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Publication date:
2007

Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):
Borgarino, B., & Brorsen, M. (2007). *Estimation of wave conditions at Liseleje location*. Department of Civil Engineering, Aalborg University. DCE Technical reports No. 23

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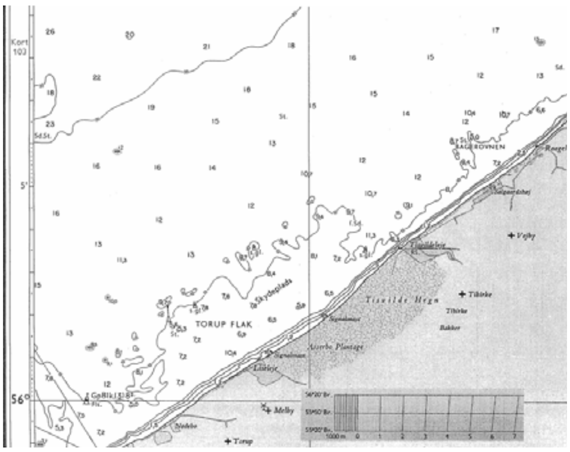

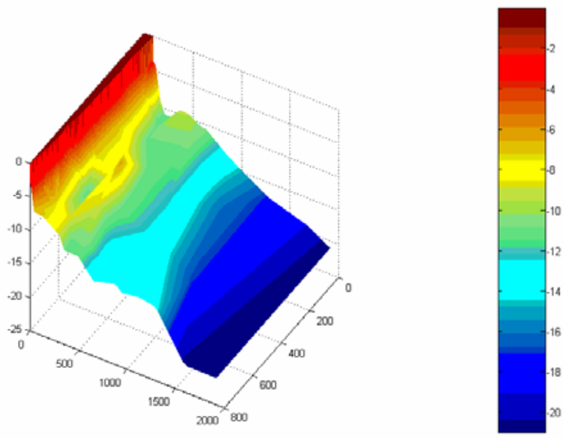

ISSN 1901-726X
DCE Technical Report No. 23

AALBORG UNIVERSITY
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Estimation of wave conditions at Liseleje location

by

Bruno Borgarino
Michael Brorsen

July 2007

Preface

This report present the near-shore waves conditions at Liseleje. This study has been carried out as a first step to evaluate the possibility of installing an overtopping wave energy converter at Liseleje.
The offshore conditions have first been calculated, using 30 years recorded wind data. Then numerical simulations have been performed to estimate the effect on the seabed on significant wave height and direction.
Finally, offshore and near-shore conditions, including energy considerations, are displayed in this report.

This study has been performed in July 2007 at Aalborg University by Bruno Borgarino, under the supervision of Jens Peter Kofoed and Michael Brorsen (AAU).

Version	***Date***	***Author***	***Comment***
0.0	31.07.2007	Bruno Borgarino	First version

Published 2007 by
Aalborg University
Department of Civil Engineering
Sohngaardsholmsvej 57,
DK-9000 Aalborg, Denmark

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Introduction

This report presents all the steps performed to have a rough estimation of the wave conditions at Liseleje location. This study has been based on the method of the Coastal Engineering Manual.

Given the situation of the site (see Figure 1), it is assumed that no swell propagates until Liseleje. Indeed, this site is surrounded by land: Swedish coast at East, Norwich coast at North, Danish coast at South and West. The access to open sea, on the top of Denmark, is limited. Consequently, the sea is only formed by the influence of the wind speed, the time duration of a wind event, and the length of the fetch.

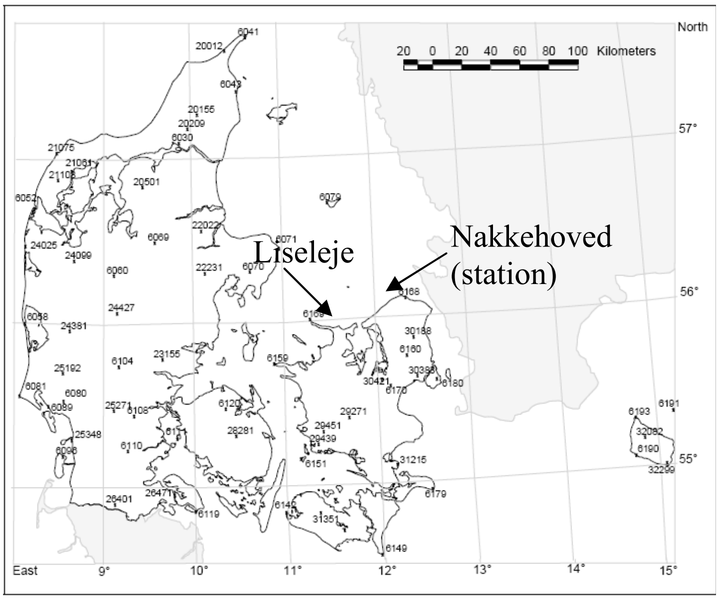

Figure 1: Position of the site and of the measure station used

The parameters that are searched are the peak period (Tp), the significant wave height (Hm0) and the probabilities of occurrence, necessary to describe irregular sea states.

1. Offshore conditions

1.1 Calculation of the fetch

The calculation of the fetch is made in the twelve directions of the wind rose, so as to fit the available wind data. For each direction, rays are plotted every 7.5° in the -45°/+45° range around this direction, until the nearest coast. The fetch is the average of the segments length weighted by he cosine of the angle from the main direction.

So as to apply this method, the open source software gvSIG has been chosen. Coastal maps of Denmark, Sweden and Norway in shapefile format have been found at the following URL: http://biogeo.berkeley.edu/bgm/gdatares.php. To situate precisely Liseleje on the map, the easier way has been to georeference a satellite picture.
The projection system chosen in order to minimize errors in measurements is the UTM Datum 1950. According to the ESPG database (European Petroleum Survey Group), this projection in adapted to Denmark.
Figure 2 shows the example of fetch measurement for the 0° direction.

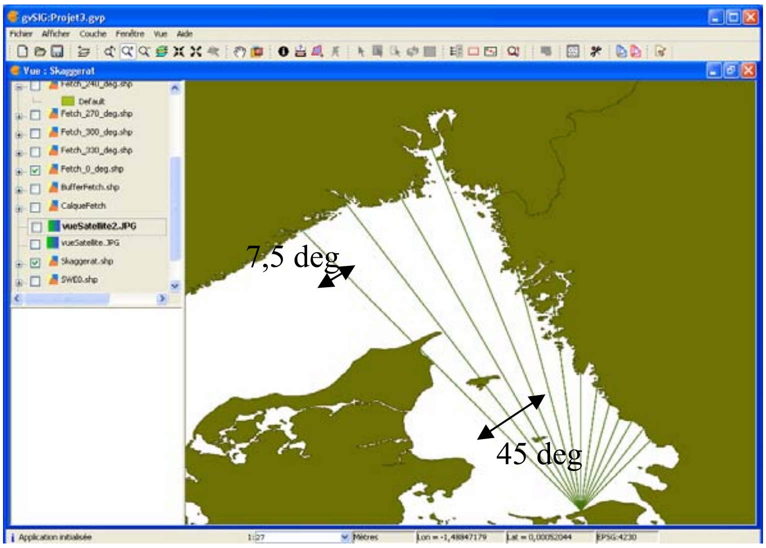

Figure 2: Screen print of the gvSIG interface for the calculation of the northern fetch

The length of the fetch in every direction is given below:

Direction (degrees)	Fetch (m)
0	207
30	108
60	54
90	20
120	0
150	0
180	0
210	3
240	124
270	69
300	158
330	208

Table 1: Fetch length

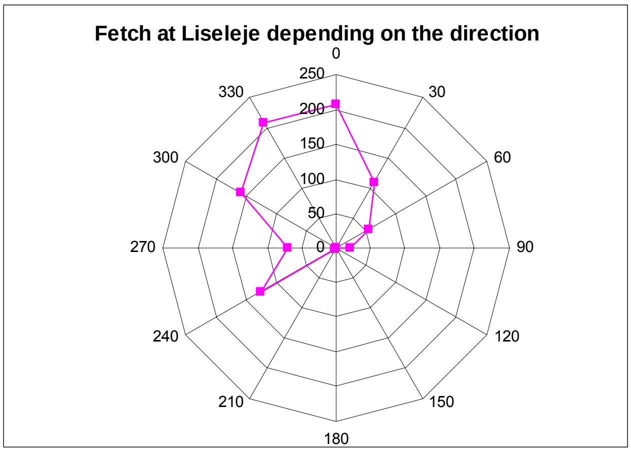

Figure 3: Fetch length

1.2 Treatment of the wind data

The available wind data are the annual wind rose at a site close to Liseleje. This rose is extracted from the Technical Report 99-13, “Observed wind speed and direction in Denmark, with climatological standard normals”, displayed by the Danish Meteorological Institute. Wind data are displayed 10 m above the ground level.

It has been assumed that these data apply to Liseleje for different reasons:

- These sites are closed each other: they are both on the Northern coast of Sealland.
- The topology of these sites is very similar (sand beaches and flat land)

The annual wind rose is given in the table below:

Direction (deg)	0	30	60	90	120	150	180	210	240	270	300	330
0,2 - 5 m/s	1,8	1,2	1,6	3,1	4	5	5,4	6	4	3	2,6	2
5 - 11 m/s	2,7	1,5	2,3	3,2	5	5,2	4,5	6,7	7,1	7	5,2	3,3
> 11 m/s	0,8	0,5	0,4	0,1	0,1	0,1	0,1	0,1	0,3	0,7	1,7	1,2
Mean speed	6,9	6,8	6,5	5,3	5,5	5,3	5	5,3	6,1	6,6	7,6	7,5
Max speed	25,7	21,1	20,6	16,5	14,9	14,9	14,4	17,5	17	23,1	26,8	27,8

Table 2: Wind rose at Nakehoved. Probability of occurrence depending on the wind speed and the direction

It can be seen that these data are to synthetic to calculate the sea states: only three range of wind speed are available. It limits the future choice of the sea state ranges. Moreover, the mean wind speed in each interval is unknown.

Consequently, it has been chosen to extrapolate these data, so has to have the probability for every direction and speed range of 1 m/s. The following steps are performed:

- From available data, the coefficients of the corresponding two parameters Weibull distribution have been found.
- From this Weibull distribution, probability for every speed is deducted.

For the first step, a specific Matlab routine has been programmed. The global idea is the following:

- For every each speed range, pick a specific speed : this gives a three lines vector
- Apply the Matlab function “Weibfit” to this vector. The function returns the two parameters of the Weibull distribution.
- From this parameters, integrate the corresponding probability density function on each of the three speed ranges.
- If the total integration corresponds to the probability of occurrence given by the wind rose for each range, then the Weibull parameters are corrects.

In the second step, it is possible to use these parameters to compute a more precise wind rose. Figure 4 gives an example for direction 0°.

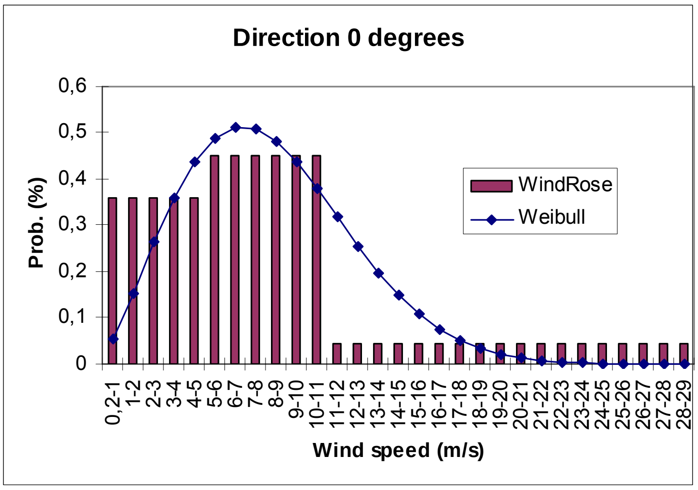

Figure 4: Weibull distribution deducted from the wind rose

Figure 5 shows the distribution for all the directions. This analysis has been performed only in the 9 directions where the fetch is different from zero.

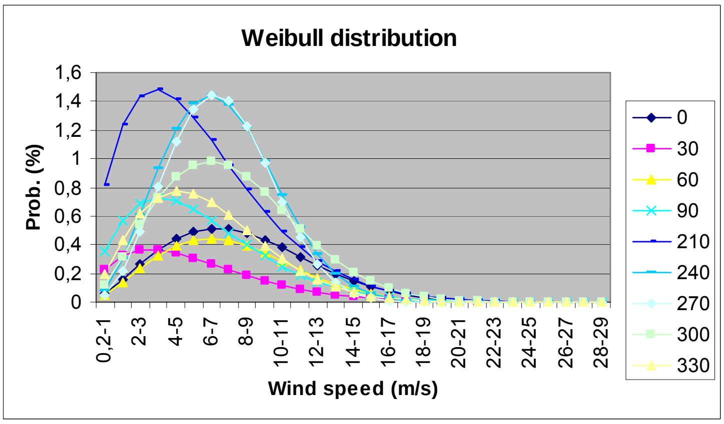

Figure 5: Weibull distribution of the wind for each direction

1.3 Time limited waves

The wave growth can be limited by two factors: the fetch, or the time duration of the wind event. The Coastal Engineering Manual gives the minimum time duration to have fetched limited waves depending on the fetch. Consequently, a time analysis on wind events is necessary to determine what limits the waves.

From geostrophic wind to ground wind

The only available time dependant data is the geostrophic wind. The Technical report 99-13 gives the value and direction of the geostrophic wind every three hours from 1968 to 1998.
These data are deducted from pressure measures; their quality should be better than for the wind roses. They are deducted from 3 stations forming a triangle in which Liseleje is included.

The relation between geostrophic and ground wind is very complex. Here, the goal is only to find a simple correspondence between these winds, in order to evaluate the duration of wind events. For other analysis, the values deducted from the wind rose will be conserved.

Equation 1 is a simplified model giving the relation between the ground and the geostrophic wind.

$$U(z) = G.\left[1 + \sqrt{2}.\sin|a|.e^{-wz}.\cos(-wz + |a| + \frac{3\pi}{4})\right] \qquad \textbf{Equation 1}$$

$$w = \sqrt{f / Km}$$

In this model:

- G is the geostrophic wind
- U is the projection of the ground wind in the direction of G
- a is the angle between geostrophic and ground wind
- z is the altitude
- f is the Coriolis parameter
- Km is a turbulent exchange coefficient. The coefficient normally varies during the time

From this model, two approximations are made:

- The angle between U and G, due to the Coriolis effects, is 20°
- U=Cte*G, where Cte is a constant; this is equivalent to say that Km is constant, what is not true. However, because we study a very large time scale, this approximation is acceptable.

From the time series of geostrophic wind, a “geostrophic wind rose”, corresponding to the ground wind direction, is computed by a specific Matlab routine. Figure 6 shows this wind rose (in blue).

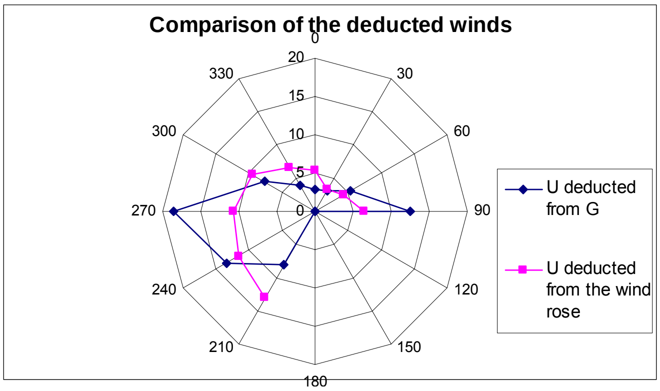

Figure 6: Comparison of the deducted winds (probabilities of occurrences)

The dominant Eastern/Western winds are more presents with U deducted from G. Despite the approximations, the deducted wind is coherent with the Danish weather.

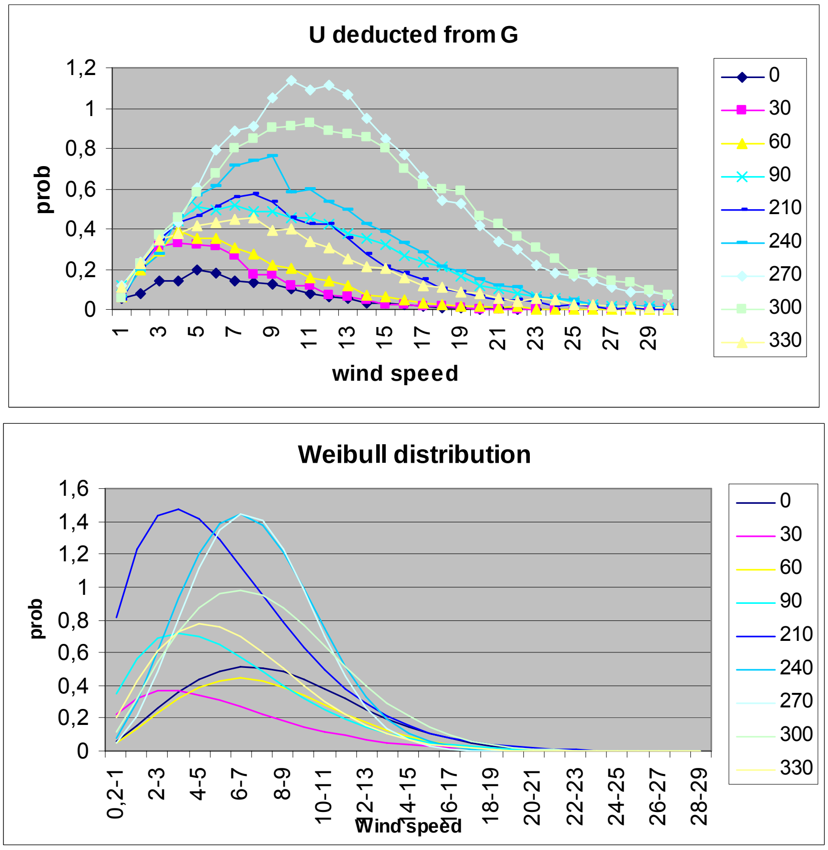

Figure 7: Comparaison between the Weibull distribution and U deducted from G

From Figure 7 it can be seen that the geostrophic wind and the Weibull wind deducted previously are not centred on the same wind speed value. In order to translate the geostrophic spectrum, speed values for each direction are multiplied by a constant corresponding to Cte.
Equations 2 and 3 show that the probability density function can be centred from λ_1 to λ_2 by such a multiplication.

$$\lambda_1 = \frac{\lambda_1}{\lambda_2}.\lambda_2 = C.\lambda_2 \qquad \textbf{Equation 2}$$

$$f(G,\lambda_1) = \frac{k.}{\lambda_2.C}\left(\frac{G}{\lambda_2.C}\right)^{(k-1)} e^{-\left(\frac{U}{\lambda_2.C}\right)^k} = f(\frac{G}{C},\lambda_2).\frac{1}{C} = f(U,\lambda_2).\frac{1}{C} \qquad \textbf{Equation 3}$$

Figure 8 displays this conversion for one direction:

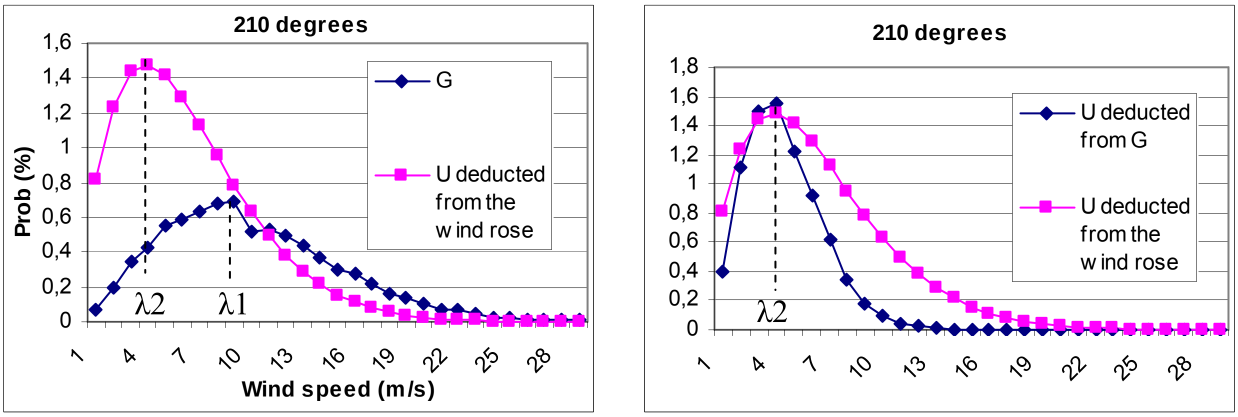

Figure 8 : Results of the conversion geostrophic wind/ground wind

The multiplication constants ensure that the dominant wind will be the same by converting the geostrophic wind in ground wind. Despite of a relatively different shape, we can find distribution quite similar from G and from the wind rose.
Further analyses have shown that the two approximations above are responsible of the differences. Anyway, because no other data are available, the multiplication constants found have been kept.

Events duration

The time series of the ground wind U is obtained by multiplying G by the good constant Cte, depending on the direction.

The mean time duration of wind event has been estimated for every direction and speed bin. The time series have first been split in twelve vectors corresponding to the twelve directions.
Then, if more than 3 hours pass between two following values in the same direction, a new event is created. The mean speed of the previous event and its duration are computed. Finally, for every speed range and direction, the mean duration of wind event are calculated.

The results have been compared with the minimum wind duration necessary to have fetch-limited wave. In most of cases, the waves will be fetch-limited.

1.4 Deduction of the offshore sea states

This part follows strictly the CEM method, compound by the following steps.

If the waves are time limited, it is necessary to calculate an equivalent fetch before continuing the calculation. Hm0 and Tp are obtained by this method, depending on the direction and the speed.

Scatter diagrams

The previous results can be recombined to obtain a scatter diagram for each direction, giving the occurrence probability depending on Hs and Tp.

So as to visualise clearly the sea states, the results have been plotted with small steps for Hs and Tp. Figure 9 and 10 shows the obtained sea states.

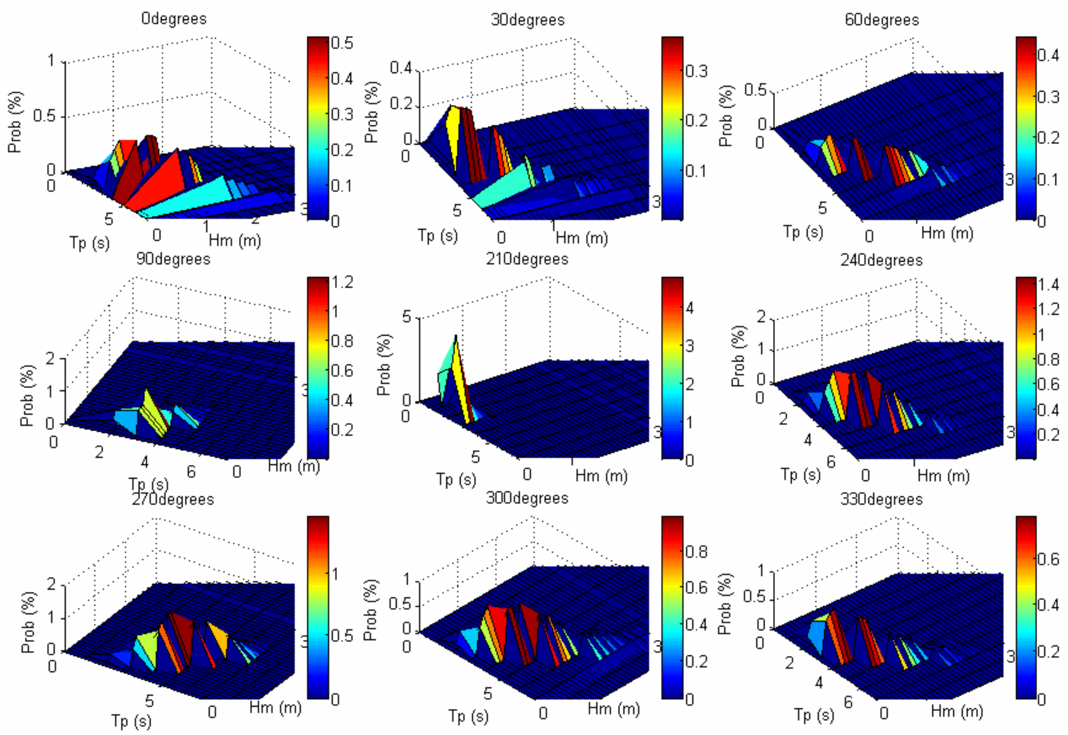

Figure 9 : Deducted offshore sea states per direction

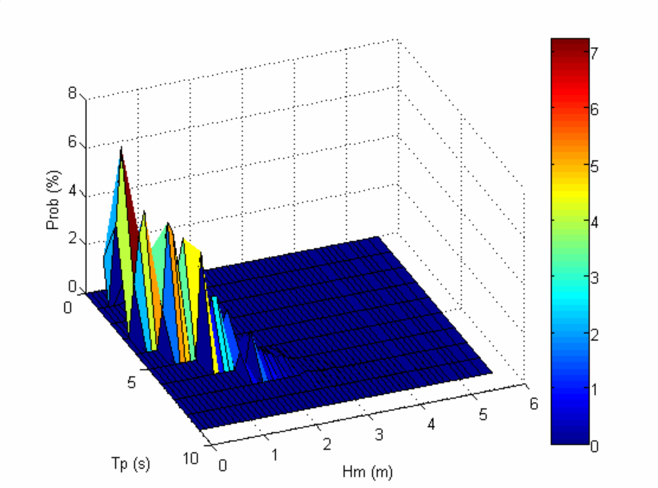

Figure 10: Offshore sea states (sum on all the directions)

However, in order to be easy to use, the probabilities have been summed in 2 second intervals for Tp and 0.5 meters intervals for Hs. Table 3 gives an example for the 0° direction.

		Tp (s)									
		1-3	3-5	5-7	7-9	9-11	11-13	13-15	15-17	17-19	19-21
Hm0 (m)	0,25-0,75	0,80	1,00	0	0	0	0	0	0	0	0
	0,75-1,25	0	1,81	0	0	0	0	0	0	0	0
	1,25-1,75	0	0,57	0,20	0	0	0	0	0	0	0
	1,75-2,25	0	0	0,26	0	0	0	0	0	0	0
	2,25-2,75	0	0	0,16	0	0	0	0	0	0	0
	2,75-3,25	0	0	0,03	0	0	0	0	0	0	0
	3,25-3,75	0	0	0,01	0	0	0	0	0	0	0
	3,75-4,25	0	0	0	0	0	0	0	0	0	0
	4,25-4,75	0	0	0	0	0	0	0	0	0	0
	4,75-5,25	0	0	0	0	0	0	0	0	0	0
	5,25-5,75	0	0	0	0	0	0	0	0	0	0

Table 3 : Offshore sea states coming from North

The offshore scatter tables for every direction are displayed in appendix 2.
The advantage of this way of displaying the results is the ability to compare from one direction to another. Because of all the previous approximations, there is no significant loss of accuracy in grouping the probability in the intervals of Hm0 and Tp.
Table 4 gives the sum of the sea states on all he directions. The sea states are low: the maximal significant height is around 3.5 meters, and the maximal peak period around 6 seconds. Given the position of Liseleje, this is coherent.

	Tp (s)				
		1-3	3-5	5-7	**Sum**
Hm0 (m)	0,25-0,75	13,91	13,29	0	27,20
	0,75-1,25	0	14,63	0	14,63
	1,25-1,75	0	5,47	2,43	7,89
	1,75-2,25	0	0,01	2,12	2,13
	2,25-2,75	0	0	0,64	0,64
	2,75-3,25	0	0	0,12	0,12
	3,25-3,75	0	0	0,03	0,03
	Sum	13,91	33,40	5,34	

Table 4 : Sum of the sea states (%)

Figure 11 gives the probability of occurrence depending on the direction. The roles of the fetch and of the dominant winds are obvious.

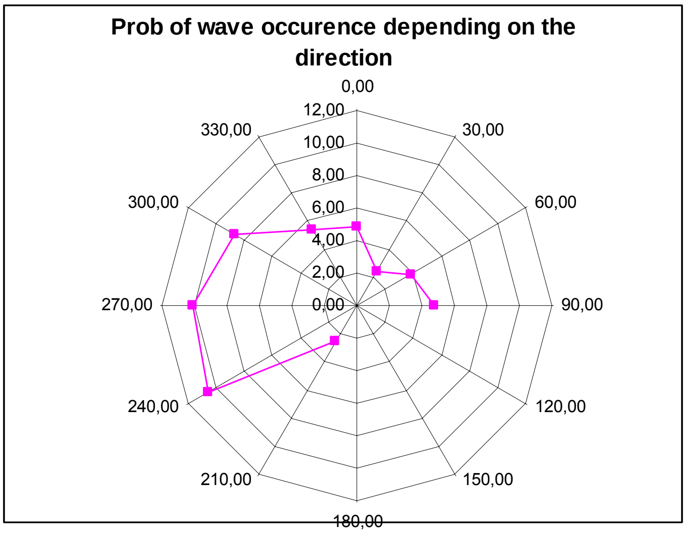

Figure 11 : influence of dominant winds and fetch

The offshore conditions are not optimal for the installation of a wave energy converter.

2. Near-shore conditions

In order to have a coherent description of the sea states at Liseleje, the influence of the shore has to be estimated.
This analysis has been performed with two simulations tools, developed at Aalborg University:

- VanLand: this software creates input data for MildSim.
- MildSim: this software solves the mild-slope equations; it computes accurately the refraction, the wave-braking and the shoaling.

2.1 Modelling of the bathymetry

From a sea maps, points with their coordinates and depths are picked. From these points, VanLand interpolates a more precise bathymetry. Figure 12 gives an example of available results:

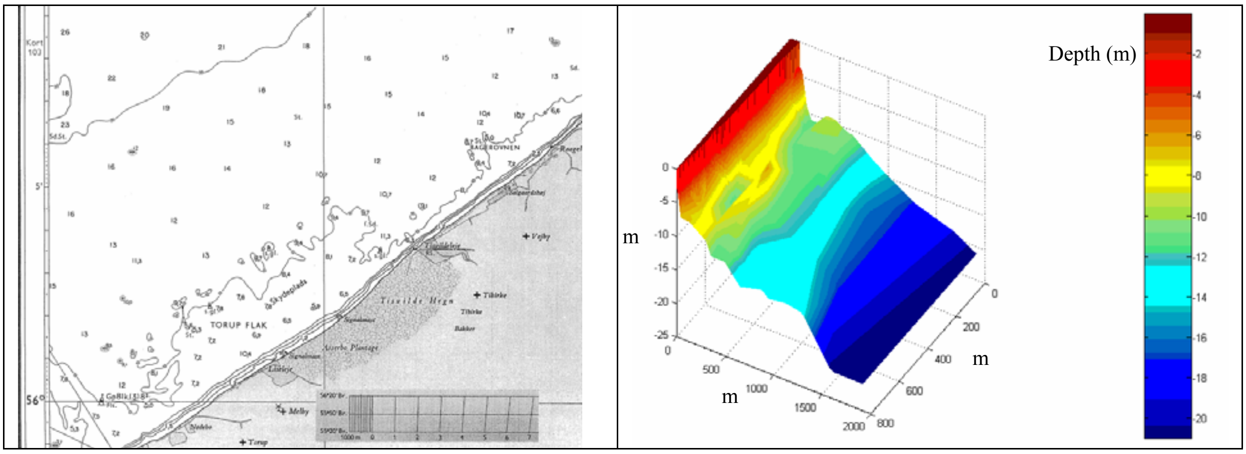

Figure 12 : modelling of the bathymetry

2.2 Consideration about modelling with MildSim

MildSim computes at each time step the surface elevation and the significant wave height of an area created with VanLand. The wave field is generated at a generation line and propagate to the shore. The border conditions are modelled by “sponge layers”: these elements multiply the sea elevation by a number less than one to represent the energy loss (propagation out of the area or absorption).

The model of the bathymetry does not extend to the shore for different reasons:

- MildSim does not work with a depth equal to zero
- Because the sea map used is not precise enough, the modelling of the wave breaking on the beach would be inaccurate
- The wave energy available directly on the shore would be too small and is not interesting

Consequently the border of the model is the 2 meters depth line. This border is made by sponge layers calibrated to have a reflection as small as possible (corresponding to the absorption of a beach).

The model created on VanLand has to be large enough to show the influence of the bathymetry, and small enough to save computation time. Because the influence of the bathymetry depends on the wave length, three different models have been created:

Tp (s)	Offshore wave length λmax (m)	Maximal depth of influence (λmax/2)	Dimensions of the model (m)	Length of the boxes (m)	Time step (s)
2	6,24	3,12	675*200	0,75	0,15
4	24,96	12,48	1000*500	2	0,2
6	56,16	28,08	1900*960	3,2	0,25

Table 5 : models created on VanLand depending on the wave length

Due to the orientation of the coast, the model has been rotated by 45 degrees to maximize the area of interest (limit the area of land):

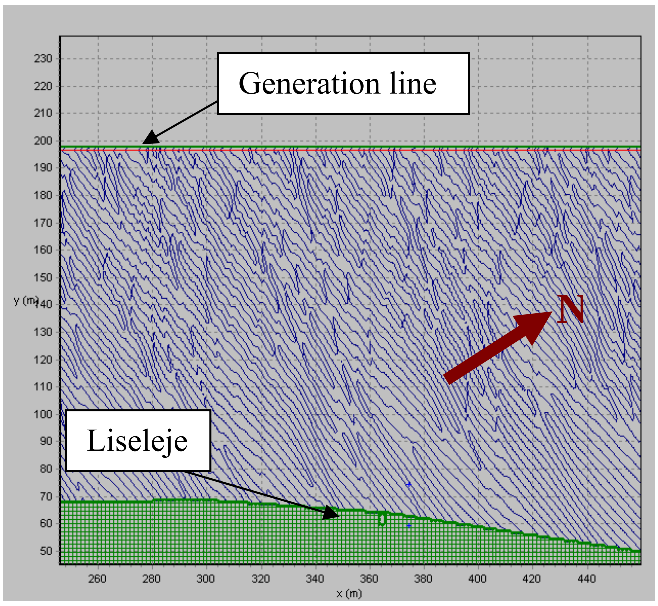

Figure 13 : Simulation of the propagation of a wave field coming from North

2.3 Simulated sea states

In order to check the models, regular wave have been tested first.
Then, all the sea states obtained in the previous part have been computed. 3D irregular waves have been sent, with the following characteristics:

- Waves can propagate in a range large of 90 degrees around the main direction. This corresponds with the range of directions used to measure the fetch.
- 20% of the waves propagate in the main direction

The following results have been saved:

- For each direction and peak period, the significant wave height field and the sea elevation field have been saved. They have been used to measure the direction change in the propagation of the waves (due to refraction).
- For each offshore significant wave height, the corresponding significant wave height at Liseleje is measured.

2.4 General considerations on the results

Figures 14, 15, 16 show the ratio between the offshore Hm0 and the corresponding value at Liseleje:

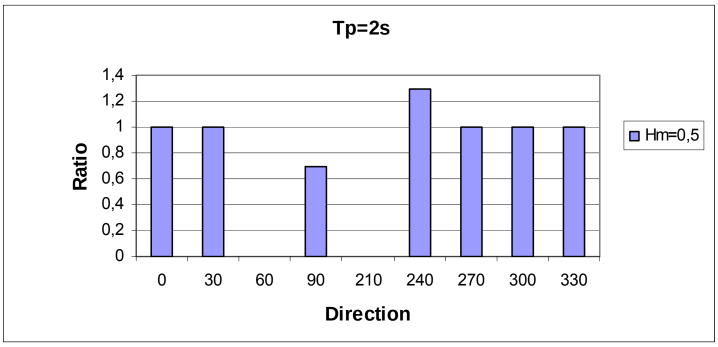

Figure 14: Hm0 near-shore/ Hm0 offshore (Tp=2 s)

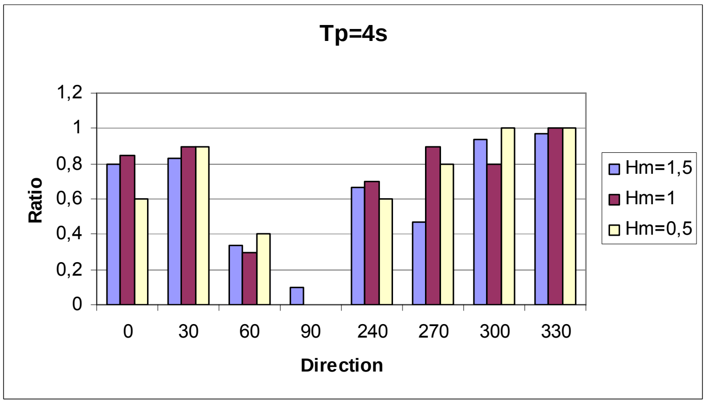

Figure 15: Hm0 near-shore/ Hm0 offshore (Tp=4 s)

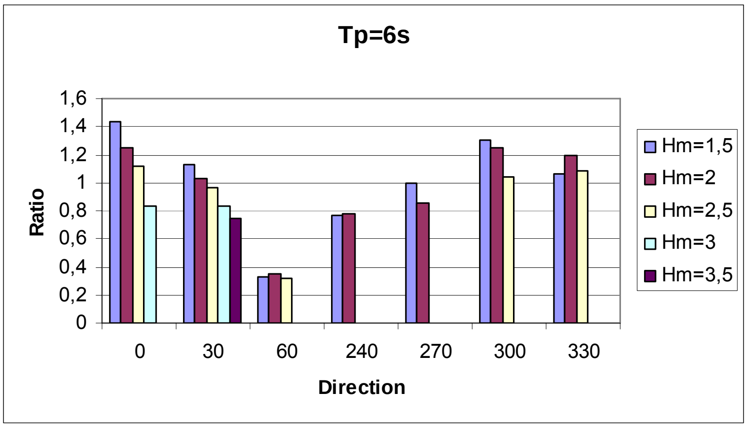

Figure 16: Hm0 near-shore/ Hm0 offshore (Tp=6 s)

In most cases, this ratio is less than one, what seems coherent. However, two phenomenons can be underlined: shoaling and wave breaking.
For a 6 seconds peak period, in the direction 0 degrees this ratio is more than one until a certain significant wave height. This shows that there is a shoaling effect due to the bathymetry, increasing the Hm0, and leading to a wave breaking if Hm0 is too important.

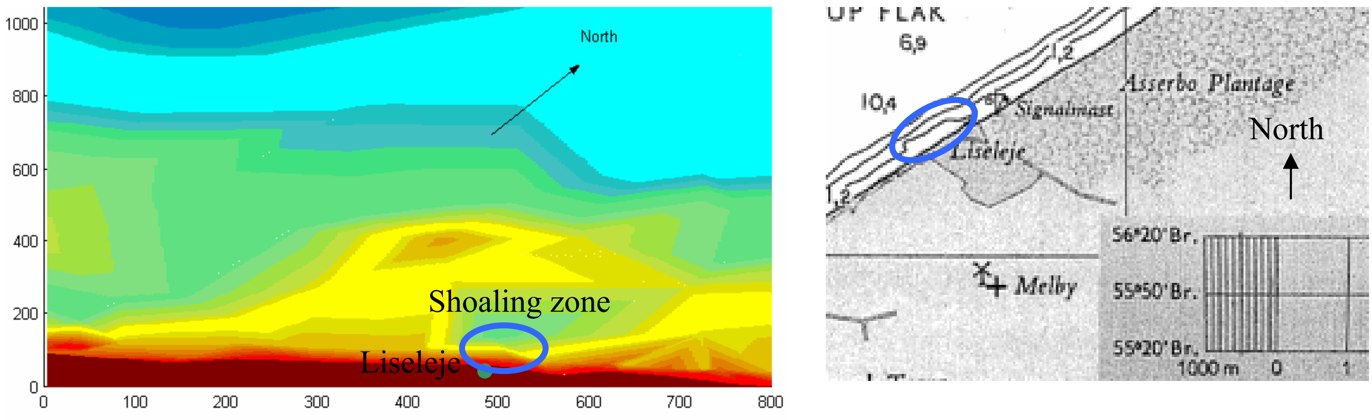

Figure 17 : Shoaling zone at Liseleje

Figure 17 displays this shoaling zone, visible on the map and on the numerical bathymetry. However, this effect may be a little overestimated because of the interpolation in VanLand.

2.5 Numerical results and near-shore sea states

Two major effects modify the sea states: a change in the incidence direction due to the diffraction and a change in the Hm0. Table 6 give an example of these changes for an offshore incidence of 30 degrees:

Hm0 (m)	Tp (s)	Prob (%)	Hm0 near-shore (m)	Incidence nearshore (degrees)
0,5	2	0,709	0,5	30
0,5	4	0,577	0,45	15
1	4	0,563	0,9	15
1,5	4	0,211	1,25	15
1,5	6	0,070	1,7	5
2	6	0,121	2,05	5
2,5	6	0,046	2,4	5
3	6	0,007	2,5	5
3,5	6	0,003	2,6	5

Table 6 : example of the influence of bathymetry on the sea states

The seabed influence is more important when Tp increases. The wave field turns in order to face the beach (see Figure 18).

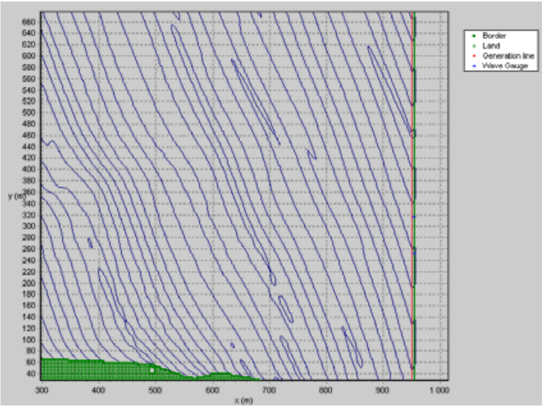

Figure 18 : example of the influence of the bathymetry on the propagation direction

The significant wave height is diminished by the proximity of the shore (see Figure 19).

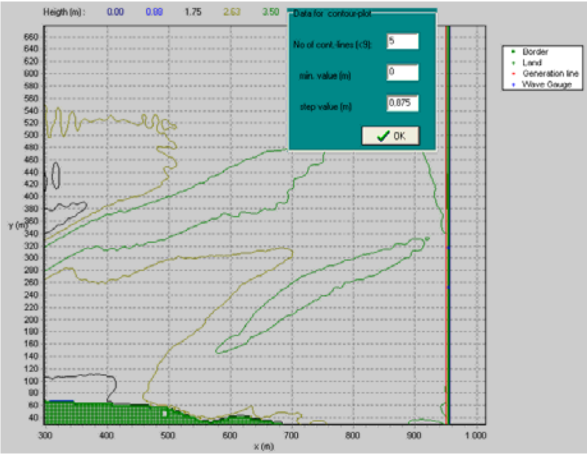

Figure 19: example of the influence of the bathymetry on Hm0

In order to have synthetic results, the sea states have been recombined: if the direction or Hm0 are sufficiently modified and go to another interval of direction or Hm0, the probability of occurrence of this sea state is moved to this new interval and summed to the previous one.

Table shows that the probability of occurrence is now concentrated on a smaller number of directions, fitting with the orientation of the beach (315 degrees) and the dominant wind.

Direction (degrees)	Prob. (%)	Average Hm0 (m)	prob*power (W)
0	4,95	1,01	14 662
30	4,05	0,58	2 469
90	3,13	0,50	668
240	2,14	0,50	457
270	17,97	0,75	24 419
300	8,47	1,05	26 891
330	5,38	0,86	10 470
Sum	46,09		

Table 7: Available energy

For each sea state, the power available per meter on wave crest has been calculated using the Equation 4:

$$P_{Wave} = \frac{\rho g^2}{64\pi}.Te.Hm0^2 \text{ (with Te=Tp/1.15)} \qquad \textbf{Equation 4}$$

The multiplication of the power available by the probability of occurrence gives an idea of the available energy for each direction (see Figure 20).

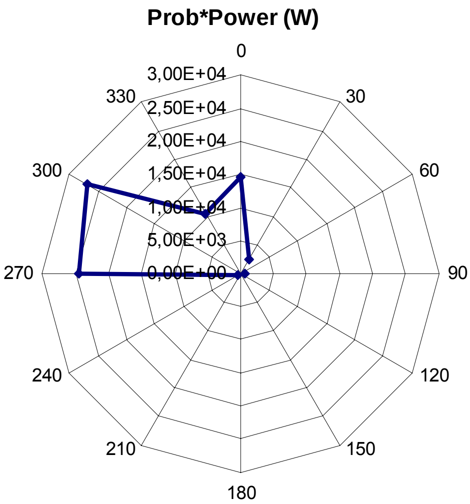

Figure 20 : repartition of the available energy depending on the direction

The final near-shore sea states for Liseleje are displayed in the following table:

	Tp (s)	**2**	**4**	**4**	**4**	**6**	**6**	**6**	**6**	**6**	**6**		
	Hm0 (m)	**0,5**	**0,5**	**1**	**1,5**	**0,5**	**1**	**1,5**	**2**	**2,5**	**3**	**Sum**	**%**
0°	Prob (%)	0,80	1,00	2,38				0,07	0,32	0,35	0,03	4,95	4,95
	Power (W)	214	427	1 710				5 771	10 260	16 031	23 084	57 497	43,60
	Power * Prob	171	428	4 067				407	3 277	5 544	768	14 662	18,13
30°	Prob (%)	0,71	2,42	0,56		2,42	0,05					6,16	6,16
	Power (W)	214	427	1 710		427	2 565					5 344	0,00
	Power * Prob	151	1 034	962		1 034	125					3 305	4,09
90°	Prob (%)	3,13										3,13	3,13
	Power (W)	214										214	0,16
	Power * Prob	668										668	0,83
240°	Prob (%)	2,14										2,14	2,14
	Power (W)	214										214	0,16
	Power * Prob	457										457	0,56
270°	Prob (%)	0,81	10,31	4,86				2,00				17,97	17,97
	Power (W)	214	427	1 710				5 771				8 122	6,16
	Power * Prob	173	4 406	8 316				11 524				24 419	30,19
300°	Prob (%)	1,60	1,94	2,59	1,16				0,40	0,80		8,47	8,47
	Power (W)	214	427	1 710	3 847				10 260	16 031		32 489	24,64
	Power * Prob	342	828	4 422	4 446				4 069	12 783		26 891	33,25
330°	Prob (%)	1,50	1,45	1,50	0,52			0,15		0,25		5,38	5,38
	Power (W)	214	427	1 710	3 847			5 771		16 031		28 000	21,23
	Power * Prob	321	621	2 566	1 996			885		4 082		10 470	12,95
											Prob	48,20	48,20
											Power (W)	131 879	100,00
											Power * Prob	80 872	100,00

Only 48% of the time is concerned. It is because the time concerning the following points has been eliminated:

- When the wind direction is 120, 150 or 180 degrees (the fetch is equal to zero)
- When the offshore significant wave height is under 0.25 meters
- When the near-shore significant wave height is under 0.25 meters

The direction where the most energy is available, are 270, 300 and 0 degrees. It is a combination between different factors: dominant winds, fetch and orientation of the beach. However, the available energy and the significant wave height are very low. Table 8 gives the probability of the different Hm0:

Hm0 (m)	Prob (%)
0,5	30,22
1	2,99
1,50	3,38
2	0,72
2,5	1,40
2,5	0,03

Table 8: Probabilities of Hm0

Conclusion

Given the few data available, many steps have been carried in order to find the sea states at Liseleje. However, the results are coherent with the Danish weather and the bathymetry, and let have a reasonable idea of the sea states. They are useful for a pre-design study at Liseleje location.
The sea states found are very low: no swell propagate to the site, all the wave are locally generated in Katterat. The effect of bathymetry does not lead to a significant loss in the wave height. It concentrates the wave propagation in a few dominant directions, what is positive for an offshore device.
This location is interesting for the main issue of the project. In the case of such lows sea states, the turbine strategy optimization has a full role to play.

Appendices

Appendix 1: parameters of the wind Weibull distribution

The probability density function corresponding to the Weibull distribution is given by Equation 5.

$$f(x \mid a,b) = a.b.x^{b-1}.e^{-ax^{b}}$$ **Equation 5**

Table gives the parameters a and b for every direction:

Direction	0	30	60	90	210	240	270	300	330
a	0,008813	0,063314	0,009759	0,048276	0,0552	0,005944	0,003706	0,010247	0,025459
b	2,1297	1,48	2,1541	1,6006	1,5411	2,4685	2,701	2,1231	1,8818

From these parameters a discrete distribution can be obtained.

Appendix 2: offshore sea states

		Tp (s)		
	0 degrees	1-3	3-5	5-7
Hm0 (m)	0,25-0,75	0,80	1,00	0,00
	0,75-1,25	0,00	1,81	0,00
	1,25-1,75	0,00	0,57	0,20
	1,75-2,25	0,00	0,00	0,26
	2,25-2,75	0,00	0,00	0,16
	2,75-3,25	0,00	0,00	0,03
	3,25-3,75	0,00	0,00	0,01

		Tp (s)		
	30 degrees	1-3	3-5	5-7
Hm0 (m)	0,25-0,75	0,71	0,58	0,00
	0,75-1,25	0,00	0,56	0,00
	1,25-1,75	0,00	0,21	0,07
	1,75-2,25	0,00	0,00	0,12
	2,25-2,75	0,00	0,00	0,05
	2,75-3,25	0,00	0,00	0,01
	3,25-3,75	0,00	0,00	0,00

		Tp (s)		
	60 degrees	1-3	3-5	5-7
Hm0 (m)	0,25-0,75	0,71	0,87	0,00
	0,75-1,25	0,00	1,16	0,00
	1,25-1,75	0,00	0,68	0,12
	1,75-2,25	0,00	0,00	0,18
	2,25-2,75	0,00	0,00	0,05

	Tp (s)		
	90 degrees	1-3	3-5
	0,25-0,75	3,13	0,72
	0,75-1,25	0,00	0,81
Hm0 (m)	1,25-1,75	0,00	0,09

		Tp (s)		
	210 degrees	1-3	3-5	5-7
Hm0 (m)	0,25-0,75	2,51	0	0

		Tp (s)		
	240 degrees	1-3	3-5	5-7
	0,25-0,75	2,14	2,82	0,00
	0,75-1,25	0,00	3,58	0,00
	1,25-1,75	0,00	1,26	0,33
Hm0 (m)	1,75-2,25	0,00	0,00	0,36

		Tp (s)		
	270 degrees	1-3	3-5	5-7
	0,25-0,75	0,81	3,90	0,00
	0,75-1,25	0,00	2,63	0,00
	1,25-1,75	0,00	0,98	1,15
Hm0 (m)	1,75-2,25	0,00	0,00	0,49

		Tp (s)		
	300 degrees	1-3	3-5	5-7
	0,25-0,75	1,60	1,94	0,00
	0,75-1,25	0,00	2,59	0,00
	1,25-1,75	0,00	1,16	0,40
	1,75-2,25	0,00	0,00	0,50
Hm0 (m)	2,25-2,75	0,00	0,00	0,30

		Tp (s)		
	330 degrees	1-3	3-5	5-7
	0,25-0,75	1,50	1,45	0,00
	0,75-1,25	0,00	1,50	0,00
	1,25-1,75	0,00	0,52	0,15
	1,75-2,25	0,00	0,00	0,21
Hm0 (m)	2,25-2,75	0,00	0,00	0,04