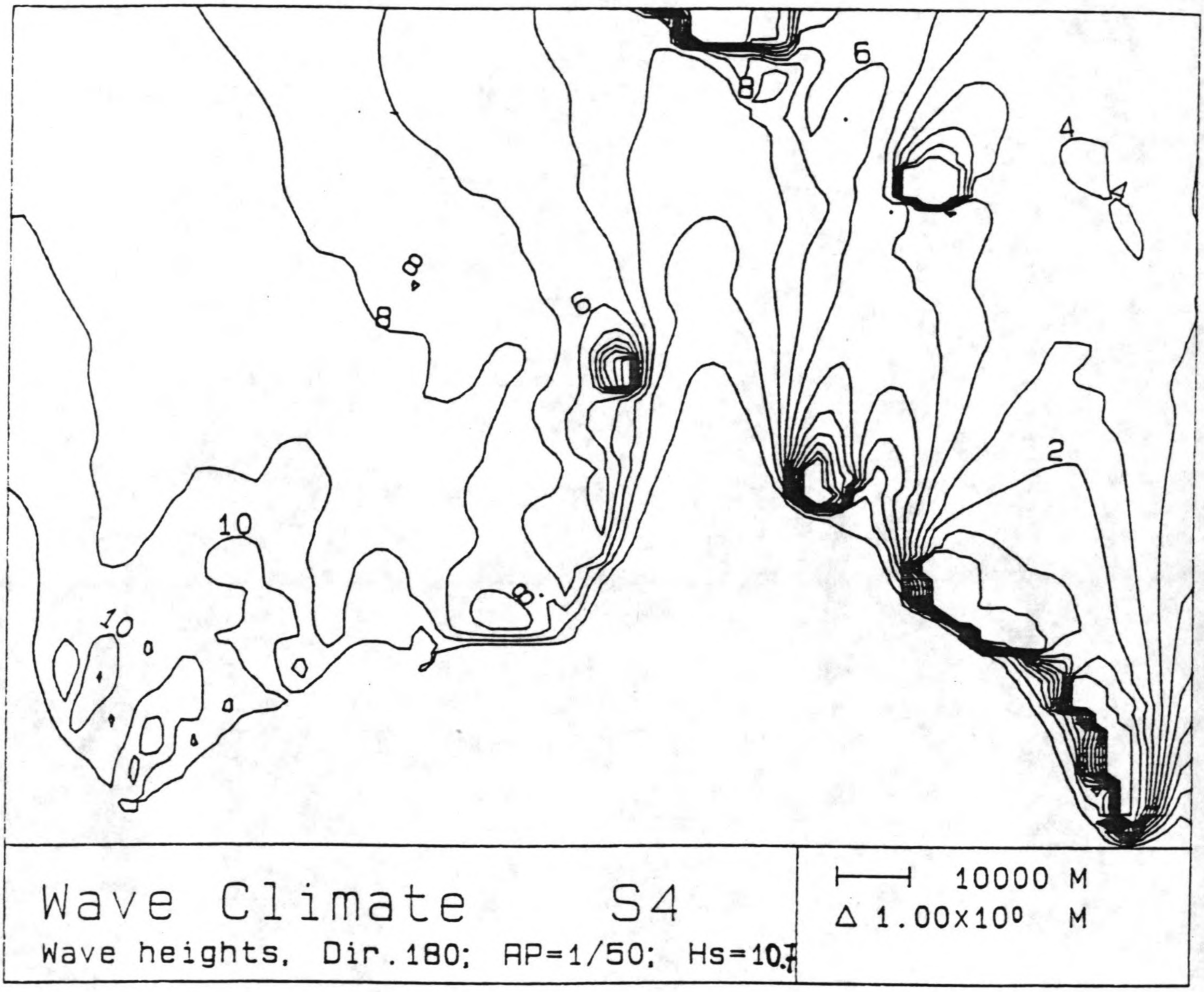


Figure C19: HISWA results, Hurricane Conditions. Return period once every 50 years. Direction 180° H_s = 10,7 meter, T_s = 12,0 seconds. Wave behaviour through window.

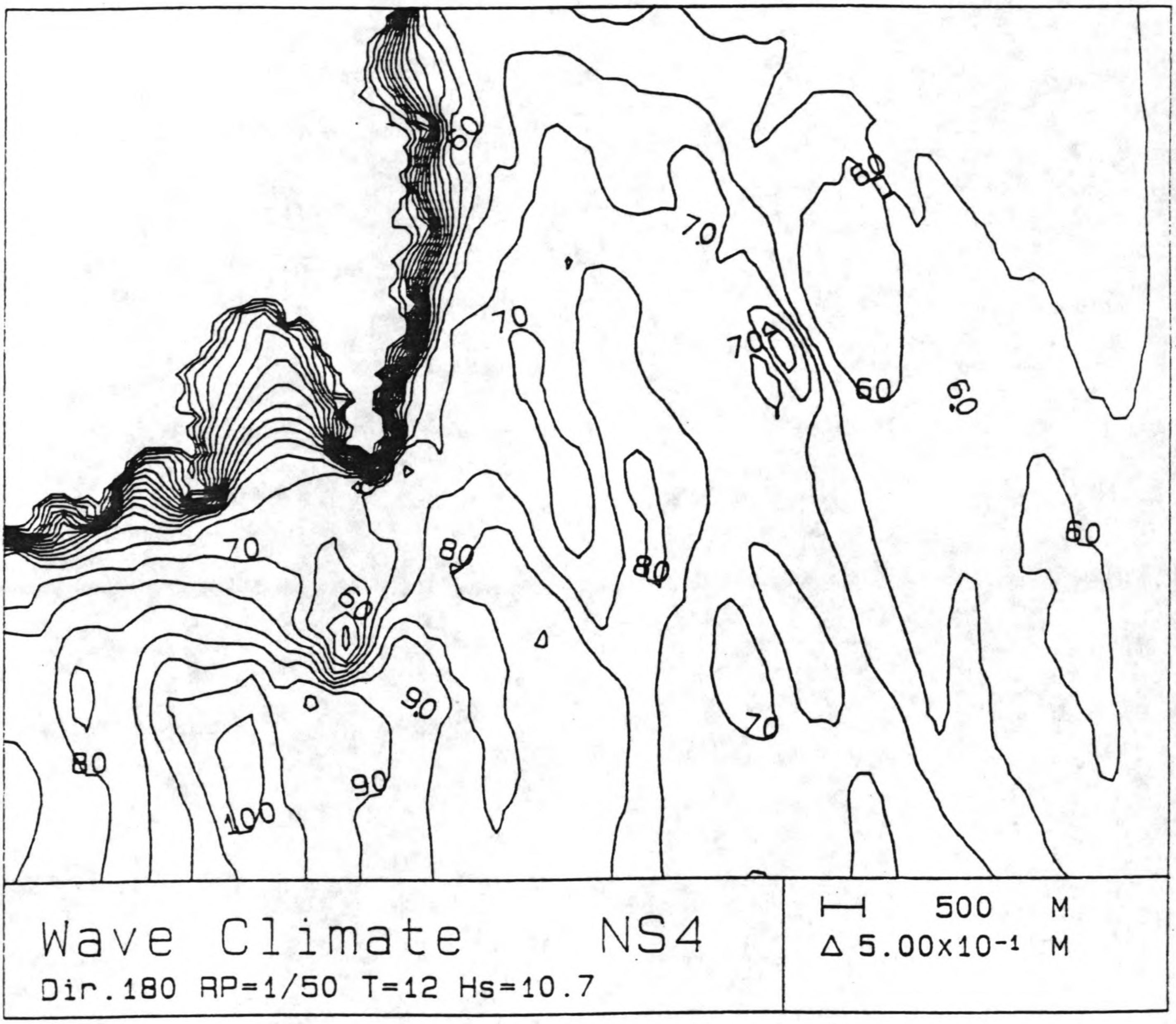


Figure C20: HISWA results, Hurricane Conditions. Return period once every 50 years. Direction 180° H_s = 10,7 meter, T_s = 12,0 seconds. Wave heights near St. Maarten.

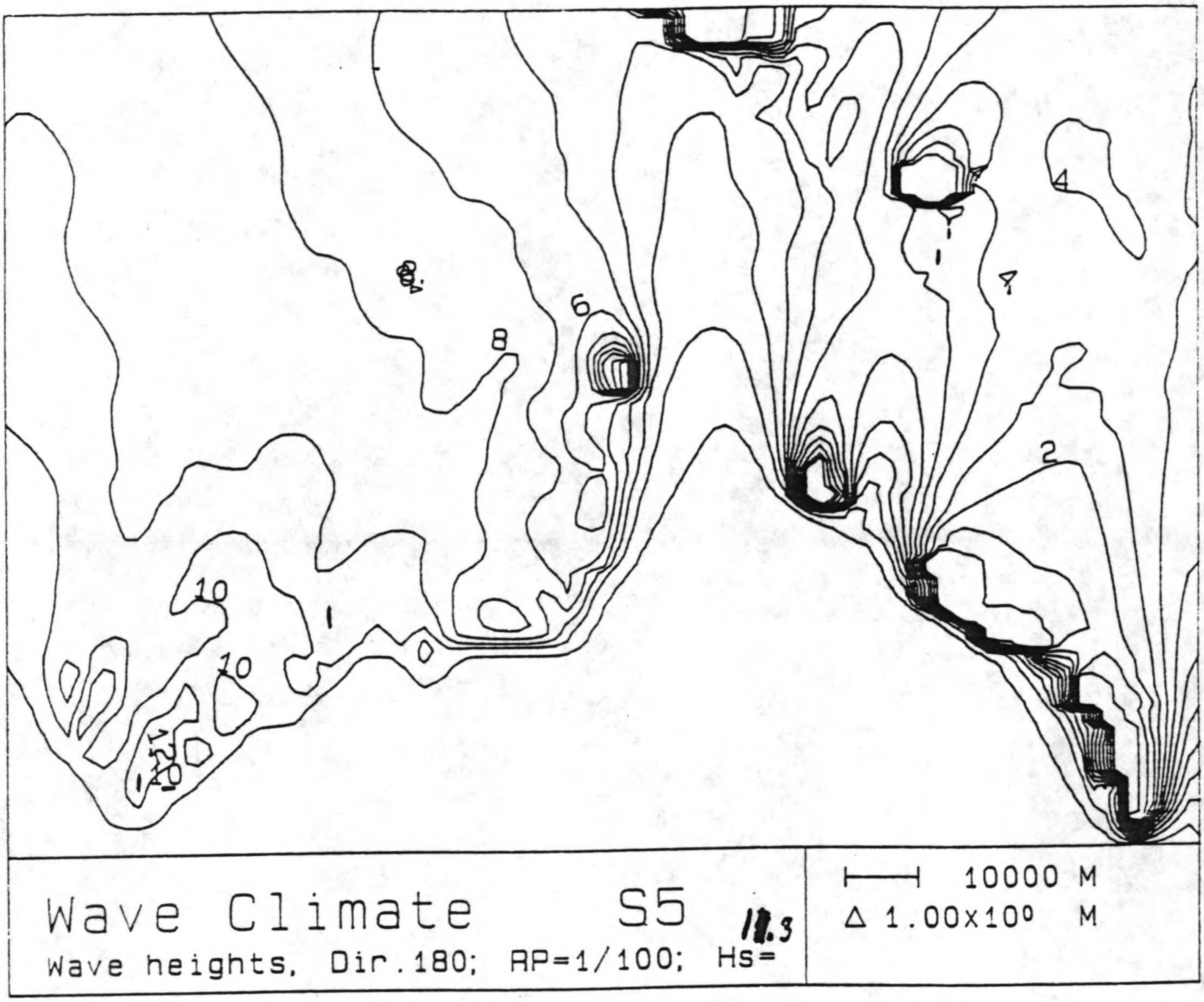


Figure C21: HISWA results, Hurricane Conditions. Return period once every 100 years. Direction 180° H_s = 11,3 meter, T_s = 12,5 seconds. Wave behaviour through window.

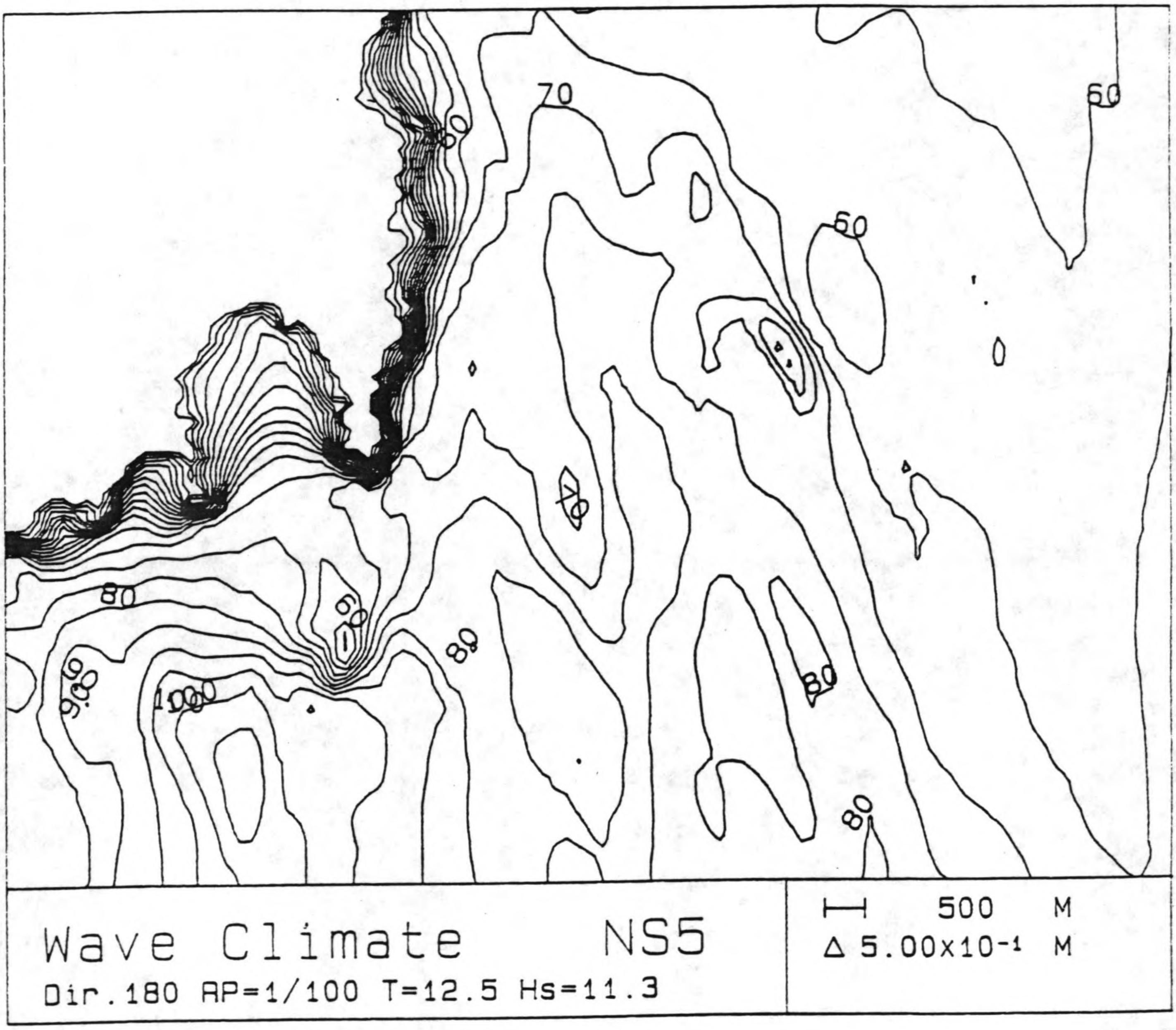


Figure C22: HISWA results, Hurricane Conditions. Returnperiod once every 100 years. Direction 180° H_s = 11,3 meter, T_s = 12,5 seconds. Wave heights near St. Maarten.

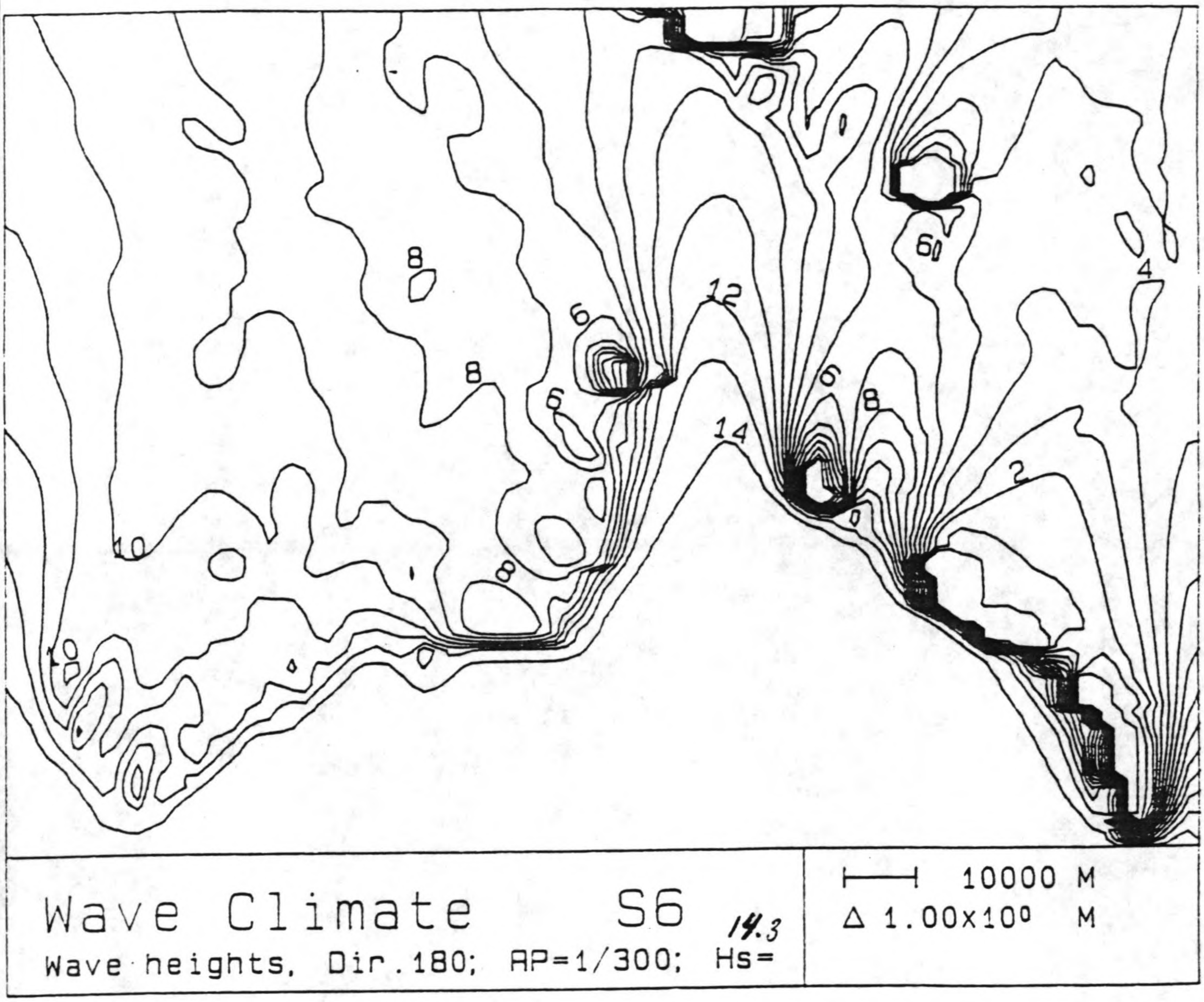


Figure C23: HISWA results, Hurricane Conditions. Return period once every 300 years. Direction 180° H_s = 14,3 meter, T_s = 14,0 seconds. Wave behaviour through window.

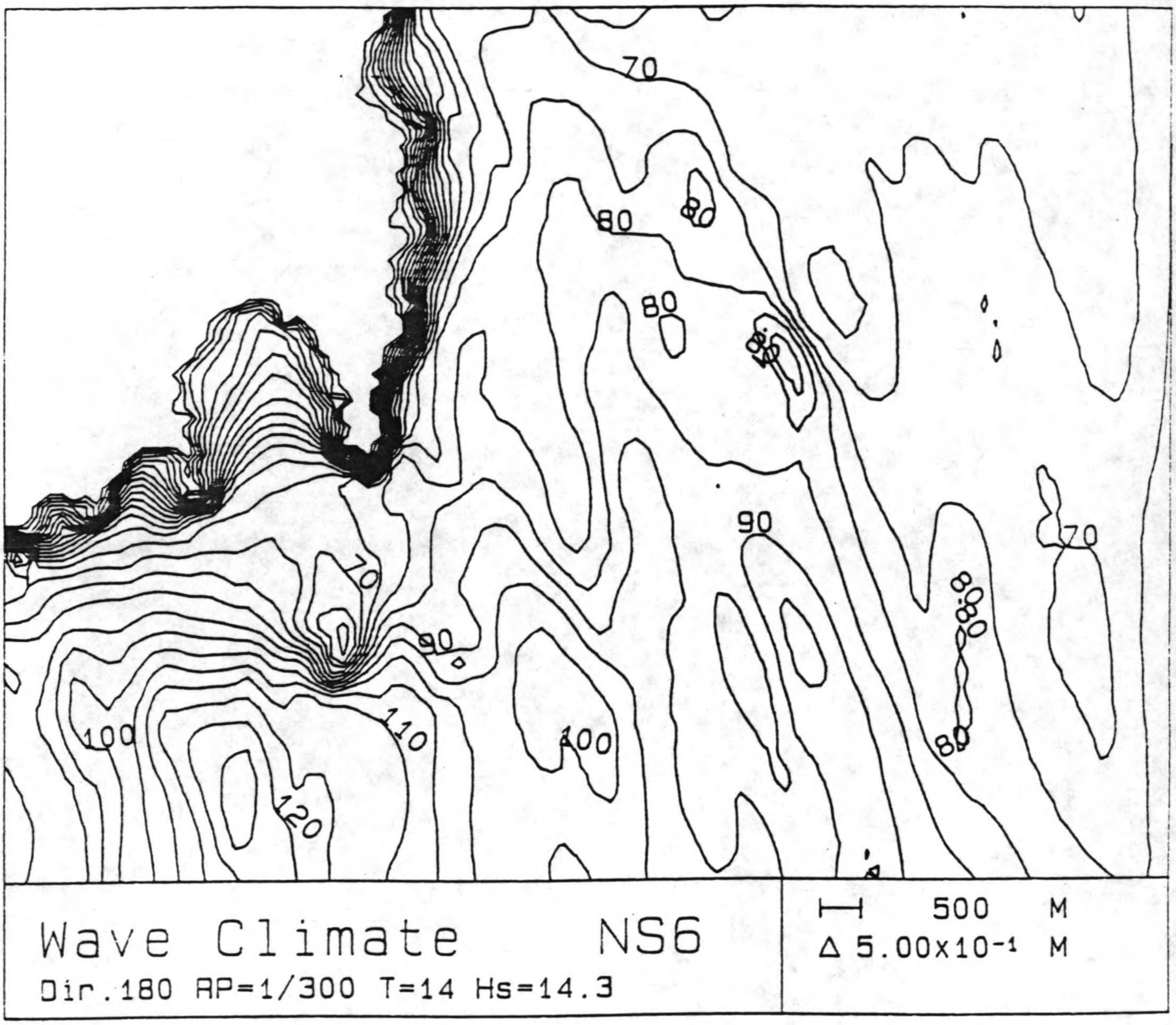


Figure C24: HISWA results, Hurricane Conditions. Returnperiod once every 300 years. Direction 180° H_s = 14,3 meter, T_s = 14,0 seconds. Wave heights near St. Maarten.

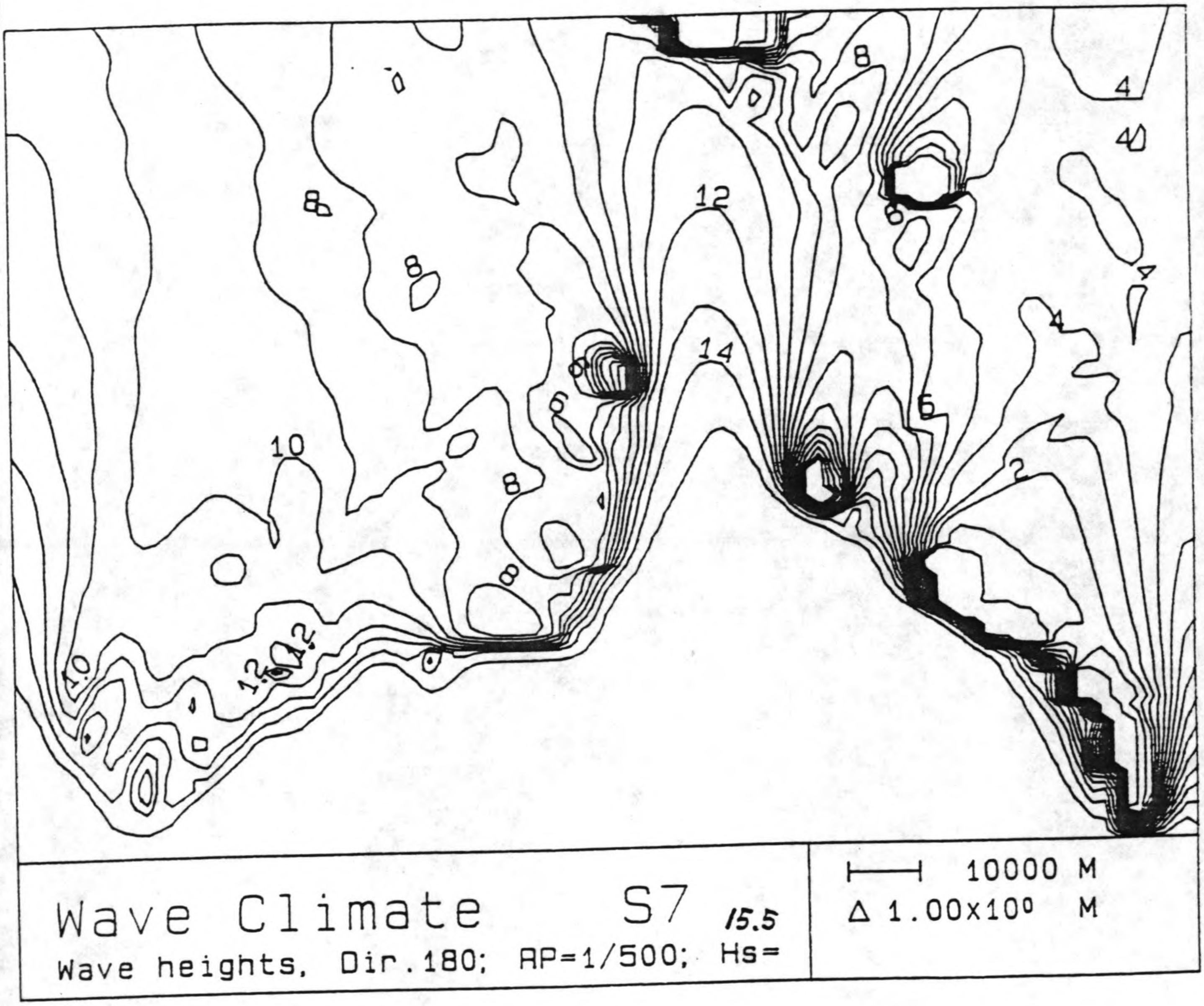


Figure C25: HISWA results, Hurricane Conditions. Return period once every 500 years. Direction 180° H_s = 15,5 meter, T_s = 14,5 seconds. Wave behaviour through window.

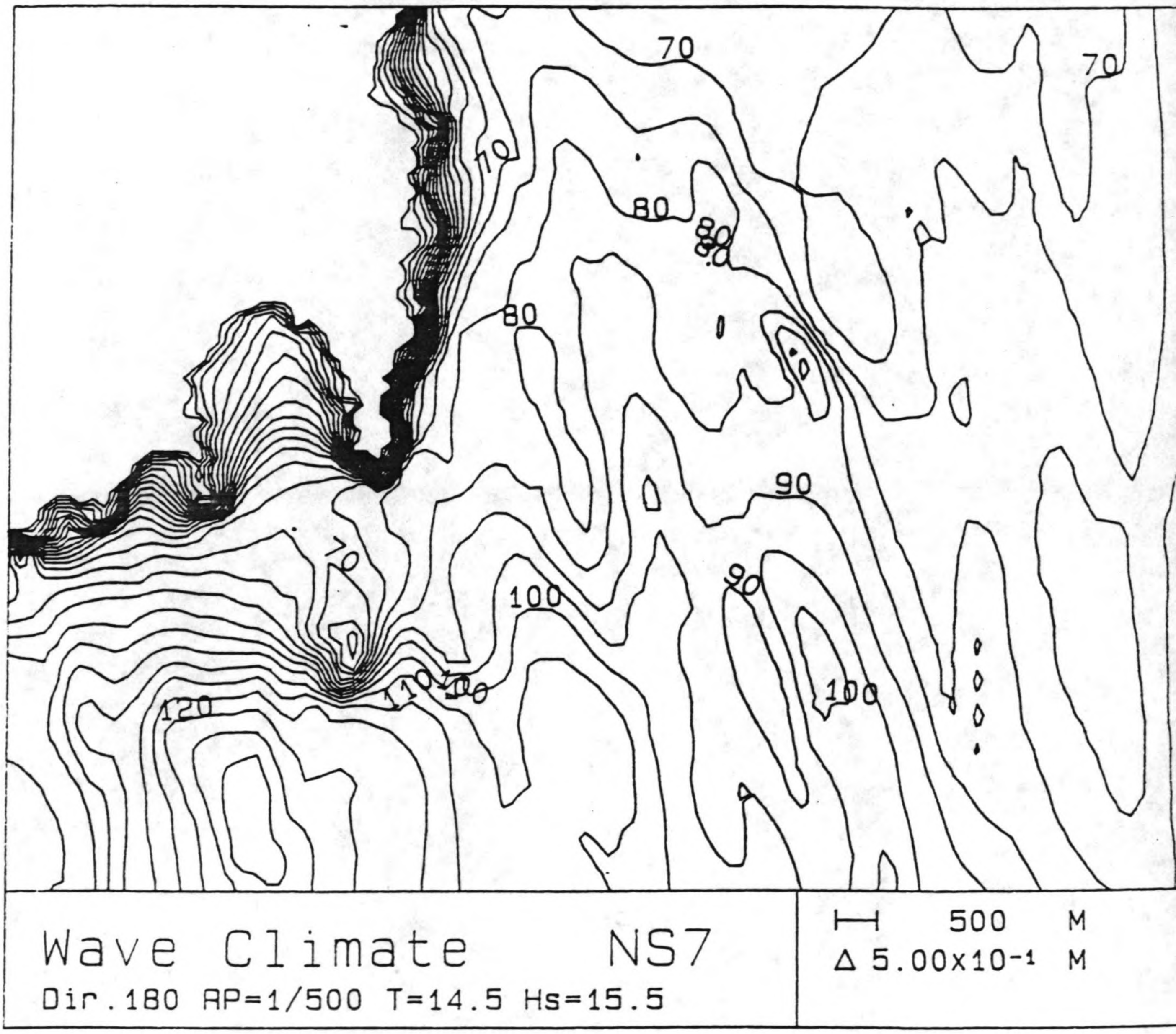


Figure C26: HISWA results, Hurricane Conditions. Returnperiod once every 500 years. Direction 180° H_s = 15,5 meter, T_s = 14,5 seconds. Wave heights near St. Maarten.

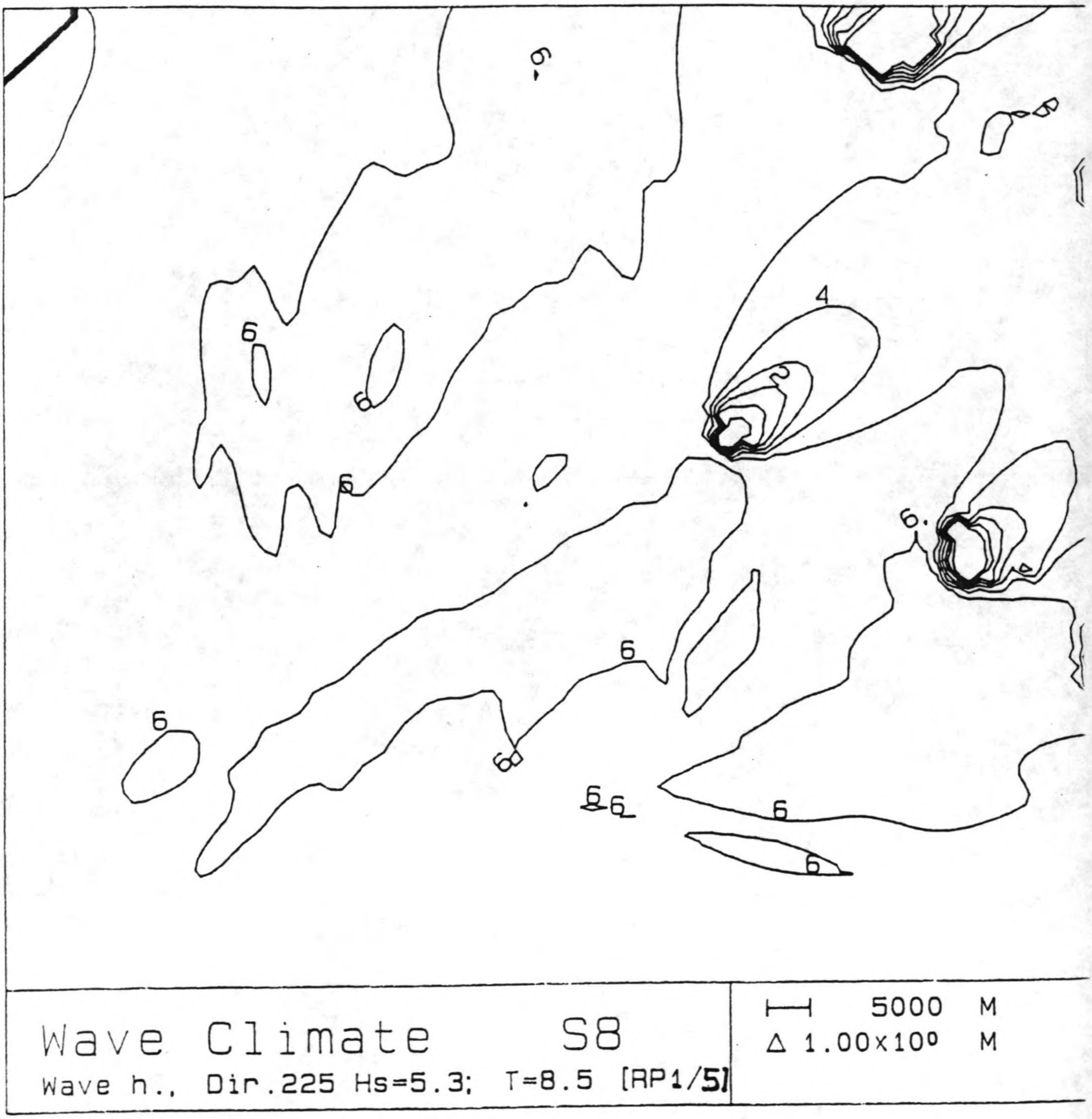


Figure C27: HISWA results, Hurricane Conditions. Return period once every 5 years. Direction 225° H_s = 5,2 meter, T_s = 8,5 seconds. Wave behaviour through window.

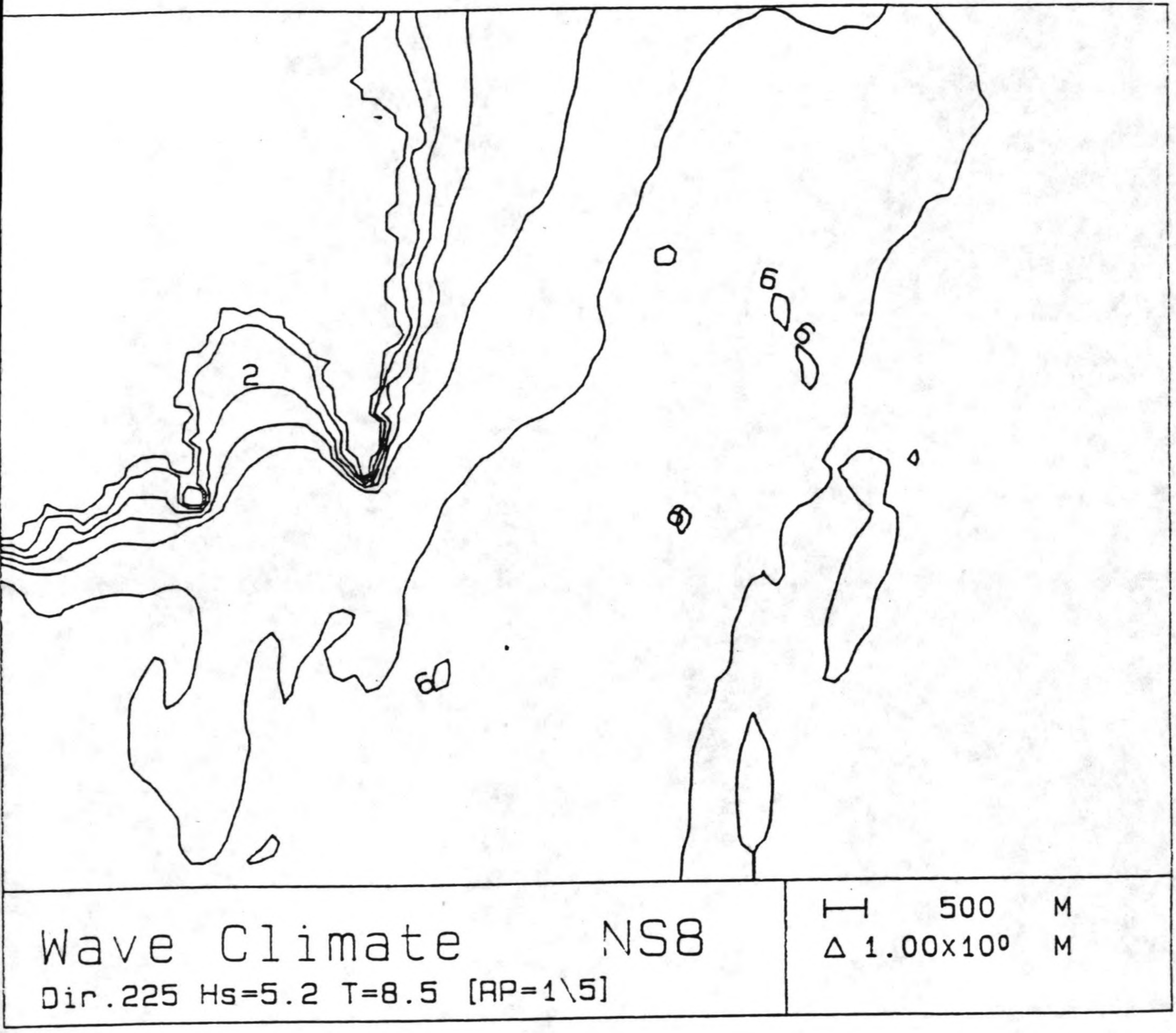


Figure C28: HISWA results, Hurricane Conditions. Return period once every 5 years. Direction 225° H_s = 5,2 meter, T_s = 8,5 seconds. Wave heights near St. Maarten.

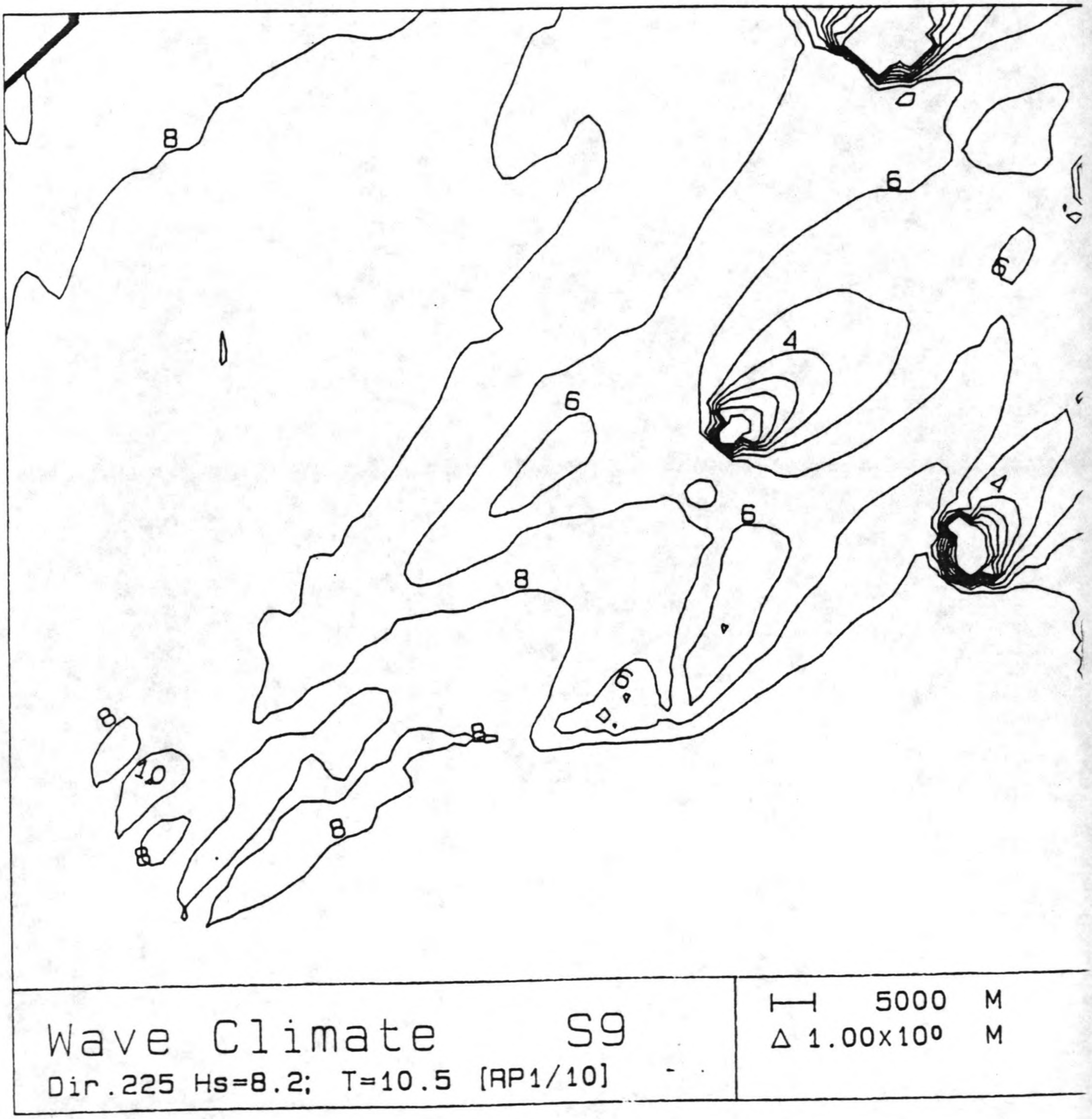


Figure C29: HISWA results, Hurricane Conditions. Return period once every 10 years. Direction 225° H_s = 8,2 meter, T_s = 10,5 seconds. Wave behaviour through window.

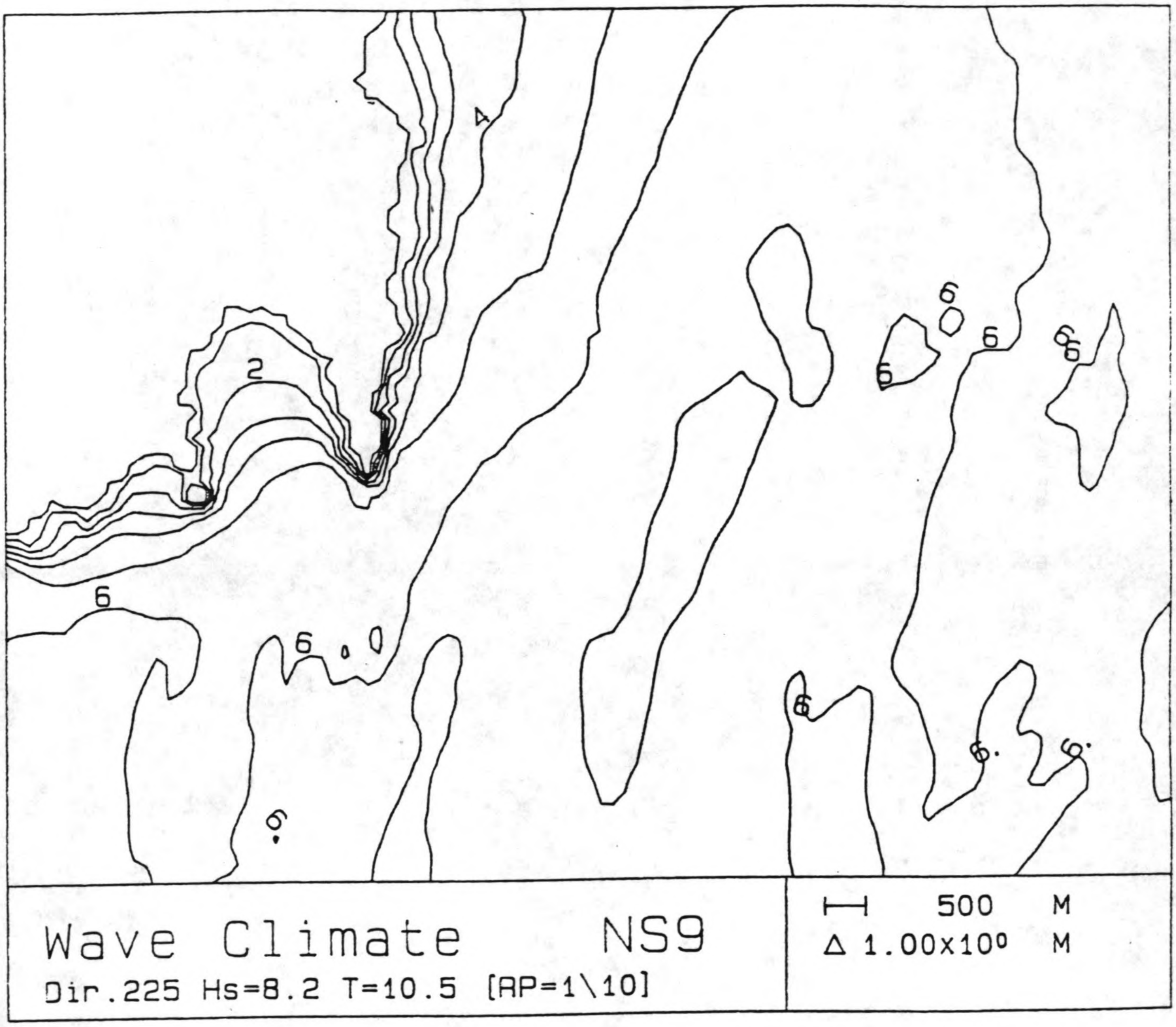


Figure C30: HISWA results, Hurricane Conditions. Return period once every 10 years. Direction 225° H_s = 8,2 meter, T_s = 10,5 seconds. Wave heights near St. Maarten.

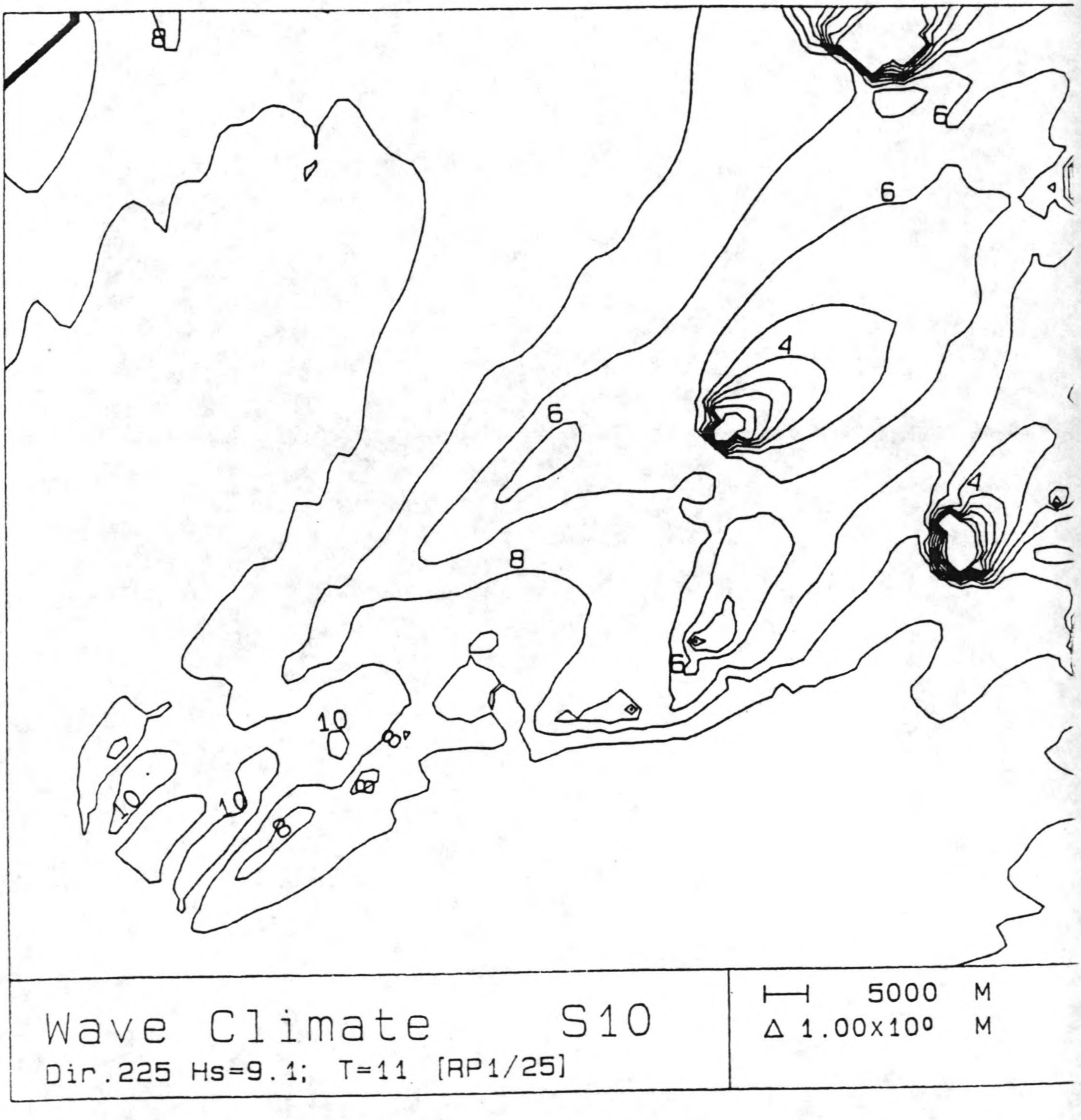


Figure C31: HISWA results, Hurricane Conditions. Return period once every 25 years. Direction 225° H_s = 9,1 meter, T_s = 11,0 seconds. Wave behaviour through window.

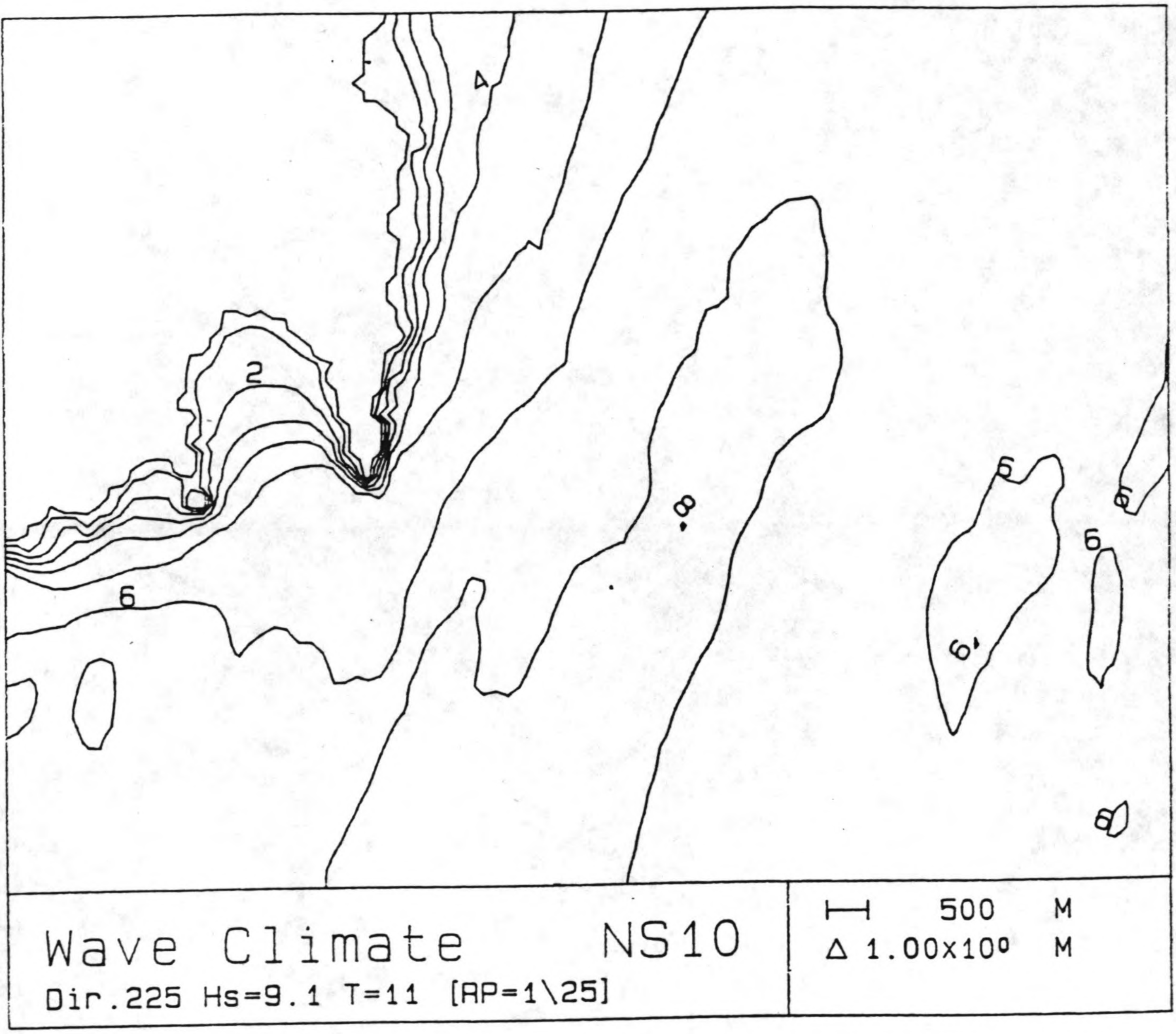


Figure C32: HISWA results, Hurricane Conditions. Return period once every 25 years. Direction 225° H_s = 9,1 meter, T_s = 11,0 seconds. Wave heights near St. Maarten.

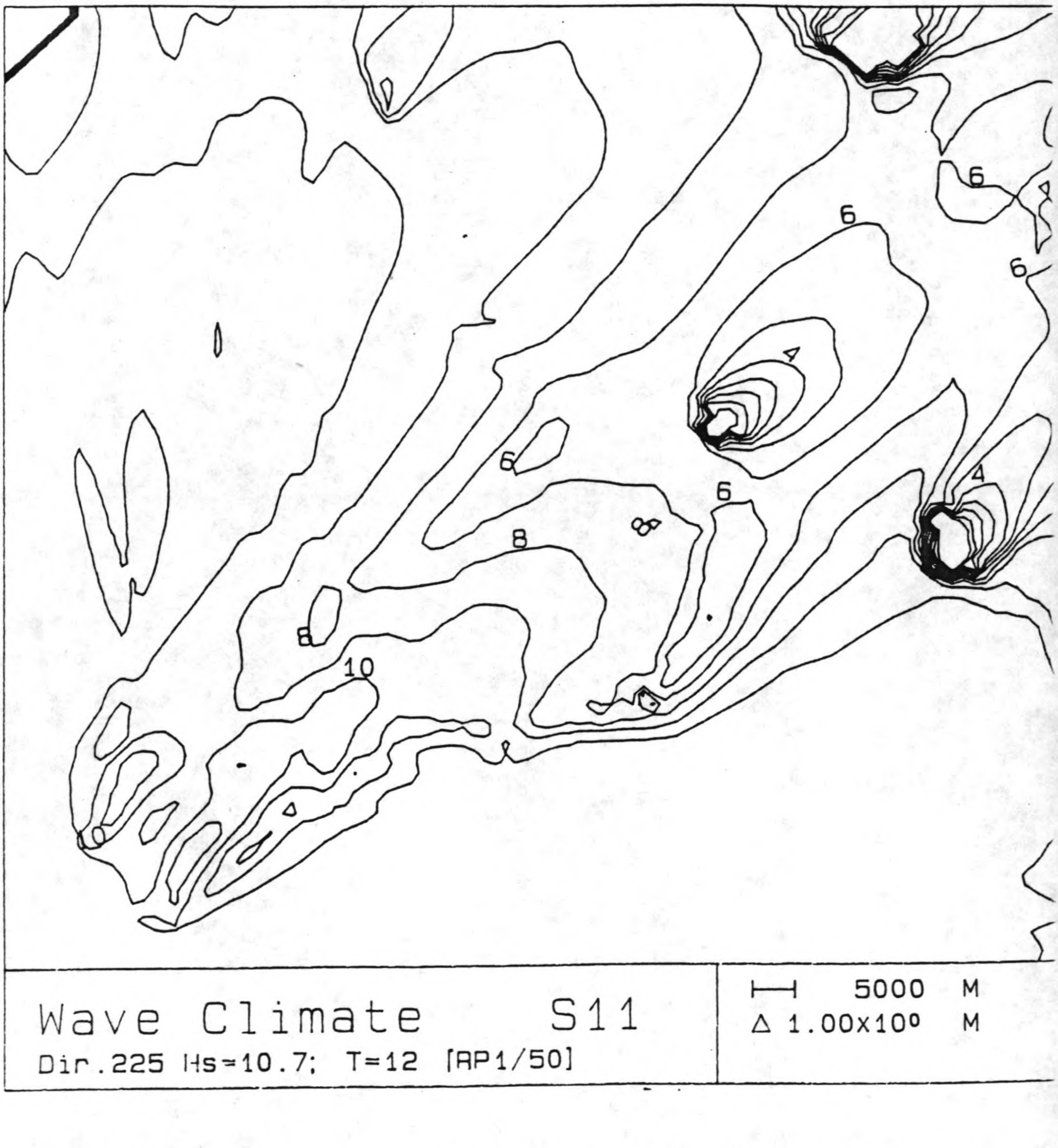


Figure C33: HISWA results, Hurricane Conditions. Return period once every 50 years. Direction 225° H_s = 10,7 meter, T_s = 12,0 seconds. Wave behaviour through window.

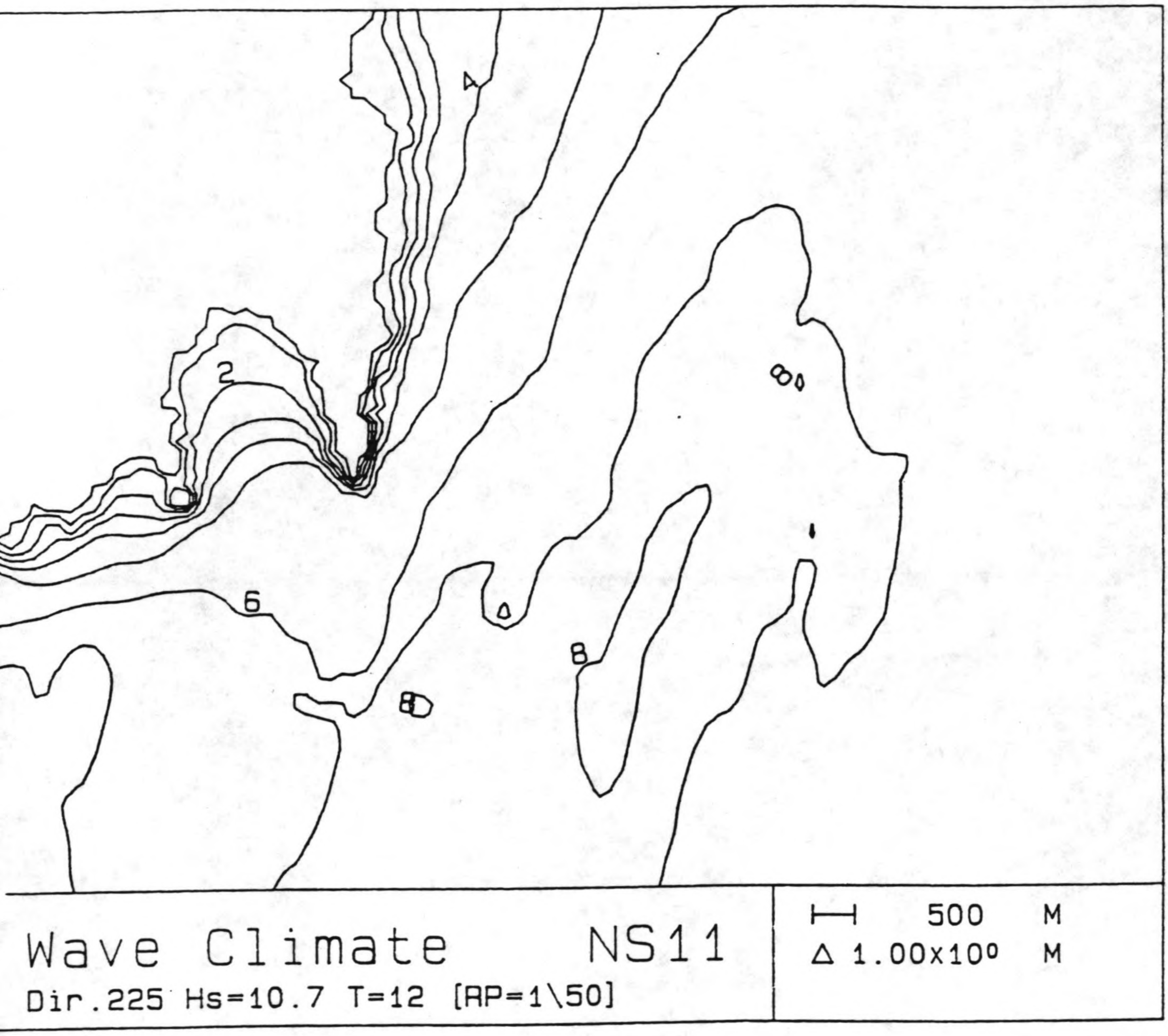


Figure C34: HISWA results, Hurricane Conditions. Return period once every 50 years. Direction 225° H_s = 10,7 meter, T_s = 12,0 seconds. Wave heights near St. Maarten.

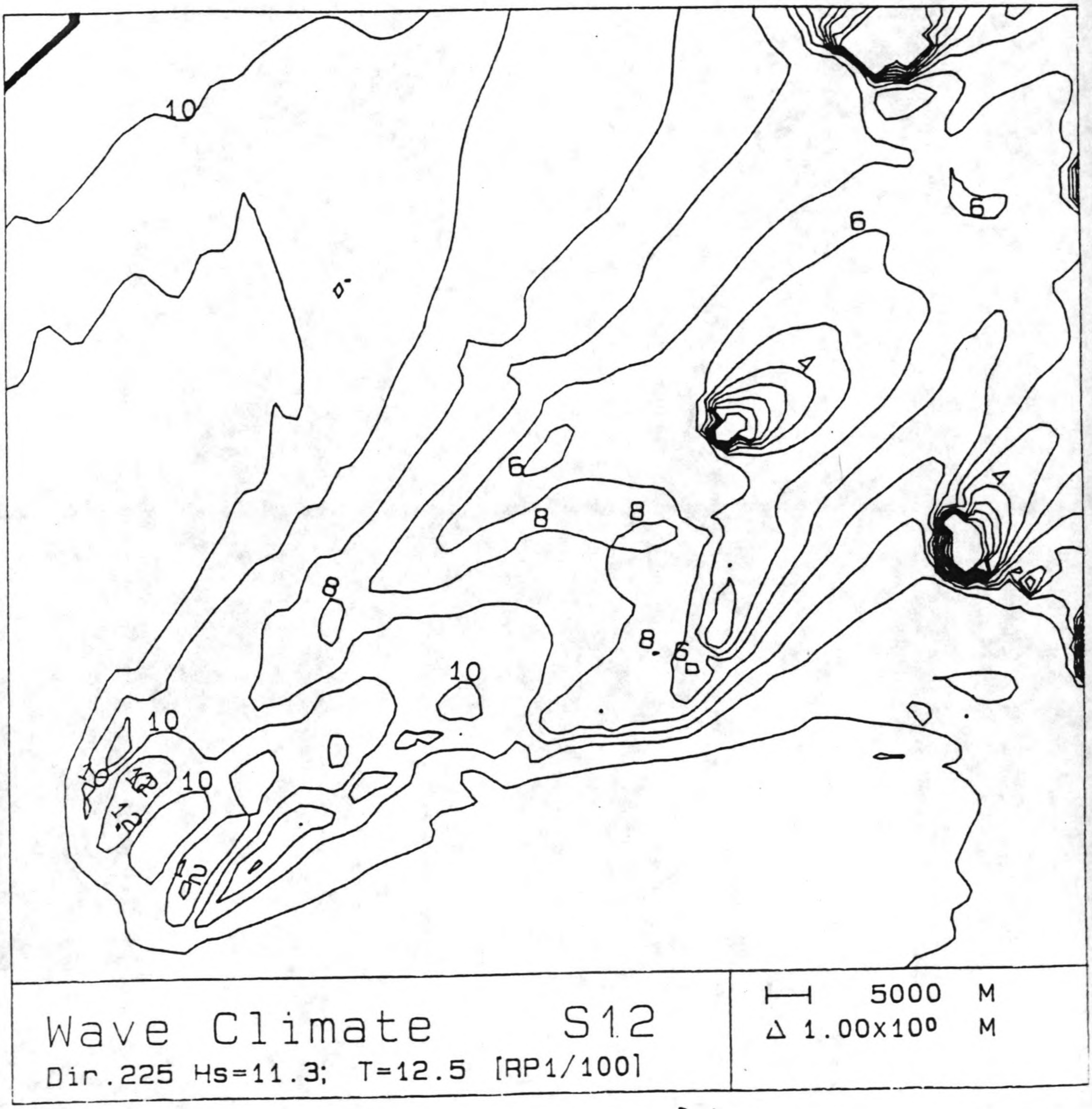


Figure C35: HISWA results, Hurricane Conditions. Return period once every 100 years. Direction 225° H_s = 11,3 meter, T_s = 12,5 seconds. Wave behaviour through window.

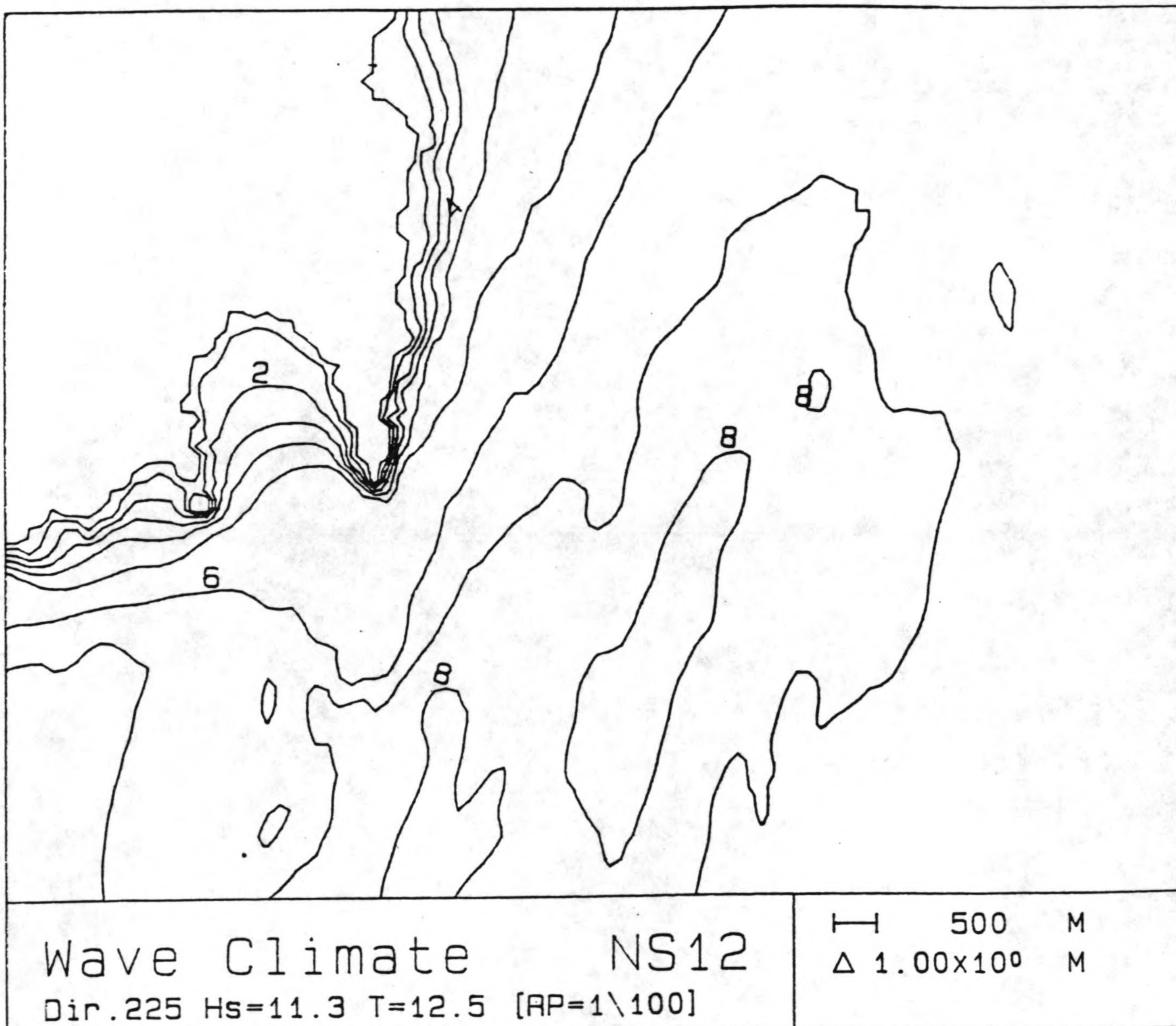


Figure C36: HISWA results, Hurricane Conditions. Returnperiod once every 100 years. Direction 225° H_s = 11,3 meter, T_s = 12,5 seconds. Wave heights near St. Maarten.

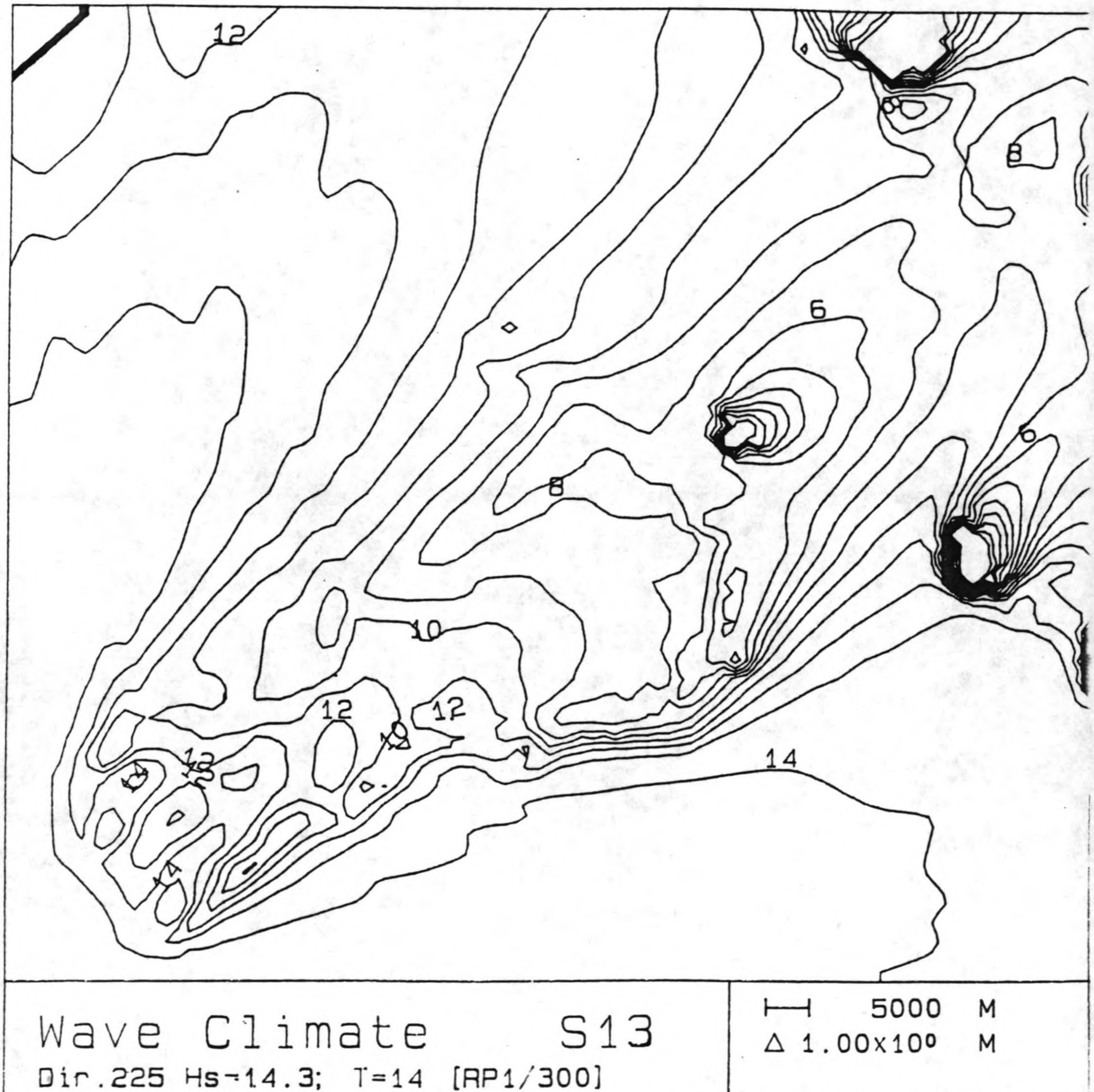


Figure C37: HISWA results, Hurricane Conditions. Return period once every 300 years. Direction 225° H_s = 14,3 meter, T_s = 14,0 seconds. Wave behaviour through window.

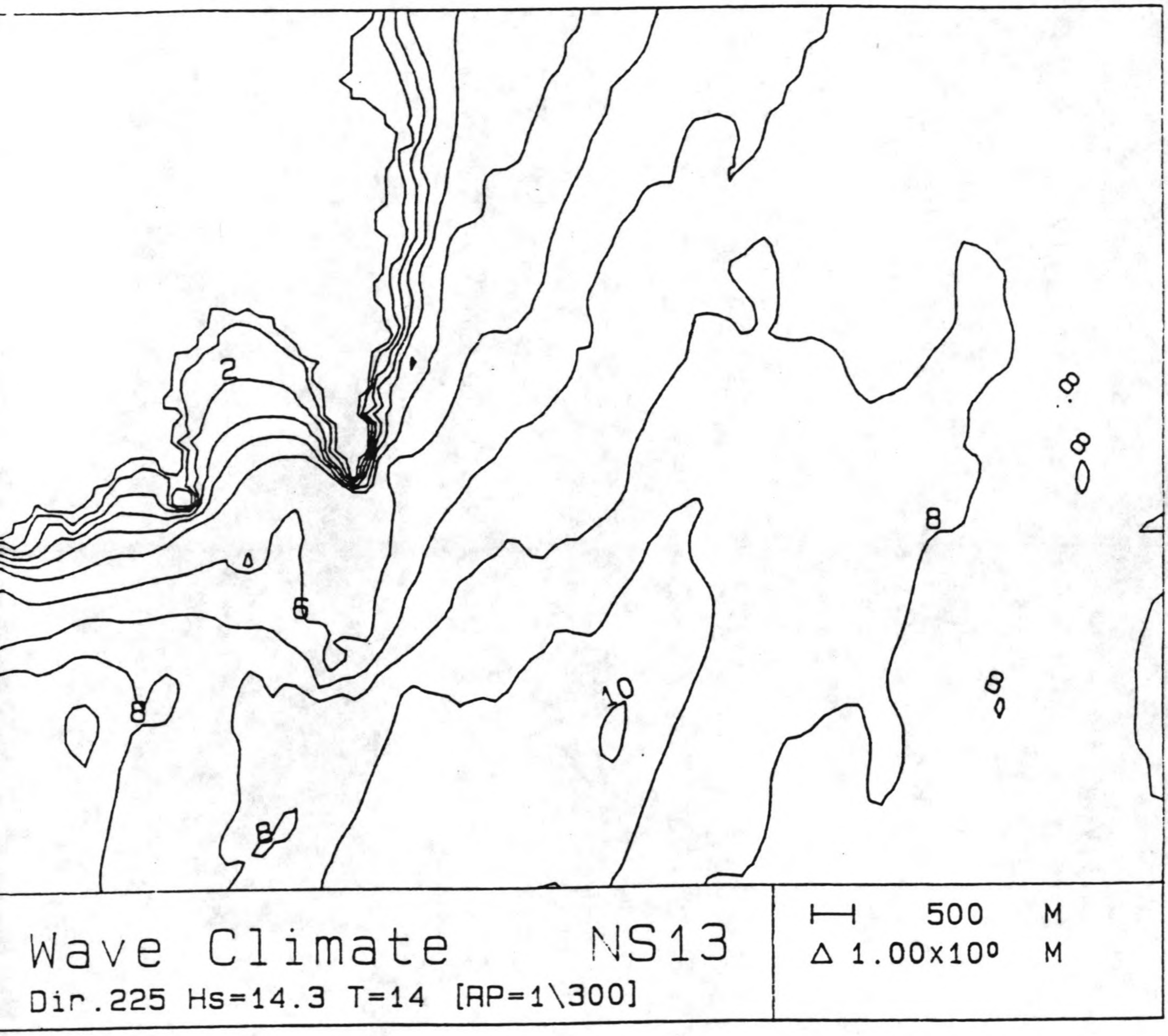


Figure C38: HISWA results, Hurricane Conditions. Returnperiod once every 300 years. Direction 225° H_s = 14,3 meter, T_s = 14,0 seconds. Wave heights near St. Maarten.

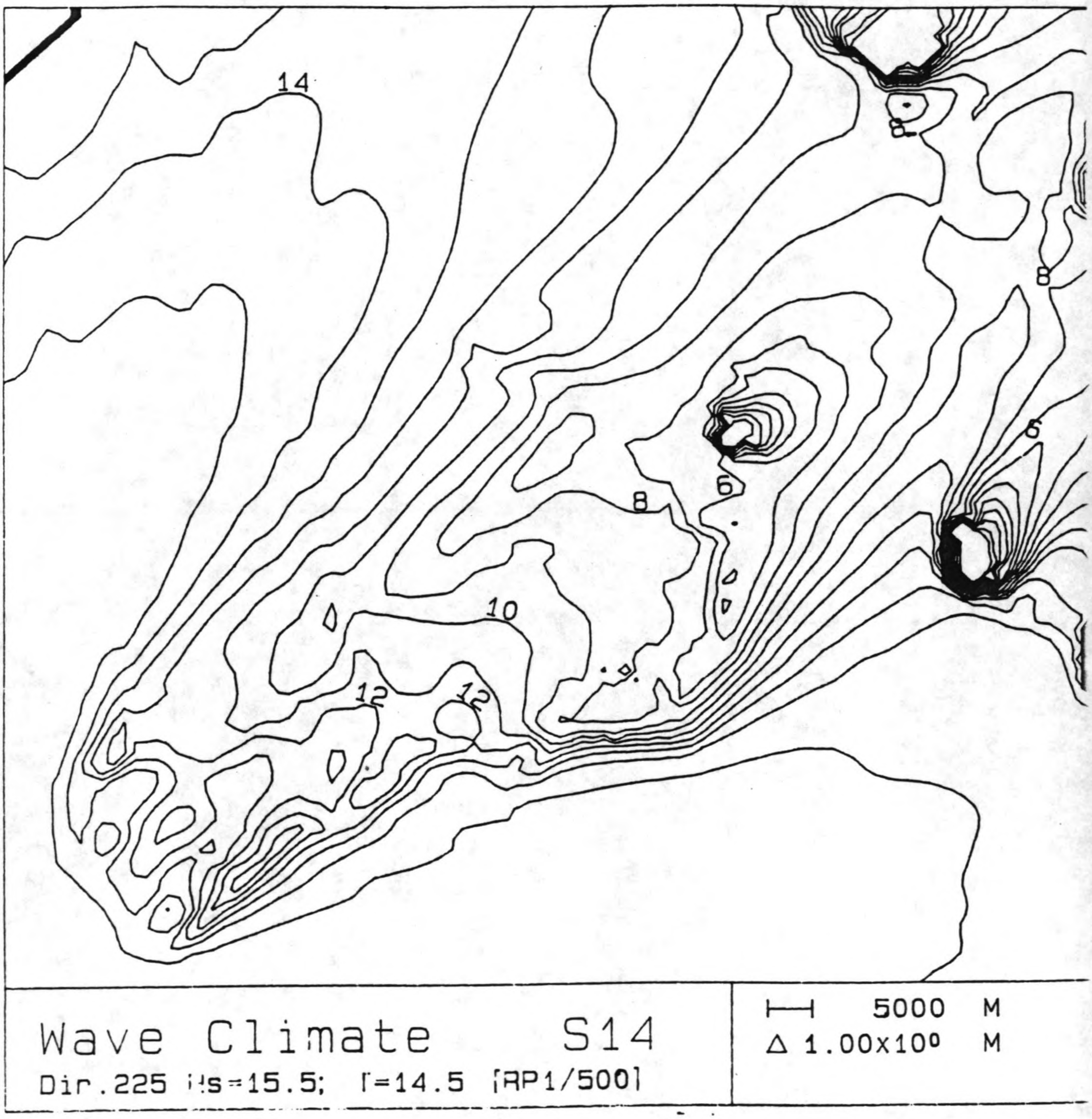


Figure C39: HISWA results, Hurricane Conditions. Return period once every 500 years. Direction 225° H_s = 15,5 meter, T_s = 14,5 seconds. Wave behaviour through window.

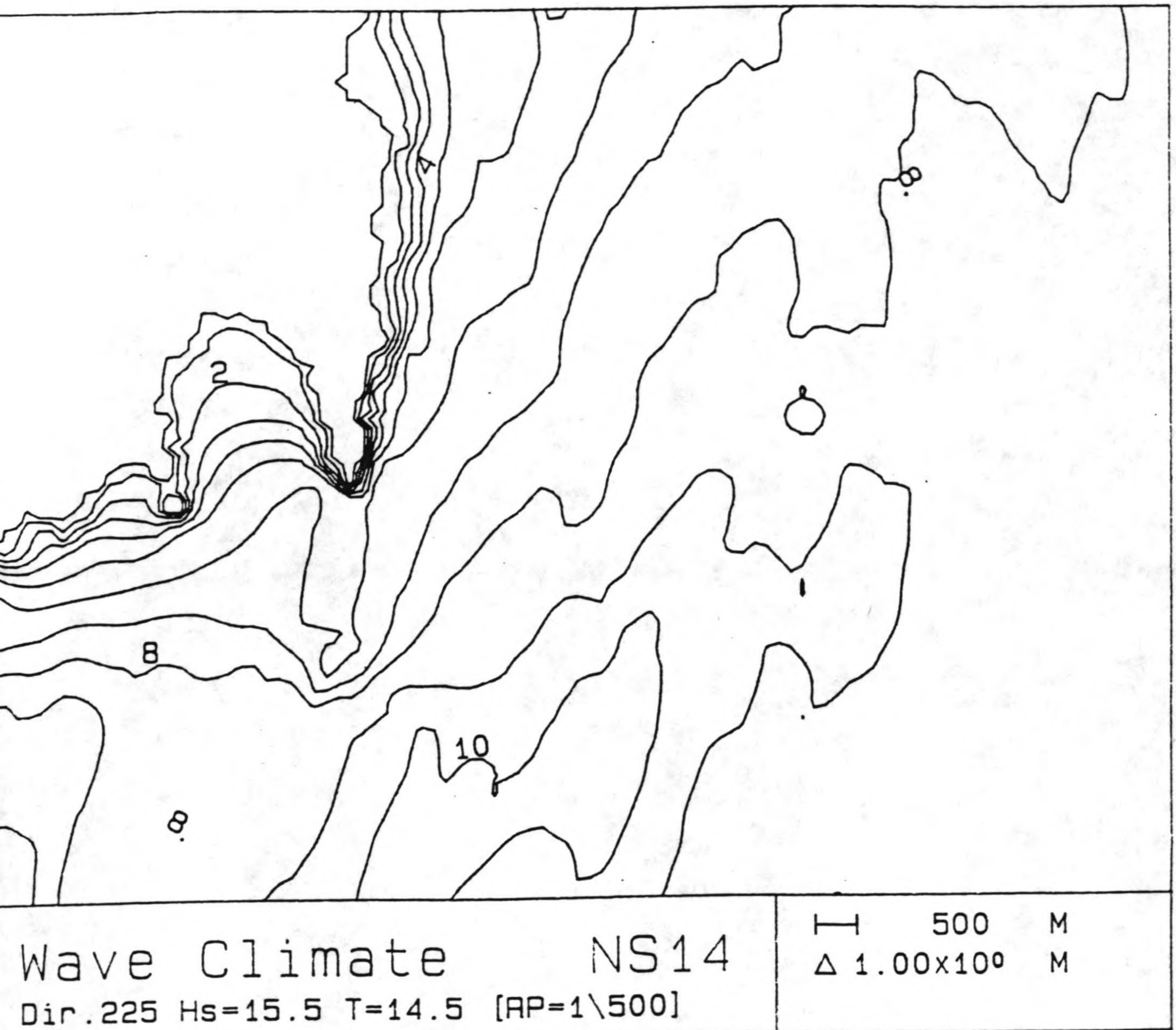


Figure C40: HISWA results, Hurricane Conditions. Returnperiod once every 500 years. Direction 225° H_s = 15,5 meter, T_s = 14,5 seconds. Wave heights near St. Maarten.

Appendix D. REFERENCES.

1. **Evaluation of environmental criteria for proposed harbor facilities in Great Bay St. Maarten Netherlands Antilles.**
   Coastal Environmental Associates (CEA)
2. **Preliminary environmental study, present situation.**
   St. Maarten Ports Authority,
   Grabowsky&Poort International BV.
3. **Breakwaters, design and construction,**
   Conference May 1983,
   Institution of Civil Engineers,
   Westminister London SW1P 3AA
4. **Wave Climate Study for the jetty at Oranje Baai St. Eustatius N.A., report H777,**
   Delft Hydraulics de Voorst
5. **HISWA user manual, prediction of stationary short-crested waves in shallow water with ambient currents.**
   N. Booij, T.H.C. Herbers, L.H. Holthuijsen, R. Schoonbeek,
   Delft University of Technology, Department of Civil Engineering.
6. **Hydrodynamics of Coastal Zones,**
   S.R. Massel,
   Elsevier Oceannographic Series.
7. **Shore Protection Manual,**
   Coastal Engineering Research Centre, Department Of The Army, Volume I and II, 1984.
8. **Lecture notes, Korte Golven b76,**
   J.A. Battjes.
9. **Tide Surges and Mean Sea level. A handbook for Engineers and Scientists,**
   D.T. Pugh,
   John Wiley & Sons.
10. **Basic Coastal Engineering,**
    Sorensen R.M.,
    John Wiley & Sons

11. **Statistical Theory of Extreme Values and some practical applications.**
Lectures edited by E.J. Gumbel
National Bureau of Standards
Applied mathematics Series .33 [issued feb. 1954]
12. **Toegepaste Fysische Oceanografie,**
Reader lecture notes X2CT1
TU Delft, section Hydrodynamics.

883619