THE WAVE CLIMATE IN THE BELGIAN COASTAL ZONE

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Abstract

The characteristics of the physical coastal system determine the sustainable development of the coastal zone. One important characteristic is the wave climate. The sediment transport of both sandy and muddy particles is very much influenced by the wave climate. Therefore a sustainable coastal morphology has to be in equilibrium with the wave climate. The coastal morphology and the sedimentology are a basis for the ecosystem in the nearshore zone. Thus, indirectly the wave climate has important consequences for the biology in the coastal zone.

Several human activities in the coastal zone depend on the wave climate as well. Evidently, to produce "green" electricity from the hydraulic energy in the sea waves can only be a success if the wave climate is known (to estimate possible profits). Likewise for sporters that want to surf the waves. Waves can also be a nuisance for human activities such as shipping and handling goods in coastal harbours, for contractors carrying out coastal engineering works or workability off-shore.

To determine the wave climate in a coastal zone it is recommended to combine in situ measurements and wave modelling. Indeed, on the one hand to cover an area is only possible with a wave model, and on the other hand in situ measurements are needed to validate and drive a wave model. This paper presents a way to determine a wave climate, for the case of the Belgian coastal zone. The in situ measurements consist of long time series (more than 10 years) of waves and wind at different locations distributed along the Belgian coastline and in the Belgian coastal waters. The wave modelling is carried out with the state of the art, free software SWAN (Simulating WAves Nearshore).

1   The Belgian part of the North Sea

Belgium is situated at the shores of the Southern North Sea. The length of the Belgian coastline is approximately 65 km. Figure 1 shows the Belgian part of the North Sea and the neighbouring countries. The coastline orientation is approximately from South-West (SW) to North-East (NE).
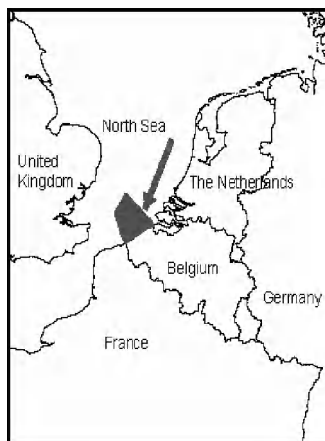

Fig. 1. The Belgian part of the North Sea. The coastline orientation is approximately from SW to NE.

2 Wind and wave statistics at measurement locations

In the early 1980's a monitoring network of winds and waves at sea was set-up in the Belgian coastal waters. It is still operational today. Its main purpose today is to inform shipping traffic.

The time series of wind and wave measurements since the 1980's allow to calculate statistical representations of the mean conditions at the measurement locations. Important variables are the wind speed, the wind direction, the wave height, the wave period and the wave direction.

Values and examples of probability distributions for these variables are given for the most seaward located measuring station approximately 30 km from the shoreline. This location is called "Westhinder". A typical wind speed is 8 m/s. Winds most frequently come from South-West (SW). The time averaged significant wave height is approximately 100 cm. A typical wave period is 6 s. See Figures 2° and 2b for the probability distribution of wind speed and wind direction.
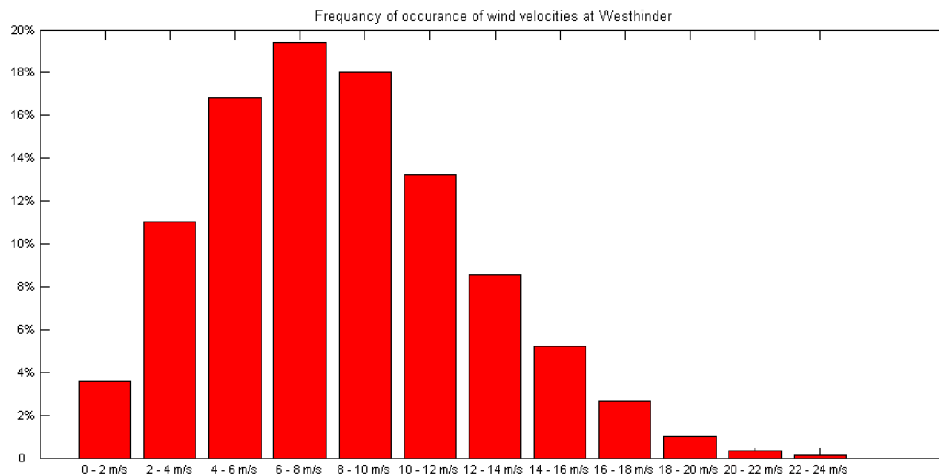

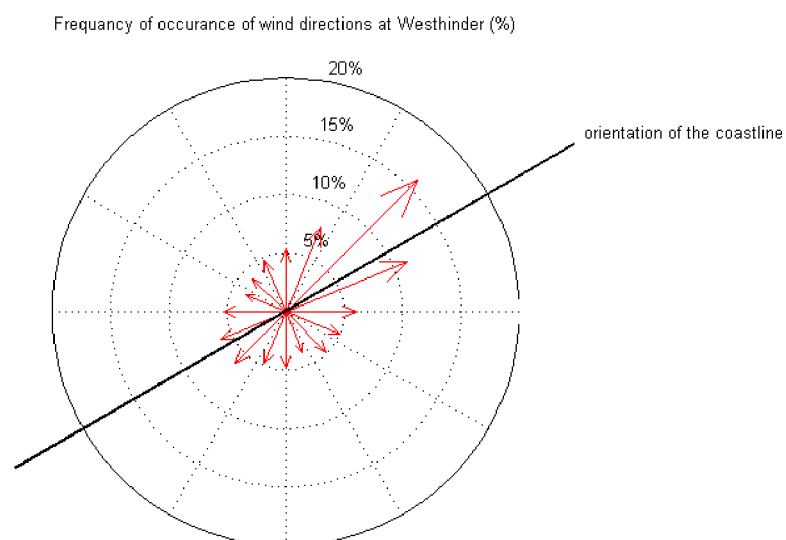*Fig. 2a. Histogram of wind velocity at Westhinder. A typical wind speed is 8 m/s.*

Fig. 2b. Probability distribution of wind direction at Westhinder. Winds most frequently come from South-West (SW).

Obviously the different wind and wave parameters are not uncorrelated. Examples of clear correlations are shown on Figures 3a, 3b and 3c.
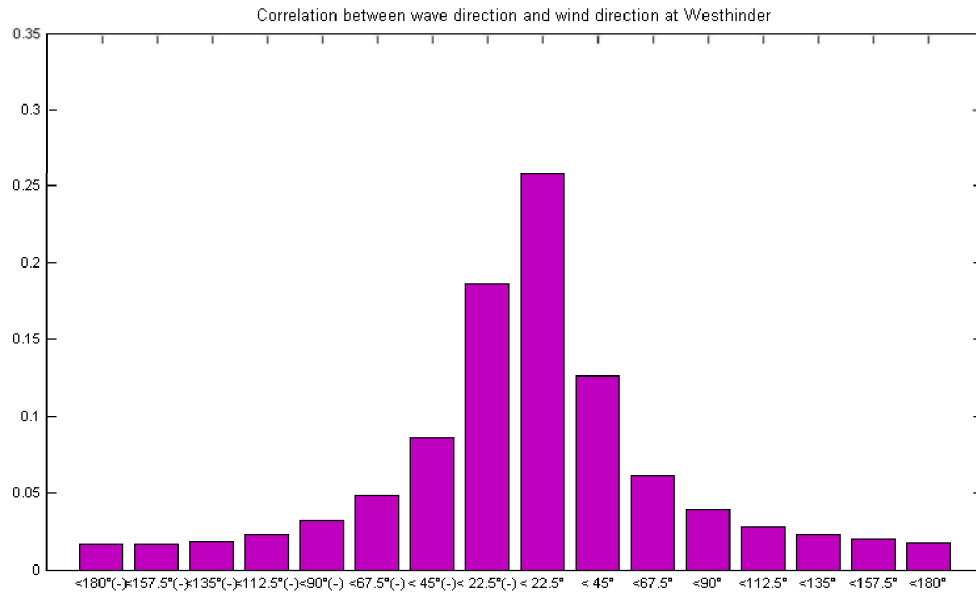

Fig. 3a. Probability distribution of the difference between the wave direction and the wind direction at Westhinder. Most of the time waves and wind come from the same direction.
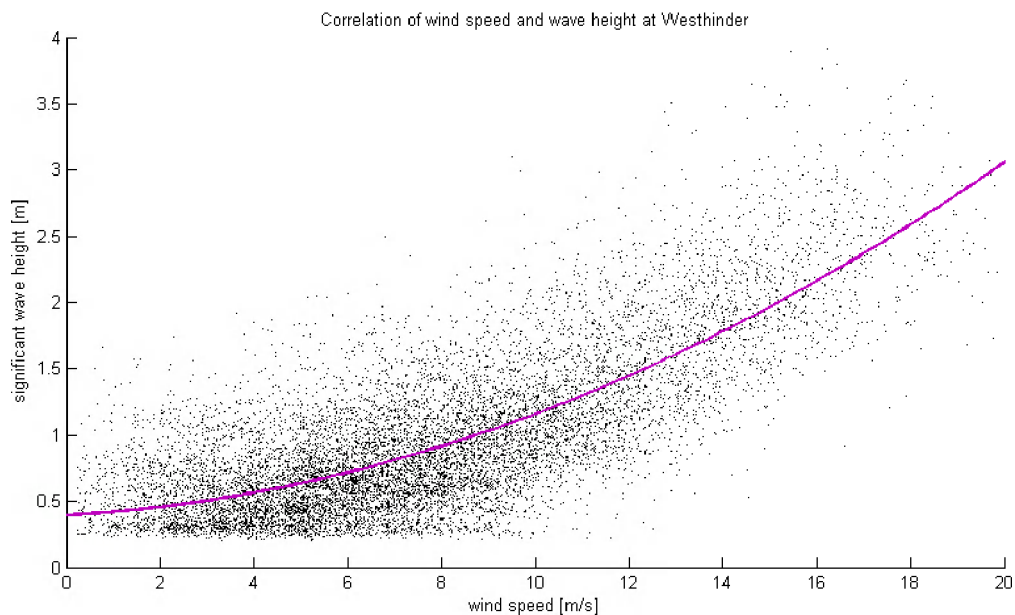

Fig. 3b. Scatter diagram between wind speed and wave height at Westhinder and quadratic regression curve. The heights of the waves and the speed of the wind are clearly correlated.
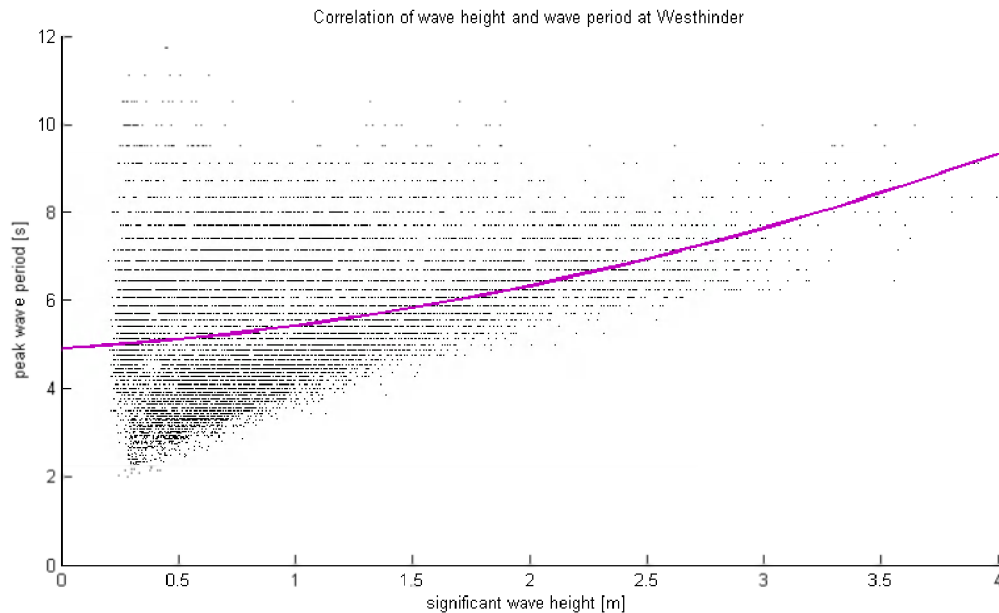
Fig. 3c. Scatter diagram between wave height and wave period at Westhinder and quadratic regression curve. In general, a higher wave height means a higher wave period.

3 Wave modelling in the Belgian coastal zone

Waves propagating in the shallow Belgian coastal zone are transformed mainly due to interaction with the sea bottom. Therefore the wave climate varies from place to place. For any given location the waves can be determined using a wave model that is able to simulate the wave propagation. We used the state of the art, free software SWAN (Simulating WAves Nearshore) [Delft University of Technology, 2008] to make a wave model for the Belgian coastal zone. The spatial resolution of the model is 250 m x 250 m and the model domain is shown in Figure 4.
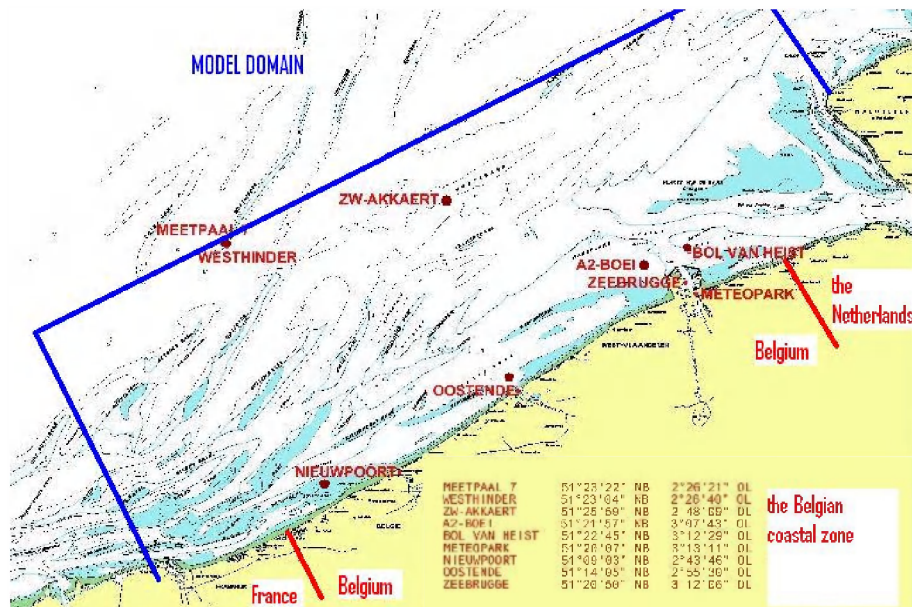

Fig. 4. Wave and wind measuring stations in the Belgian coastal zone and the wave model domain. Background: Hydrographic chart "Flemish Banks".

The most difficult task is not the making of the wave model in SWAN, but it is the establishment of the boundary conditions. The boundary conditions involve wave boundaries, wind boundaries and water levels. The seaward boundary of the model domain is chosen to be able to drive the model with the wave measurements at Westhinder. In first approximation wave boundaries are assumed to be uniform along the boundary of the model domain. The wave spectra are assumed to have a Jonswap shape (with peak enhancement factor 3.3). If one would want to improve on these wave boundaries, one would have to built a cascade of wave models starting from e.g. a model for the whole North Sea area and gradually zooming in to the Southern North Sea, the Belgian part of the North Sea and finally the Belgian coastal zone. In first approximation the wind boundaries are assumed to be uniform, using the wind measurements at e.g. Westhinder. If one would want to improve on this, one could use the additional available wind measurements in the model domain, or one could use wind field data which can be provided by weather models. In first approximation the water level is assumed to be uniform in the model domain, given the fact that the wave length of the tidal wave is much larger than the dimensions of the model domain. If one would want to improve on this, one could use varying water levels in accordance with the tidal wave. Also the effect of tidal currents could be incorporated in the wave model, but in first approximation no currents are taken into account.

With the wave model wave conditions can be calculated in the whole model domain covering the Belgian coastal zone. The model results depend of course on the boundary conditions used. Because of the correlations between the different parameters of the boundary conditions, which where given in the previous chapter 2, one can distinguish main variables from (dependent) variables of secondary importance. In first approximation, the wave height can be considered as function of the wind speed, and the wave period can be considered fully dependent of the wave height. Also the wave direction can be approximately set equal to the wind direction. The remaining main variables are the wind speed, the wind direction and the water level. The water level is important due to the vertical tide of approximately 4 m, which is large compared to the shallow sea bottom. There are numerous sand banks in the Belgian coastal zone with a water depth of only 5 to 10 m above their crests.

4 Combining measurements and wave modelling to provide the wave climate in the Belgian coastal zone

To determine the wave climate in the Belgian coastal zone we combine in situ measurements and wave modeling. The long time series of wind (and waves) at Westhinder drive the SWAN wave model to obtain an equally long time series of wave conditions at any point in the Belgian coastal zone. This way, wave climate information can be calculated for any chosen "numerical" wave measuring station.

In order to obtain statistically reliable wave climate results it is necessary to have a long time series of data, namely of the order of 10 years. In practice it is difficult to transform such a long time series with a wave model because the computation time becomes too long (when using standard hardware). Therefore a multi-linear approximation is derived from the SWAN wave model. In this method the wide range of possible boundary conditions is covered with a limited set of combinations of conditions. SWAN calculations are only carried out this set. For arbitrary boundary conditions the wave conditions are linearly interpolated between the SWAN results of the set. The set of conditions has to be determined so that the multi-linear approximation does not lead to significant loss of accuracy in the wave modelling. For the Belgian coastal zone we use a set of approximately 4000 combinations of conditions. Combinations of values for 6 variables are made. These variables are water level (4 values), wave height (5 values), a ratio between the wind speed and the wave height (3 values for

wind sea, 1 value for swell), the direction of the wind (12 values), a ratio between the wave height and the wave period (the wave steepness) (4 values), and a binary distinction between wind sea and swell (the wave spectrum is separated in two parts, which are transformed with two different wave models, and then added together again). For this set of conditions we showed that there is no loss of accuracy in the wave modeling [IMDC, 2008].

As an exercise we also examined the results when using a further simplification, namely transforming only a set of 40 boundary conditions that are the combinations of 8 wind directions with 5 wind speeds. Furthermore, instead of performing multi-linear interpolation a simple classification is used. The classes used are 8 directional sectors with a width of 45° (N, NW, W, SW, S, SE, E, NE) and 5 classes of wind speeds (0...4 m/s, 4...7 m/s, 7...10 m/s, 10...14 m/s, > 14 m/s). Median values of these classes are used as input for the wave modeling. A reduction of the wind speed to approximately 90% is applied because the wind measurements are performed 20 à 25 m above the water level, while SWAN assumes wind input at 10 m above the water level. Wave height, wave period and wave direction are determined using the regression results given in chapter 2. For the water level the mean water level is used (+2,5 m TAW). This way some variability in the waves will be lost, but the most essential variability is included namely the varying wind directions and the varying energy level of the boundary conditions (~ wind speed, wave height, wave period). For every combination the wave model is run (in stationairy mode); so 40 runs with SWAN are performed. The boundary conditions are summarized in Figure 5. The probability of occurance of each of the 40 classes is given in Figure 6.

	N	NE	E	SE	S	SW	W	NW
0...4 m/s	wind speed 1 m/s, significant wave heigth 0.25 m, peak wave period 4 s, wave direction = wind direction = 0...45...90...135...180...225...270...315 °							
4...7 m/s	wind speed 5 m/s, significant wave heigth=0.50 m, peak wave period=4.5 s, wave direction = wind direction = 0...45...90...135...180...225...270...315 °							
7...10 m/s	wind speed 7 m/s, significant wave heigth=0.75 m, peak wave period=5 s, wave direction = wind direction = 0...45...90...135...180...225...270...315 °							
10...14 m/s	wind speed 11 m/s, significant wave heigth=1.25 m, peak wave period=6 s, wave direction = wind direction = 0...45...90...135...180...225...270...315 °							
> 14 m/s	wind speed 14 m/s, significant wave heigth=2.00 m, peak wave period=7 s, wave direction = wind direction = 0...45...90...135...180...225...270...315 °							

Fig. 5. Boundary conditions of 40 SWAN runs.

Σ=100%	N	NE	E	SE	S	SW	W	NW
0...4 m/s	1.53%	1.69%	1.68%	2.69%	2.14%	2.01%	1.80%	1.36%
4...7 m/s	2.55%	3.44%	3.34%	3.49%	3.59%	4.52%	3.28%	2.11%
7...10 m/s	2.69%	3.86%	3.19%	1.81%	2.91%	6.44%	3.24%	2.26%
10...14 m/s	1.72%	2.46%	2.00%	0.53%	1.77%	7.94%	3.09%	2.16%
> 14 m/s	0.61%	0.72%	0.67%	0.08%	0.56%	5.23%	1.63%	1.20%

Fig. 6. Probability distribution of the combinations of wind sector and wind speed class at Westhinder.

The wave climate results are illustrated in Figures 7 and 8. Figure 7 shows the spatial distribution of the yearly averages wave height in de the Belgian coastal zone. One can observe the gradient of diminishing average wave height from deeper water towards the coastline. Figure 8 shows along the eastern part of the Belgian coastline the net direction of the wave energy flow, which is defined as the vector sum of wave energy flows for the different classes (discretised with sectors of 45°). One can observe that the net direction evolves gradually from W in deeper water towards NW - N close to the coastline. This is caused by refraction and the general orientation of the coastline.
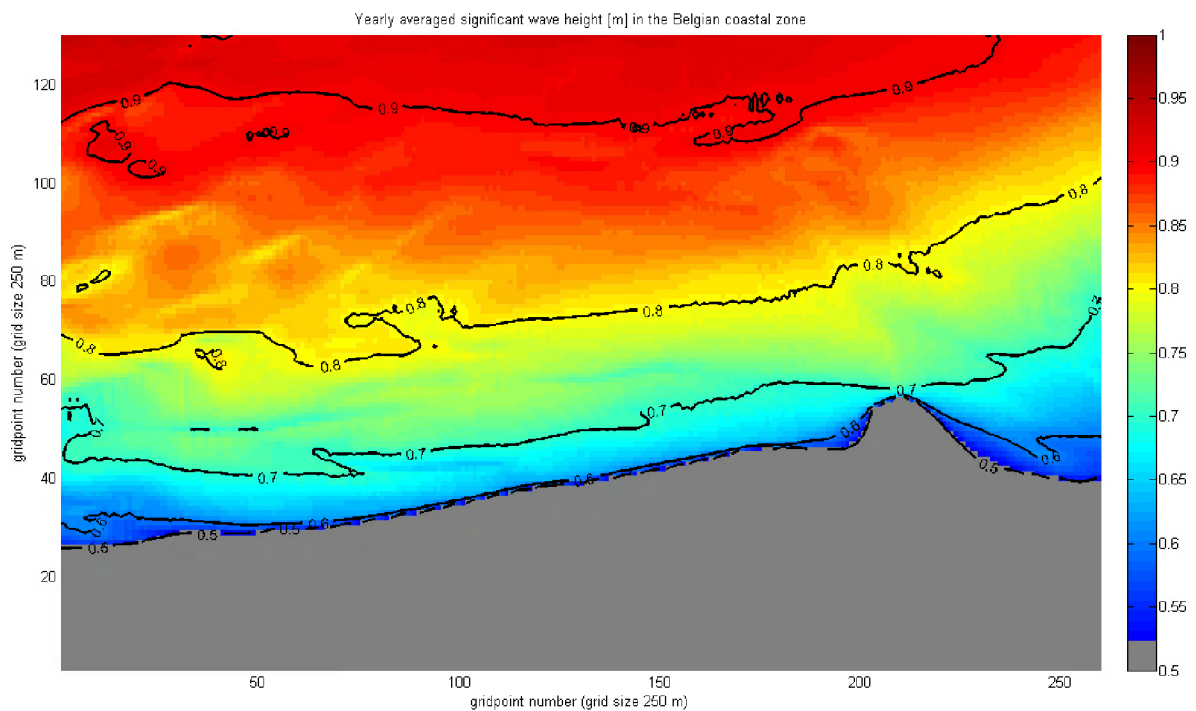

Fig. 7. The spatial distribution of the yearly averaged significant wave height in the Belgian coastal zone.
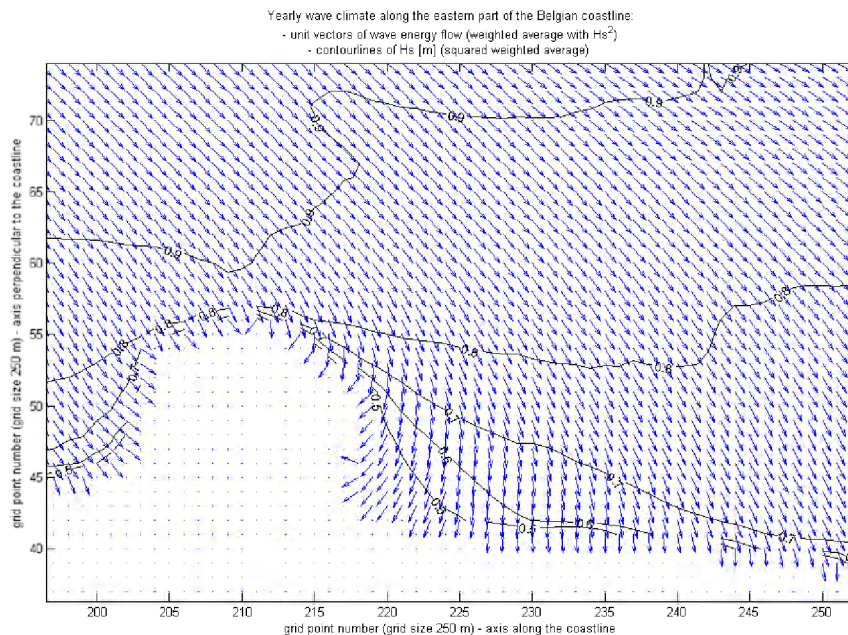
Fig. 8. The spatial distribution of the net direction of the wave energy flow along the eastern part of the Belgian coastline.

With the results and methodology presented, it is possible to produce many more figures and tables of wave climate (geo)statistics (for the Belgian coastal zone and other coastal zones). All depends on the specific processes of interest.

Conclusions

To determine the wave climate in a coastal zone it is recommended to combine in situ measurements of winds & waves with wave modelling. Indeed, on the one hand to cover an area is only possible with a wave model, and on the other hand in situ measurements are needed to validate and drive a wave model. In this paper the methodology is illustrated for the case of the Belgian coastal zone.

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