Looking for observational signs of "Changing Storminess"

EU-project WASA
contract no. EV5V-CT94-0506

report: RIKZ/OS-96.157x

author: W. Bijl
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Ministerie van verkeer en Waterstaat

Directoraat-Generaal Rijkswaterstaat

Ministry of Transport, Public Works and Water Management
Directorate-General for Public Works and Water Management
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Summary

This report considers the analysis of long-term observational records of sea-level, wave height and wind within the context of a possible change in storminess over north-west Europe.

To detect any sign of changing storminess, sea-level, wave height and wind data-sets of stations in the near-coastal areas of north-west Europe (figure 2.1) have been collected and homogenized.
The time period which is covered by these data-sets is of order 100, 30 and 40 years respectively.
To extend the time-horizon of the wave height and wind data-sets (which is relative short for trend analysis), 2 methods have been applied. In essence, these methods are focused on relating sea-level, wave height and wind data during the period of overlap, with the aim to apply possible relations to the period in which only sea-level data is available.
In addition to these 2 methods, a downscaling method has been used which, under the assumption that storm maxima of sea-level and wave height are strongly coupled, wave height statistics (order of 30 years) adjusts on the basis of sea-level statistics (order of 100 years).

The detection of trends and fluctuations in the data-sets has been performed using 2 (main) methods:

- Maxima analysis method (paragraph 4.1). This method implies the detection of storm-related trends and fluctuations in several 2-yearly quantities of the data-sets.
- Quantile analysis method (paragraph 4.2). This method involves the determination of the roughness/smoothness of succeeding decades in relation to the complete period which is covered by the data-sets.

Besides these main methods, some additional variants have been developed in order to be able to discuss various aspects of these methods (and of the data-sets involved).

The attempts to identify and quantify a connection between sea-level, wave height and wind data did not lead to unequivocal results. It is necessary to investigate and test the applied methods in a more detailed way before their results can be used in a quantitative way.
The downscaling method on the other hand turned out to be more successful and leads to the conclusion that as a result of extending the time-horizon of the wave height statistics into the past, the 10^{-2}-quantile value of wave height maxima slightly increases. The standard deviation of the estimation of this 10^{-2}-quantile value is however of the same order, which implies that this slight increase is not significant.

Trends and fluctuations in the data-sets show that, although there is considerable variability on relative small time scales, over the complete measurement period no sign of a significant increase in storminess over north-west Europe can be detected.

More specific, the results indicate similar features for stations in the German Bight and for stations in the south-western North Sea. In the latter area, the variability on relative short time scales is more moderate and there seems to be a tendency towards a small weakening of the storm climate. In the German Bight, the data features a more enhanced variability, with no indication of a weakening of the storm climate.

General conclusion is that the storm climate over north-west Europe has not systematically worsened over the past 100 years, but there is considerable natural variability on smaller time-scales.

Contents

1. Introduction

1.1 Problem description

1.1.1 Background

For the low-lying countries around the North Sea, the safety of the coast is a matter of major concern.
About half of the Netherlands for example is lying below mean sea-level and without coastal defence structures like sea-walls, dikes or storm surge barriers, half of the country would be endangered by flooding. In the past, these coastal defence structures were designed on the basis of a knowledge of the severest recorded storm event. Nowadays, a more scientific approach is applied to the design of these structures [de Ronde et al., 1995a]. Extreme value statistics are computed for observed hydraulic parameters like sea-level and wave height, and safety standards are set for various coastal areas (depending on their economic importance). In essence, this approach means that on the basis of extreme value statistics of sea-level and wave height data, estimates of these hydraulic parameters are obtained which correspond to the safety standard of a specific part of the coast.

The methodology described above is also used by the oil-industry to design offshore constructions. Recently however, several papers have been published which suggest an substantial increase in wave heights in the north-east Atlantic over the past 3 or 4 decades [Carter et al., 1988], [Hogben, 1995], [van Hooff, 1994]. This would imply that the statistically derived wave height, which corresponds to the safety standard of offshore constructions, may be unsafe.
Therefore the oil-industry (and others) have become very concerned about the validity of the existing extreme value wave height statistics.

This concern is subscribed by the insurance industry, which has incurred unprecedented losses due to unusual severe storms in recent years [Leggett, 1993]. As a result, the question has been raised whether these recently observed severe storms are normal events in the spectrum of storms or whether they must be understood as indicators of an increased storm related risk.

1.1.2 Extreme value statistics

Central factor in the concerns described above is the validity of the existing extreme value statistics of sea-level, wave height and wind. To perform extreme value statistics, *long* and *homogeneous* data-sets of observed parameters are required.

In this study, the only parameter which has been observed fairly uniform with respect to the observation technique over more than 100 years is sea-level data.

In case of wave height and wind, most of the available data-sets are however either short or affected by inhomogeneities. The latter mainly because of gaps in the data-sets and changes in observation techniques.
To homogenize these data-sets means for example that slow fluctuations or trends which have been introduced in the data-sets by a change of the observation technique, must be excluded. Complicating factor is that these slow fluctuations or trends also may have been introduced by a change of the observed parameter as a result of natural climate variability or man-induced enhanced greenhouse effect. So, if a data-set has been 'contaminated' by a change of the observation technique, then it is rarely possible to make this data-set homogeneous in order to isolate the effects of natural climate variability or man-induced enhanced greenhouse effect.

1.1.3 Greenhouse effect

It is clear that the trigger mechanism of the concerns with respect to the validity of the existing extreme value statistics of sea-level, wave height and wind, is formed by speculations on the man-induced enhancement of the greenhouse-effect.
In essence, the greenhouse-effect is a natural process, necessary for conditions of life on earth. Since the Industrial Revolution however, human activities are responsible for an artificial enhancement of the greenhouse-effect. The consequences of this enhancement with respect to the natural climate system are however difficult to specify, which can mainly be attributed to the poor understanding of the natural variability of the climate system. Up to now for example, the bounds of this natural variability are still not clearly specified [Schuurmans, 1995].
This implies that in data-sets of observed parameters like sea-level, wave height or wind, it is very difficult to make a distinction between fluctuations or trends which are part of the natural variability of the climate and those which can be attributed to a possible man-induced enhanced greenhouse-effect.

1.2 Problem formulation

As described in paragraph 1.1, from various sides concern has been raised about the validity of the existing extreme value statistics of sea-level, wave height and wind. This concern is however directly related to the discussion about climate change as a result of a man-induced enhancement of the greenhouse-effect (section 1.1.3). This means that this concern can be translated to the following (more basic) question:

Is there any sign of (man-induced) climate change apparent in data-sets of sea-level [1], wave height and wind?

As in case of performing extreme value statistics, to answer this question long and homogeneous data-sets of observed parameters are required in order to:

- exclude fluctuations or trends in the data-sets which have been introduced by a change of the observation technique.

[1] Sea-level data-sets show a wellknown signal of (man-induced) climate change, namely sea-level rise. The present study does not focuse on this signal.

- make a distinction between fluctuations or trends as a result of natural climate variability and those as a result of a man-induced enhanced greenhouse effect.
- be able to perform trend analysis.

As described in section 1.1.2, these data-sets are however not available for all 3 parameters which are taken into account in this study. Only sea-level data has been observed over a relative long period in a more or less uniform way.

1.3 Problem approach

To tackle the problem formulated in paragraph 1.2, in this study the following 3 main topics have been specified:

- Collection of the most long and homogeneous data-sets of sea-level, wave height and wind in the north-west European continental shelf area.

- Investigation of possible (statistical) connections between sea-level, wave height and wind data.

  The underlying idea is that it is very likely that fluctuations or trends in sea-levels and wave heights are related to fluctuations or trends in frequency and intensity of storms [de Valk, 1995]. If for example sea-level maxima are relatively low in a certain period of time, the same might hold for wave height maxima, because both depend primarily on the wind. So theoretically it can be argued that there must be some connection between those 3 types of data. This implies that, whenever a reliable connection is found, this provides a possibility to extend (statistically) the relative short time-horizon of the wave height and wind data-sets by using long and homogeneous sea-level data-sets.

- Detection of fluctuations or trends in the collected sea-level, wave height and wind data-sets.

1.4 Set-up of the report

The report is built up as follows:

In chapter 2, first of all the characteristics of the data-sets used in this study will be described in detail. After that, the selections which have been carried out in order to make these data-sets suitable for statistical (trend) analysis are outlined.
Chapter 3 deals with analysis methods which have been used within the context of the supposed connection between sea-level, wave height and wind data. Three methods and their results are described and visualized in this chapter. The methods outlined in the first 2 paragraphs are focused on obtaining insight into possible connections between the 3 types of data, while in the third paragraph a (downscaling) method is presented which is based on the assumption that this connection is already known.
Chapter 4 is focused on the detection of fluctuations or trends in those data-sets which cover a time period which is sufficiently long for the applied trend-analysis methods. In this chapter, 3 (main) analysis methods and their results (trendlines) are described. Besides that, for each individual trendline

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the significance of the calculated trend is determined, because besides the fact that there is a trend, it is almost more important to know whether this trend differs significantly from zero (or not).
In addition to these main methods, many variants of each method are described and discussed in this paragraph, in order to take all aspects of the data-sets into account.
Finally, chapter 5 contains some discussion and concluding remarks.

1.5 Acknowledgements

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The study was initiated in 1993 by Rijkswaterstaat, the National Institute for Coastal and Marine Management / RIKZ, where the following persons were involved:

W. Bijl, J. Doekes, J. Hoekema, J.G.A. van Marle, J.G. de Ronde and A.P. Roskam (National Institute for Coastal and Marine Management).

The data-sets described and analyzed in the study are obtained from the following persons/institutes:

- British coast:	R. Flather (Proudman Oceanographic Laboratory / POL).
- Dutch coast:	J. Doekes, J. Hoekema (National Institute for Coastal and Marine Management / RIKZ).
- German coast:	H. von Storch (Max-Planck-Institut für Meteorologie / MPI).
- Danish coast:	T. Schmith (Danish Meteorological Institute / DMI).
- Norwegian coast:	M. Reistad (Norwegian Meteorological Institute / DNMI)

The present report has been written by W. Bijl (National Institute for Coastal and Marine Management).

2. Data

In the first paragraph of this chapter, the characteristics of the sea-level, wave height and wind data used in this study will be described in general terms (paragraph 2.1). In paragraph 2.2, the selection methods which have been applied to make these data-sets suitable for statistical (trend) analysis, will be outlined.

2.1 General description

2.1.1 Sea-level data

In table 2.1, the (original) sea-level data of stations used in this study is summarized. The position of these stations is shown in figure 2.1.

Table 2.1 Sea-level data

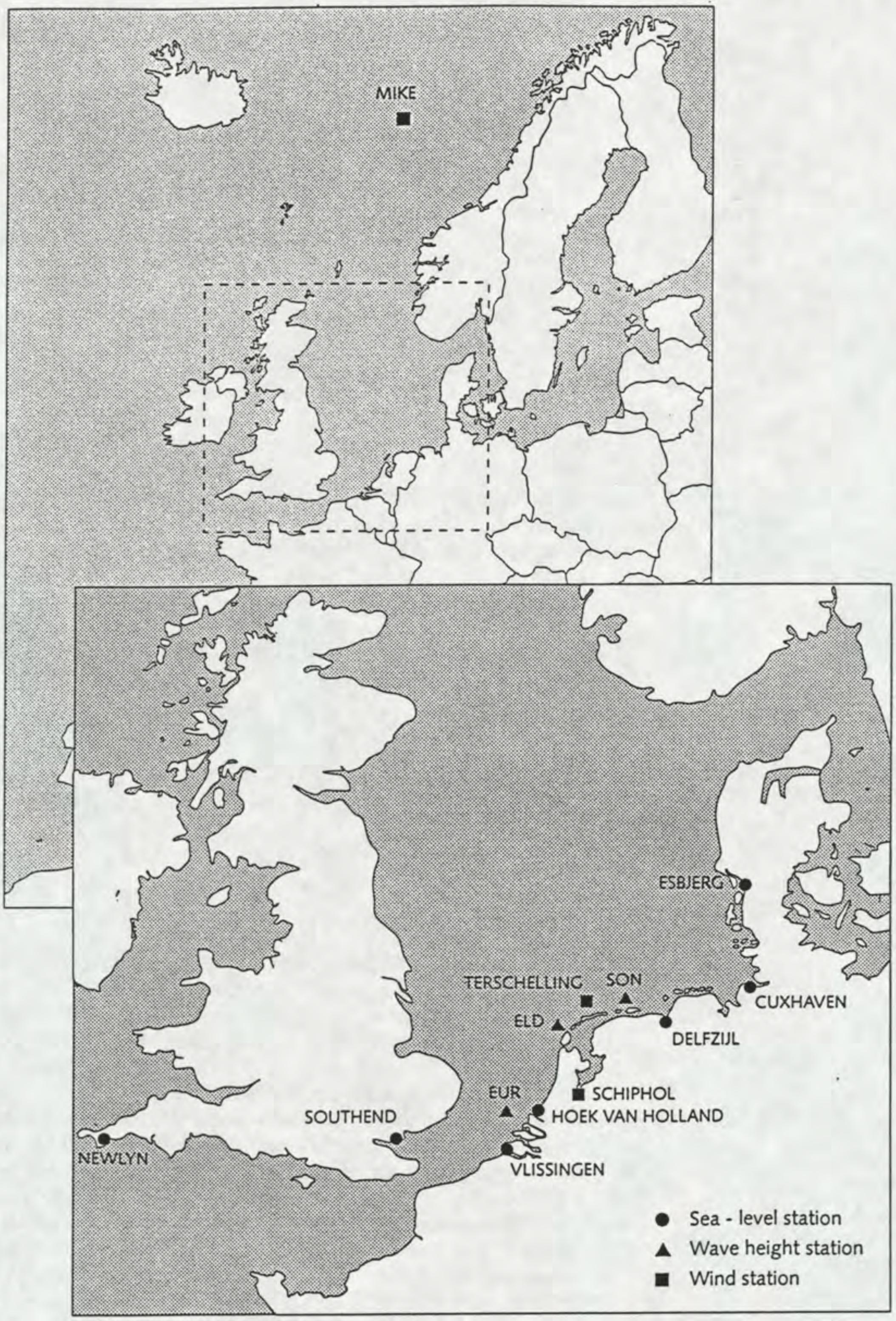
	High-water data			Hourly data
	complete	day-light	daily maximum	
Newlyn				01-01-1916/31-12-1995
Southend				01-03-1929/31-12-1980
Vlissingen	01-01-1882/31-12-1993[1]			
Hoek van Holland	01-01-1888/31-12-1993[1]			
Delfzijl	01-01-1882-3/-12-1993[1]	01-01-1827/31-12-1993		
Cuxhaven	01-01-1843/31-12-1992			
Esbjerg			01-01-1889/13-05-1996	

In table 2.1,

- 'Complete' high-water data means that the data-set contains all water levels at high-tide, which means that with a lunar tide period of 12h25min approximately 2 observations per day are available.
- 'Day-light' high-water data means that the data-set contains the water level at the first high-tide after 6.00 a.m. of each day of the observed period.
  Before 1882, water levels at high-tide were only observed during day-light and in cases of extreme events like severe storms, providing 1 obser-

[1] For this coastal station also high-water set-up data is available, which is by definition the observed high-water level minus the corresponding astronomical water level at high-tide, regardless of a time shift.

figure 2.1 Position of measurement stations



vation per day. To allow this valuable old data to be used in the present study, the 'complete' high-water data over the period 01-01-1882/31-12-1993 was depleted from 2 observations to one observation per day by selecting the water level at the first high-tide after 6.00 a.m. of each day. Here it is assumed that the data before and after 01-01-1882 is more or less consistent. There results a data-set much longer than the high-water and the high-water set-up data. A disadvantage of this resulting data-set is that during the period 01-01-1882/31-12-1993 valuable data is omitted.

- 'Daily maximum' high-water data means that the data-set has been aggregated from hourly readings of water levels and simply contains the daily maximum water level of these 24 hourly readings. No interpolation has been performed to approximate the water levels at high-tide.
- 'Hourly' data means that the data-set contains hourly water levels of each day of the observed period.
  In order to remove the unwished influence of the sample interval of 1 hour (in relation to the time of high-tide), a squared spline approximation method [van der Made, 1979], [de Jong et al., 1983] has been applied, providing 'artificial' water levels at high-tides for each day of the measurement period.

In general, the above described sea-level data has been observed fairly uniform with respect to the observation technique. Besides that, some of these data-sets also have been corrected for other factors influencing the homogeneity in a negative way, e.g. variation of the ordnance datum, registration gaps, etc. A detailed description of the latter corrections is for the Dutch stations given in [Dillingh et al., 1993] and for station Cuxhaven in [Jensen et al., 1992]. However, as described in [Bijl et al., 1997], for the British stations and for station Esbjerg, no systematic investigation of the homogeneity of the data-sets has been carried out.

In the data-sets however, still other factors can be present which effect the homogeneity in a negative way or which have to be ignored with respect to the aim of the study. The most important are relative sea-level rise (net effect of sea-level rise and land subsidence), effects of harbour works, dredging activities, etc.
To eliminate these undesirable influences, for all data-sets, the long-term trend of the annual mean water level at high-tide (table 2.2) has been subtracted. As described in [von Storch et al., 1996], by this operation possible creeping inhomogeneities are averted which may arise from a variety of processes like relative sea-level rise or slow adjustments to anthropogenic interferences.

With respect to the 'high-water set-up' data-sets (available for the Dutch coastal stations), it has to be mentioned that these data-sets feature the storm-related set-up at high-tides, which is by definition the observed high-water level minus the corresponding astronomical water level at high-tide, regardless of a time shift.
To construct these data-sets, for each station the astronomical water levels were analyzed and computed in blocks of 10 years by means of a tidal analysis with the culmination method [de Ronde, 1984]. This ensured that the resulting data-sets are not affected by changes in the hydraulic regime, either gradual or abrupt [Dillingh et al., 1993]. Within the context of this study, these data-sets are very valuable because they reflect only the storm-related water level variations. The computation of the astronomical water levels involves however an enormous amount of work, as a result of which the construction of this type of sea-level data-sets has been possible only for the Dutch coastal stations Vlissingen, Hoek van Holland and Delfzijl.

Table 2.2 Trend-correction, used to eliminate the long term trend of annual mean high-water level at selected coastal stations

Coastal station	Period	Trend-correction C [cm]
Newlyn	1916-1995	C=0.18*(1995-year)
Southend	1929-1980	C=0.28*(1980-year)
Vlissingen	1882-1886	C=0.34*(1993-year)-14.0
	1887	C=26
	1888-1993	C=0.34*(1993-year)
Hoek van Holland	1888-1964	C=0.12*(1993-year)+15.8
	1965	C=14
	1966-1993	C=0.53(1993-year)
Delfzijl	1882-1959	C=0.18*(1993-year)+11.4
	1960-1978	C=0.40*(1993-year)+6.0
	1979-1993	C=0.40*(1993-year)
Cuxhaven	1843-1992	C=0.27*(1992-year)
Esbjerg	1889-1995	C=0.22*(1995-year)

2.1.2 Wave height data

In principle, wave height measurement data is available over a long period of time. With respect to the observation method, the available data-sets are however far from homogeneous.

In the Netherlands for example, from 1926 up to about 1970 wave height measurements were performed at so called light-vessels. Until 1949, the state of the sea was characterised with index-numbers for sea, swell and wave direction. After this period, wave height, wave period and wave direction were directly estimated by visual observation.
Since 1950, wave height measurements were also carried out using a variety of instruments like wave amplitude recorders, wave staffs, etc. Since the seventies, buoys (wave-rider, wavec) are used to measure systematically wave height, wave period, wave directions, etc.
As described in [Hoozemans, 1987], it will be very difficult to construct usable, homogeneous time series on the basis of these data-sets.

In this study, 3-hourly wave height measurement data from stations in the Netherlands (figure 2.1) is used over the period 1979-1993 (table 2.3), mainly because only since 1979 the observation method has been quite uniform. During this period, the data has been handled in a systematic, continuous way and also the processing software has not changed substantially. So it is assumed that during this period the data is fairly homogeneous [Roskam, 1994].

In addition to the above described measurement data, also hindcast data of wave height is available from the North European Storm Study (NESS) project (table 2.3). Within this NESS project, on the basis of observed meteorological events over a period of 25 years, wind and wave data has been generated for the North Sea and surrounding parts of the Atlantic Ocean, whereby special attention has been paid to storm periods [Francis, 1992], [de Ronde et al., 1995b].

Due to its relative long time span (1964-1989), the NESS hindcast wave height data-set is very useful, because with the help of this hindcast data-set the length of the observation records can be virtually doubled. Of course one must be aware of systematic differences between the NESS and measured wave heights and of the lower accuracy of the NESS data.

Table 2.3 Wave height data

	Wave height data	
	measurement data	NESS data
EUR	01-01-1979/31-12-1993	01-10-1964/31-03-1989
ELD	01-01-1979/31-12-1993	01-10-1964/31-03-1989
SON	01-01-1979/31-12-1993	01-10-1964/31-03-1989

Therefore, before combining these 2 data-sets, a bias-correction has to be applied to the original NESS hindcast data in order to correct systematic errors as much as possible. This has been done on the basis of the overlapping period 1979-1989. According to [de Ronde et al., 1995], a method whereby a linear connection between the observed (H_{m0}-observed) and NESS (H_{m0}-NESS) wave height data is assumed yields the best results. Table 2.4 shows this connection for the 3 selected wave height measurement stations.

Table 2.4 Connection between observed and NESS wave height data.

	H_{m0}-NESS [m]	Connection
EUR	H_{m0}-NESS<3.25	H_{m0}-observed = 1.05(H_{m0}-NESS)-0.58
	3.25 ≤ H_{m0}-NESS<4.25	H_{m0}-observed = 1.70(H_{m0}-NESS)-2.69
	H_{m0}-NESS ≥ 4.25	H_{m0}-observed = 1.02(H_{m0}-NESS)+0.20
ELD	H_{m0}-NESS<2.88	H_{m0}-observed = 0.70(H_{m0}-NESS)
	H_{m0}-NESS ≥ 2.88	H_{m0}-observed = 1.13(H_{m0}-NESS)-1.25
SON	H_{m0}-NESS<3.25	H_{m0}-observed = 0.98(H_{m0}-NESS)-0.74
	H_{m0}-NESS ≥ 3.25	H_{m0}-observed = 1.25(H_{m0}-NESS)-1.60

2.1.3 Wind data

In the Netherlands, wind data is available over a relative long period of time at various stations, but as in case of the wave height data-sets most of these data-sets suffer from inhomogeneity.

On light-vessels for example, wind data has been collected from 1859 up to 1980. However, during World War II data from the period 1859-1885 has been lost while from 1886-1906 the data is only available in annual reports. These annual reports, which have been made up from ships logs, do however not contain data which is suitable for trend analysis or extreme value statistics. Also data from the remaining period 1907-1980 is often not very useful [Hoozemans, 1989]. The wind speed for example was estimated with the help of the Petersen-scale, which describes the visual impact of wind on the sea surface. It is clear that this introduces a very subjective element in the data: the experience and instructions of the observer.

On land, the first wind measurement stations were established in the second half of the 19th century. Up to 1950 however, most of these stations were equipped with badly placed wind anemometers (on buildings, between obstacles, etc.) which were not suited for continuous registration. Since 1950, new wind measurement stations have been utilized, equipped with well-placed continuously registrating wind anemometers. Most of the data-sets of these stations are however still inhomogeneous. Main reasons are displacements of the wind anemometer, sheltering of the wind anemometer by growing vegetation or new buildings, installation of a new anemometer (type) and registration gaps [Wieringa et al., 1983].

In this study, wind data (wind speed and wind direction) is used from the Dutch stations Schiphol and Terschelling (hourly readings) and from platform Mike in the Norwegian Sea (3-hourly readings).
Main reason for using the data-sets of Schiphol and Terschelling is the fact that these data-sets have already been analyzed and corrected for the above mentioned factors influencing the homogeneity of the data. For a more detailed description one is referred to [Oemraw, 1986], [Wieringa et al., 1983]. The wind data-set of platform Mike is also reasonably homogeneous, but according to local authorities there may be some small inhomogeneities due to different ships and wind anemometers.

In table 2.5, the data-sets of the 3 selected locations are summarized; their position is shown in figure 2.1.

Table 2.5 Wind data

	Wind data
Schiphol	06-06-1950/31-12-1991
Terschelling	01-11-1948/31-12-1994
Mike	01-01-1949/31-12-1995

One of the properties of the above described wind data is the highly fluctuating character. This in contradiction to wave height and (especially) to sea-level data.
With a view to the investigation of possible connections between the 3 types of data (chapter 3), it is has been decided to reduce this variability of the wind data in order to make this data more comparable to wave height and sea-level data. This reduction has been achieved by applying a 6-hourly moving average procedure to both the wind speed and wind direction.

2.2 Selection methods

2.2.1 Sea-level data

To put a series of values of a stochastic variable through a statistical (trend) analysis, it is required that:

- the values belong to the same statistical distribution.
- the values are mutually independent.

The sea-level data-sets of the selected stations do however not satisfy these 2 requirements. Main raisons are meteorologic and hydraulic factors and (except for the high-water set-up data) the deterministic character of the astronomical tide [Dillingh et al., 1993].
However, with the help of appropriate selection methods it is possible to make these data-sets suitable for a statistical analysis within the scope of possible trends and variations in storminess. In the following, for each defined type of sea-level data, these selections will be described.

High-water set-up

To ensure the homogeneity of the high-water set-up data of the 3 selected Dutch coastal stations, a threshold value (0.3 m.) and a storm season selection (1 October - 15 March) have been applied; the threshold value to provide the same peak-over-threshold distribution and the storm season selection to select elements of the same (common) distribution [Dillingh et al., 1993].

In addition, the interdependence (autocorrelation) has been suppressed by applying an appropriate selection method in the time-domain. Use is made of the D-S-*i* selection method, which involves that each selected element has to be higher than *i* preceding and *i* following elements in the data-set. For the high-water set-up data-sets, detailed analysis (based on observed autocorrelation) revealed a time-window of 2 days [Dillingh et al., 1993]. Because high-water set-up data is approximately available 2 times per day, this implies to i=4 as best alternative.

'Complete' high-water

The selection method applied to the 'complete' high-water data-sets of the selected stations along the Dutch coast is based on the above described selection methods for high-water set-up data. In fact, the selection consists of the restriction that only those elements of the 'complete' high-water data-sets are retained which correspond to the selected elements of the high-water set-up data-sets.

For station Cuxhaven and the British stations Newlyn and Southend, the selection methods described above (threshold value, storm season and D-S-4 selection) have been applied directly to the high-water data-sets (high-water set-up data is not available). Deviating factor is the threshold value, which for Cuxhaven and Southend amounts to 1.75 m. and for Newlyn to 1.25 m. These threshold values have been found by 'trial and error', using the rule that the number of selected elements per storm season of these high-water data-sets must equal the number of selected elements per storm season of the Dutch high-water (set-up) data-sets.

To check whether this approach is consistent with the selection method applied to the Dutch high-water data-sets, for station Delfzijl the selection methods (threshold value, storm season and D-S-4 selection) have also been applied directly to the high-water data-set. As for station Cuxhaven and the British stations, the threshold value has been adjusted in an appropriate way (1.65 m. instead of 0.30 m.). Comparing the resulting data-set with the one which has been obtained on the basis of the selected elements of the high-water set-up data-set, reveals however only minor differences in selected storm periods.

'Day-light' and 'daily maximum' high-water

The selection methods applied to the 'day-light' and 'daily maximum' high-water data-sets of the stations Delfzijl and Esbjerg respectively, are in principle the same as described for the Dutch high-water set-up data-sets. Different aspects are the applied threshold value (1.65 m. resp. 1.10 m.) and the number of elements of the data-set involved in the selection method which is used to suppress autocorrelation. The latter aspect is caused by the fact that each element of these 'day-light' and 'daily maximum' high-water data-sets represents 1 day, while in case of the high-water set-up data-sets this time-span is represented by 2 elements (approximately). Therefore, to be consistent with the afore described selection methods, the D-S-4 selection method has been adjusted to a D-S-2 selection method. This means that each selected element has to be higher than 2 preceding and 2 following elements in the data-set.

2.2.2 Wave height data

The selection methods applied to the combined measurement and NESS wave height data-sets are in principle the same as described for the sea-level data-sets. This implies the introduction of a threshold value and a storm season selection to ensure the homogeneity of the data-sets, while a selection method in the time-domain is used to suppress autocorrelation.

For the stations EUR, ELD and SON, the applied threshold values are 2.7 m., 2.9 m. and 2.6 m. respectively. These values are obtained by 'trial and error', using the rule that the number of selected elements per storm season of these wave-height data-sets must equal the number of selected elements per storm season of the sea-level data-sets.
Contrary to the storm season selection (which is left unchanged), it was also necessary to adjust the selection in the time-domain, because wave height data is available every 3 hour instead of 1 or 2 times per day. So, to be consistent with the selection method applied to the sea-level data-sets (time window of 2 days), a D-S-16 selection in the time-domain has been applied.

2.2.3 Wind data

Also the selection methods applied to the wind data-sets are in principle the same as described for the sea-level data-sets (threshold value, storm season selection and D-S-*i* selection). As in case of the wave height data-sets, there are however some differences due to character (threshold value) and time-interval (D-S-*i* selection) of this data.

The threshold values which have been applied to the stations Schiphol, Terschelling and Mike are 12 m/s, 14 m/s and 17.5 m/s respectively. As indicated before, these values are obtained by 'trial and error', using the rule that the number of selected elements per storm season of these wind data-sets must equal the number of selected elements per storm season of the sea-level data-sets.
It also turned out to be necessary to adjust the selection in the time-domain, because wind data is available hourly (Schiphol, Terschelling) or 3-hourly (Mike). So, to be consistent with the selection method applied to the sea-level data-sets (time window of 2 days), a D-S-48 resp. D-S-16 selection in the time-domain has been applied.

3. Connections

As indicated in chapter 1, it is likely that fluctuations or trends in sea-level and wave height data are related to fluctuations or trends in frequency and intensity of storms, because both phenomena depend primarily on the wind. In this chapter, the result of several methods used to get insight into possible connections will be described.

3.1 Analysis of maxima

The first method which is used to get insight into possible connections between the 3 types of data is the 'maxima analysis' method. This method involves the following 3 steps:

1) Dividing a data-set into a large number of succeeding sub-periods. The minimum length of these periods is determined by step 3 of the method, which requires that each period must include at least 20 values (storm periods). Mainly because of the data-reduction as a result of applying the threshold value, the storm season selection and the time-window of 2 days, this is only achieved by using periods of at least 2 years. (paragraph 2.2).
2) Sorting the data of each 2-yearly period.
3) Determination and visualization of the following quantities of each 2-yearly period:

   - maximum : highest value of the sorted 2-yearly data
   - maximum-5 : fifth value of the sorted 2-yearly data (counting from the highest)
   - maximum-10 : tenth value of the sorted 2-yearly data (counting from the highest)
   - maximum-20 : twentieth value of the sorted 2-yearly data (counting from the highest)

This well-known and rather straightforward analysis method has been applied to the sea-level, wave height and wind data-sets described in chapter 2, whereby due to the main perspective of this maxima analysis method:

- only data from the overlapping period 01-10-1964/31-12-1991 is used.
- only data is used from stations which are relative close to each other.

In Annex A part 1, the result of this method is visualized for various combinations of sea-level stations (Vlissingen, Hoek van Holland, Delfzijl), wave height stations (EUR, ELD, SON) and wind stations (Schiphol, Terschelling). Main idea was that, if combinations would show some similarity between the analysis results of the sea-level (high-water set-up), wave height and wind data in question, these results could form the basis of a more detailed analysis on this subject. Unfortunately, there appears to be almost no similarity. Even when the same type of data is compared (Annex A part 2), it is still very hard to detect any similar behaviour.

To improve the results, an additional selection method has been applied to the selected sea-level (high-water set-up), wave height and wind data-sets, whereby only the data associated with a specific wind sector is retained. The wind sectors which have been used are 285°-345° (small north-west sector) and 255°-15° (large north-west sector). For the sea-level stations Vlissingen and Hoek van Holland and for wave height station EUR, this selection has been carried out on the basis of the wind data-set of Schiphol; for sea-level station Delfzijl and the wave height stations ELD and SON on the basis of the wind data-set of Terschelling.
Applying the maxima analysis method to these (directional) data-sets reveals however results which are quite similar to the omni-directional results, especially for the 2-yearly maximum and maximum-5 values. The latter can be explained by the fact that, for the selected sea-level and wave height stations, the severest storms are mainly north-westerly storms.

Conclusion of this paragraph is therefore that the maxima analysis method, as applied to the data-sets available in this study, does not lead to a better understanding of the supposed connection between sea-level, wave height and wind data. The results of this method, as visualised in Annex A, will however be very useful to get insight into possible trends or fluctuations in the data-sets (chapter 4).

3.2 Quantile analysis

The second method which is used within the scope of a possible connection between the 3 types of data is the 'quantile analysis' method. In the following, first of all the methodology will be outlined.

1) To be consistent with the maxima analysis method, the first step is to split up a data-set into succeeding periods of 2 year.

2) The second step has been developed to take more aspects of the data into account as in case of the maxima analysis method. This has been achieved by fitting the 20 highest elements of each 2-yearly period with the following (conditional) 2-parameter Weibull frequency distribution which approximates exceedance frequency curves above a certain threshold value ω:

$$P[x>a|x>\omega] = e^{(\frac{a}{\sigma})^{\alpha}+(\frac{\omega}{\sigma})^{\alpha}}$$

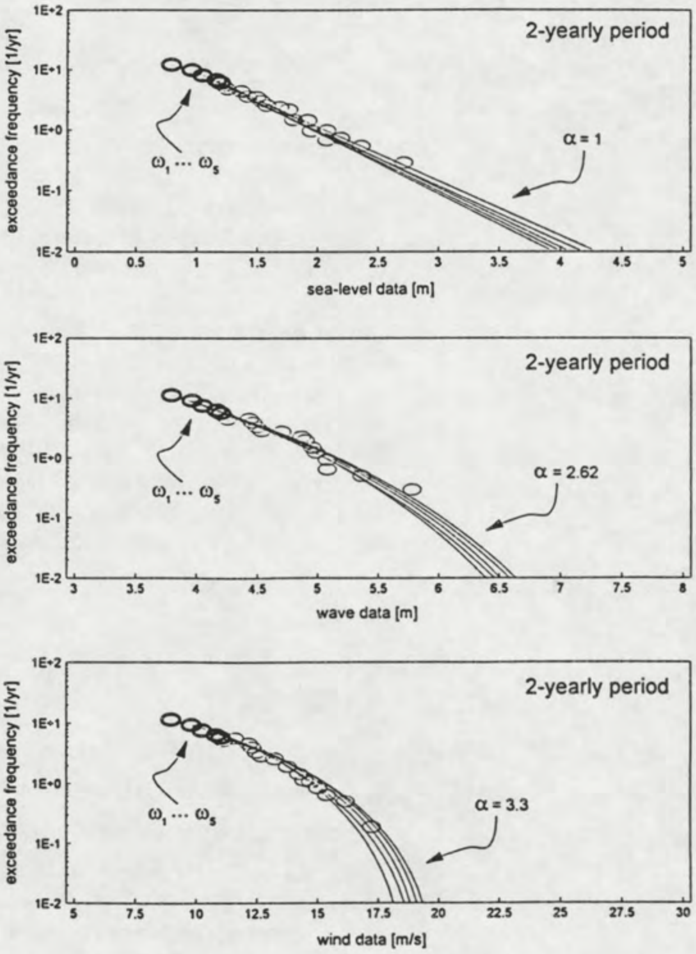
where α is the parameter which determines the shape or curvature of the frequency distribution; σ is the parameter which determines the scale of the frequency distribution; ω is the threshold value.

In order to create a robust and stable method, 2 parameters of this 3-parameter distribution have been pre-defined level: the threshold value ω and the shape or curvature of the distribution α. In this study, for each of the 3 types of data, a fixed α is used. Detailed analysis revealed for sea-level data $\alpha=1$ (straight line on log-scale), for wave data $\alpha=2.62$ and for wind data $\alpha=3.3$ as best estimate for this Weibull parameter. The higher the value of α, the stronger the curvature of the

Weibull fit.
The second element contributing a robust and stable method is that the estimates of exceedance frequencies are made on the basis of a range of thresholds. For each 2-yearly period, 5 Weibull fits are carried out on the basis of 5 different threshold values. These threshold values are obtained from a threshold range which is formed by the lowest 5 of the 20 selected elements (figure 3.1).

3) The third and final step of the method is to calculate for each 2-yearly period the 10^0-, 10^{-1} - and the 10^{-2}-quantile value. These quantile values can be understood as the values (e.g. water level at hight-tide, wave height, wind speed) which will be exceeded only once per year, once per 10 year and once per 100 year respectively.
For each of these 3 quantile values, 5 estimates are available (based on the 5 different threshold values). The mean of these 5 values is used as best quantile estimate.

figure 3.1 Illustration of step 2 of the quantile analysis method



The result of this quantile analysis method is, for the same (combinations of) stations as described for the maxima analysis method, summarized in Annex B part 1.

table 3.1 Correlation coefficients of various combinations of sea-level, wave height and wind data (quantile analysis method)

	Vlissingen			Hoek v Holland			Delfzijl			Eur			Eld			Son			Schiphol		
	10^{0} quantile	10^{-1} quantile	10^{-2} quantile	10^{0} quantile	10^{-1} quantile	10^{-2} quantile	10^{0} quantile	10^{-1} quantile	10^{-2} quantile	10^{0} quantile	10^{-1} quantile	10^{-2} quantile	10^{0} quantile	10^{-1} quantile	10^{-2} quantile	10^{0} quantile	10^{-1} quantile	10^{-2} quantile	10^{0} quantile	10^{-1} quantile	10^{-2} quantile
Vlissingen																					
Hoek v Holland	0.72	0.62	0.60																		
Delfzijl	0.46	0.43	0.44	0.74	0.74	0.73															
Eur	0.47	0.63	0.67	0.58	0.53	0.53															
Eld							0.51	0.57	0.56	0.40	0.45	0.47									
Son							0.79	0.76	0.74	0.12	0.02	0.04	0.47	0.58	0.58						
Schiphol	0.57	0.41	0.36	0.67	0.60	0.57				0.67	0.58	0.54									
Terschelling							0.36	0.09	0.02				0.41	0.56	0.59	0.68	0.51	0.44	0.49	0.35	0.54

From this Annex it follows that, compared to the maxima analysis method, there is more similarity visible between the analysis results of the sea-level (high-water set-up), wave height and wind data in question.
To describe this similarity in a more quantitative way, table 3.1 shows the correlation coefficients for the selected combinations of stations. The corresponding scatter diagrams are shown in Annex B part 2. One must be aware that both in table 3.1 and Annex B part 2 the names of the measurement stations also denote the type of data which is compared.
Critical values of the correlation coefficients shown in table 3.1 for some relevant percentages of significance are 0.514 (95%), 0.592 (98%) and 0.641 (99%). It should however be emphasized that a high percentage of significance does not automatically mean that it is possible to predict one of the two quantities on the basis of the other (with sufficient accuracy). In fact, it only means that there is a good chance that a connection exists between the 2 quantities. To predict one quantity on the basis of the other with sufficient accuracy, besides a high percentage of significance, it is also required that the correlation coefficient itself is high.

On the basis of the results shown in Annex B and table 3.1, the following can be stated:

- Although at first instance the overall picture of the results shown in Annex B and table 3.1 is not very distinct, it is clear that the majority of the combinations shows reasonable correlations, which means that with the help of the described quantile analysis method it is possible to demonstrate connections between the various data-sets. This does not mean that it is possible to predict one quantity on the basis of the other (with sufficient accuracy).
- The analysis results of stations which are relative close to each other show in general higher correlations than the results of stations which are relative far apart (e.g. Delfzijl-SON). In addition, when the same type of data is compared, sea-level data shows a better correlation than wave height and wind data (e.g. Hoek van Holland-Delfzijl).

In order to investigate the sensitivity of the quantile analysis method with respect to

- the length of the periods in which a complete data-set is split up
- the number of elements involved in the Weibull fit procedure

the above described methodology has been changed in the following way:

1) Instead of dividing the data-sets into succeeding periods of 2 year, the data-sets are split up into (moving) 5-yearly periods with an interval of 1 year. If a data-set for example would cover the period 1900-1990, than this set is divided into the sub-periods 1900-1904, 1901-1905, ... , 1985-1989, 1986-1990.

2) The next step is to sort the data of each 5-yearly period and to fit the 40 highest elements of each period with the (conditional) 2-parameter Weibull frequency distribution which approximates exceedance frequency curves above a certain threshold value ω.
For each 5-yearly period, 20 Weibull fits are carried out, based on a threshold range which is formed by the lowest 20 of the 40 selected elements.

3) The final step of the method is to calculate for each 5-yearly period the 10^{0}-, 10^{-1}- and the 10^{-2}-quantile value. For each of these 3 quantile

table 3.2 Correlation coefficients of various combinations of sea-level, wave height and wind data (adjusted quantile analysis method)

	Vlissingen			Hoek v Holland			Delfzijl			Eur			Eld			Son			Schiphol		
	10^0 quantile	10^{-1} quantile	10^{-2} quantile	10^0 quantile	10^{-1} quantile	10^{-2} quantile	10^0 quantile	10^{-1} quantile	10^{-2} quantile	10^0 quantile	10^{-1} quantile	10^{-2} quantile	10^0 quantile	10^{-1} quantile	10^{-2} quantile	10^0 quantile	10^{-1} quantile	10^{-2} quantile	10^0 quantile	10^{-1} quantile	10^{-2} quantile
Vlissingen																					
Hoek v Holland	0.87	0.82	0.81																		
Delfzijl	0.78	0.74	0.72	0.87	0.90	0.89															
Eur	0.63	0.69	0.70	0.42	0.52	0.56															
Eld							0.38	0.17	0.10	0.23	0.22	0.23									
Son							0.60	0.68	0.71	0.14	0.06	0.01	0.54	0.41	0.34						
Schiphol	0.39	0.37	0.37	0.40	0.37	0.36				0.67	0.63	0.62									
Terschelling							0.75	0.70	0.67				0.20	0.00	0.06	0.29	0.28	0.28	0.15	0.16	0.17

values, 20 estimates are available (based on 20 threshold values). The mean of these 20 values is used as best quantile estimate.

The results of this adjusted quantile analysis method are summarized in Annex C, part 1 and 2. As for the original method, correlation coefficients have been calculated in order to describe these results in a more quantitative way (table 3.2). One must be aware that both in table 3.2 and Annex C the names of the measurement stations also denote the type of data which is compared.
Critical values of the correlation coefficients shown in table 3.2 for some high percentages of significance are 0.389 (97.5%), 0.464 (99%) and 0.507 (99.5%). Again it should however be emphasized that a high percentage of significance does not automatically mean that it is possible to predict one of the two quantities on the basis of the other (with sufficient accuracy). Besides a high percentage of significance, it is also required that the correlation coefficient itself is high.

On the basis of these results, it can be concluded that the adjusted quantile analysis method shows in general the same results as the original method.

This means that:

1) The conclusions based on the original method are also valid for this adjusted method:

   - The majority of the combinations shows reasonable correlations, which means that with the help of the described quantile analysis method it is possible to demonstrate connections between the various data-sets. This does not mean that it is possible to predict one quantity on the basis of the other (with sufficient accuracy).
   - The analysis results of stations which are relative close to each other show in general higher correlations than the results of stations which are relative far apart (e.g. Delfzijl-SON). In addition, when the same type of data is compared, sea-level data shows a better correlation than wave height data and wind data (e.g. Hoek van Holland-Delfzijl or Hoek van Holland-Vlissingen).

2) In general, the quantile analysis method is not very sensitive to the length of the periods in which a complete data-set is divided and to the number of elements involved in the Weibull fit procedure.

There are however some differences between the results of the adjusted and original method which are worthwhile to be mentioned. Table 3.3 shows these differences.
From this table it follows that the adjustment of the method has improved the correlation coefficients between the analysis results of sea-level (high-water set-up) data, while in case of wave height and wind data there appears to be a worsening of these coefficients.
Another point to note is that conclusion 2 is not applicable to the stations ELD (wave height) and Terschelling (wind), because the analysis results of these stations seem to be very sensible to the adjustment of the method.

Taking all results presented in this paragraph into account, main conclusion is that with a relative stable and robust method like the quantile analysis method, it is possible to demonstrate possible connections between sea-level, wave height and wind data. It is however necessary to investigate and test this method in a more detailed way, before the analysis results can be used in a quantitative way.

table 3.3 Difference in correlation coefficients between adjusted and original quantile analysis method for various combinations of sea-level, wave height and wind data

	Vlissingen			Hoek v Holland			Delfzijl			Eur			Eld			Son			Schiphol		
	10^{0} quantile	10^{-1} quantile	10^{-2} quantile	10^{0} quantile	10^{-1} quantile	10^{-2} quantile	10^{0} quantile	10^{-1} quantile	10^{-2} quantile	10^{0} quantile	10^{-1} quantile	10^{-2} quantile	10^{0} quantile	10^{-1} quantile	10^{-2} quantile	10^{0} quantile	10^{-1} quantile	10^{-2} quantile	10^{0} quantile	10^{-1} quantile	10^{-2} quantile
Vlissingen																					
Hoek v Holland	0.15	0.20	0.21																		
Delfzijl	0.32	0.31	0.28	0.13	0.16	0.16															
Eur	0.16	0.06	0.03	-0.16	-0.01	0.03															
Eld							-0.13	-0.40	-0.46	-0.17	-0.23	-0.24									
Son							-0.19	-0.08	-0.03	0.02	0.04	-0.03	0.07	-0.17	-0.24						
Schiphol	-0.18	-0.04	0.01	-0.27	-0.23	-0.21				-0.00	0.05	0.08									
Terschelling							0.39	0.61	0.65				-0.21	-0.56	-0.53	-0.39	-0.23	-0.16	-0.34	-0.19	-0.37

3.3 Downscaling method

The downscaling method described in this paragraph is basically different from the methods described in the paragraphs 3.1 and 3.2. Those methods were used to get insight into possible connections between sea-level, wave height and wind data, while this downscaling method is based on the assumption that this connection exists. So this downscaling method is as it were 1 step forward compared to the maxima and quantile analysis method.

Basic idea behind the downscaling method is that maxima of high-water set-up (available over more than 100 year) can be used to extend the time horizon of wave height and wind statistics (of order 30 and 40 year respectively). If for example high-water set-up maxima are relatively low in a certain period of time, the same might hold for the wave height maxima because both depend primarily on the wind speed.
Assuming that those 2 phenomena are strongly dependent, it can be argued that estimates of exceedance frequencies of high-water set-up maxima can be used to adjust the exceedance frequencies of wave height maxima. It should be emphasized that the degree of dependence of wave height maxima and high-water set-up maxima determines the appropriate adjustment of the exceedance frequencies of wave height maxima.
If for example storm maxima of wave height and high-water set-up are completely independent, the method should not be applied. On the other hand, if they are totally dependent, the method can be applied straightforward. In this study it is assumed that both phenomena are strongly dependent.

The method which is used is schematically visualised in figure 3.2 and consists of the following steps [Bijl, 1995b], [de Valk, 1995]:

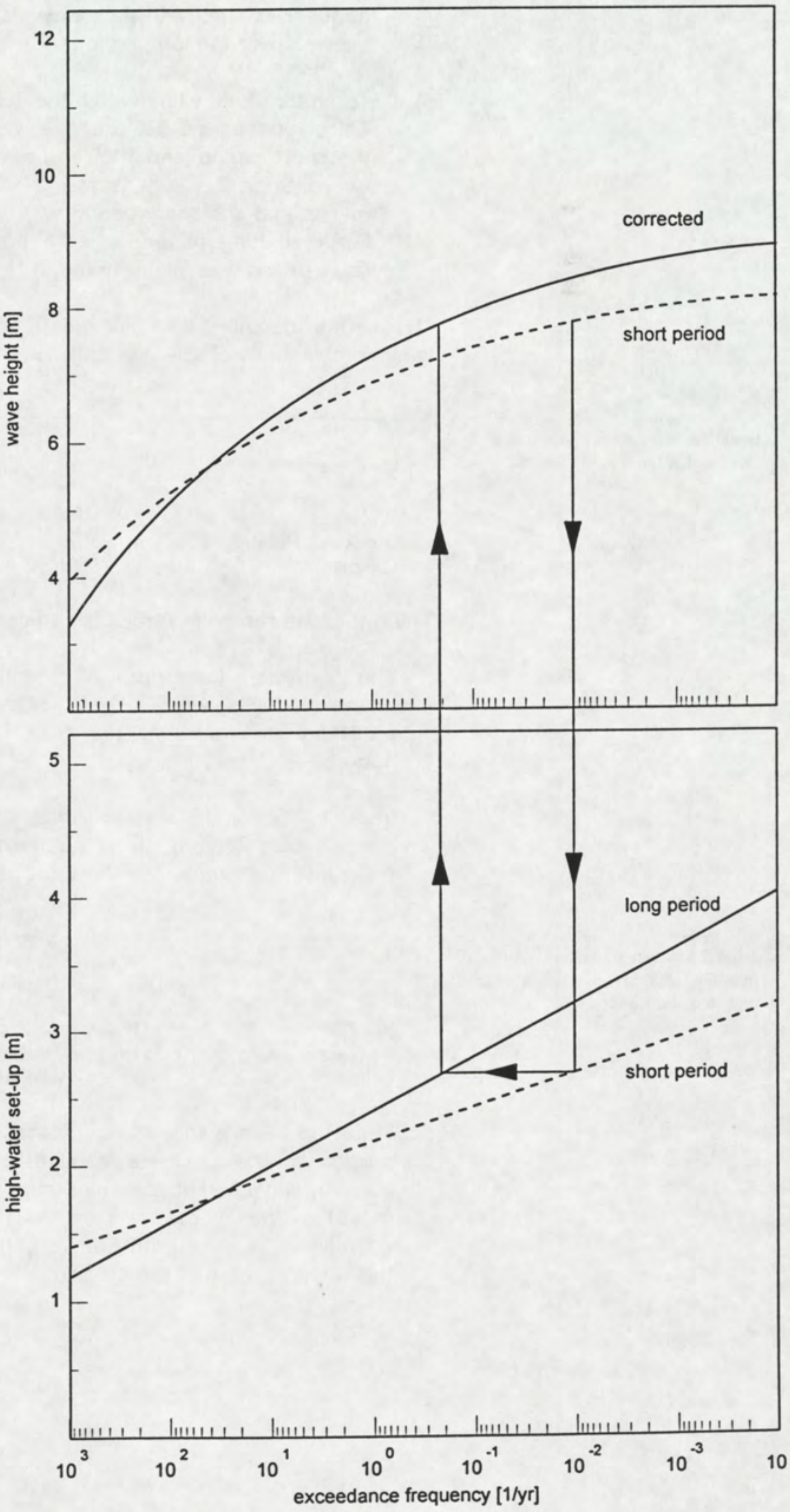
1) Estimation of exceedance frequencies of high-water set-up maxima over the longest record available (further referred to as the long period) and the period 01-01-1965/31-12-1993 (further referred to as the short period).

   As in case of the quantile analysis method, the (conditional) 2-parameter Weibull frequency distribution (see paragraph 3.2) is used for this purpose. The estimates of the exceedance frequencies are made over a range of thresholds, with α fixed (α=1) and only σ estimated for these thresholds. The applied threshold range is formed by threshold values with exceedance frequencies ranging from 5/year up to 1/year.

2) For each threshold value within the defined threshold range:
   Determination of deviations of the estimates of exceedance frequencies of high-water set-up maxima over the short period in relation to the estimates of exceedance frequencies of high-water set-up maxima over the long period (by relating the estimates of the long and the short period).

3) Estimation of exceedance frequencies of wave height maxima over the short period on the basis of the (conditional) 2-parameter Weibull frequency distribution. These estimates of exceedance frequencies have been made over the same threshold range as described in step 1), with α fixed (α=2.62) and only σ estimated for these thresholds.

figure 3.2 Illustration of the method, used to adjust the exceedance frequencies of wave height maxima on the basis of high-water set-up maxima



4) For each threshold value within the defined threshold range:
   Application of the in step 2 calculated deviations to the in step 3 calculated estimates of exceedance frequencies of wave height maxima over the short period. The resulting (corrected) exceedance frequencies are 'artificial' exceedance frequencies of wave height maxima over the long period.

5) For each threshold value within the defined threshold range:
   Calculation of the 10^{-2}-quantile value of wave height maxima over the short period and the 'artificial' long period. The difference between these 2 values is called 'adjustment'. A negative adjustment means that the short period was relatively smooth compared to the 'artificial' long period, while a positive adjustment means that this short period was relatively rough.

The method described and illustrated above has been applied to the following combinations of sea-level and wave height stations (table 3.4):

table 3.4 Selected combination of sea-level and wave height stations

Sea-level station	Wave height station
Vlissingen	EUR
Hoek van Holland	EUR
Delfzijl	SON

The results are shown in Annex D and can be summarized as follows:

- The adjustment (as a result of extending the time-horizon) of the 10^{-2}-quantile value of wave height maxima over the short period is, in contradiction to what was found in [de Valk, 1995], within plausible bounds.

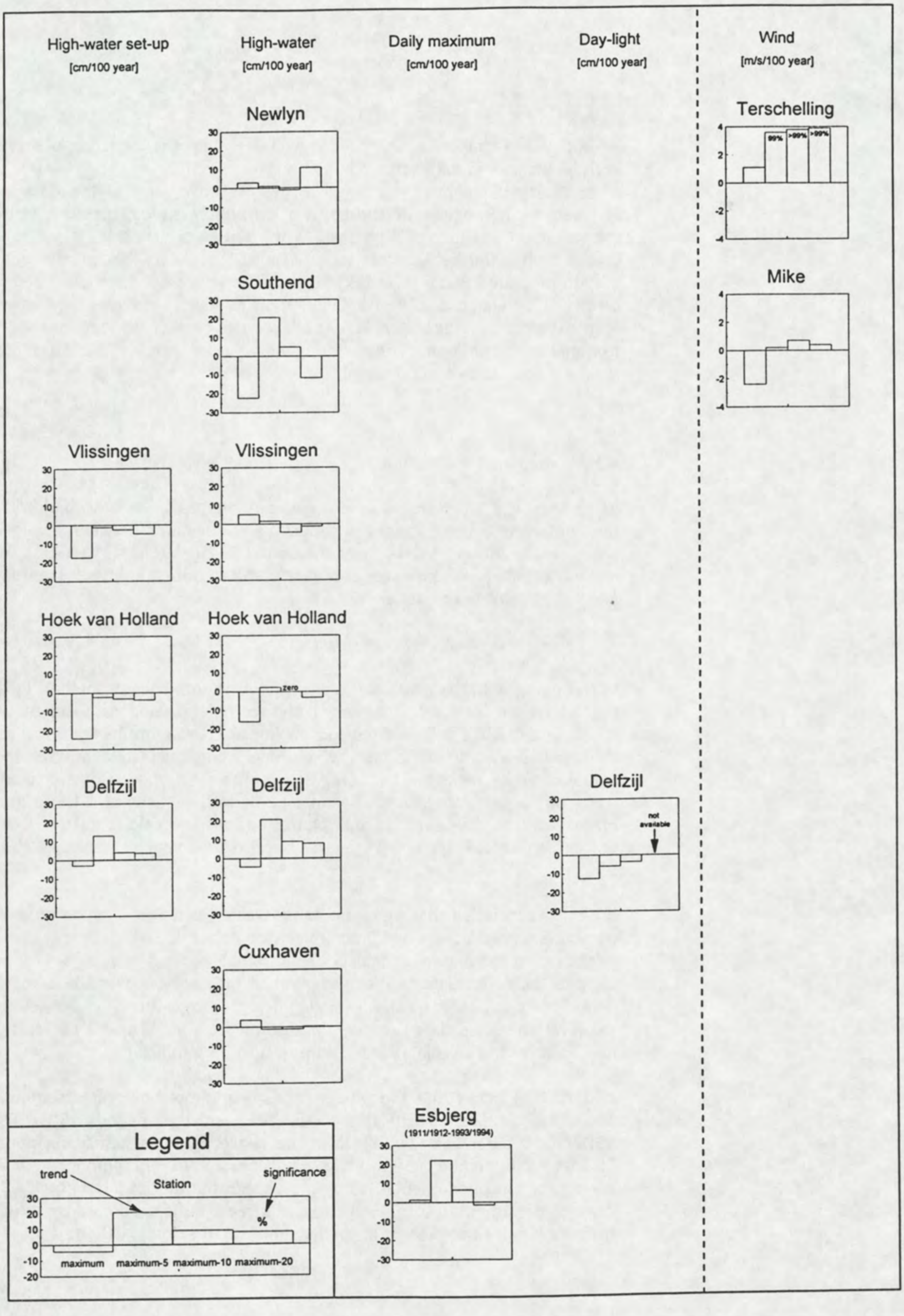
- In table 3.5, for the specified threshold range, the mean adjustment (as a result of extending the time-horizon) of the 10^{-2}-quantile value of wave height maxima over the short period is summarized.

table 3.5 Mean adjustment of the 10^{-2}-quantile value of wave height maxima over the short period

	EUR	SON
Vlissingen	-0.19 m	
Hoek van Holland	-0.23 m	
Delfzijl		-0.03 m

From this table it follows clearly that, as a result of extending the time-horizon of the wave height statistics into the past, the 10^{-2}-quantile value of wave height maxima slightly increases (see definition of 'adjustment'). However, the standard deviation of the estimation of the 10^{-2}-quantile value is for both EUR as SON about 0.3 m., which implies that this slight increase of the 10^{-2}-quantile value is not significant.

figure 4.1 Characteristics of trend lines
(maxima analysis method)



4. Trends and fluctuations

As outlined in chapter 1, this chapter will deal with the detection of trends and fluctuations in data-sets.
A necessary requirement for trend analysis is however that the data-sets involved are homogeneous and cover a long time-period. Therefore, in this chapter main attention will be paid to the sea-level data-sets, in particular to the high-water set-up data-sets, because these data-sets purely reflect the storm-related water level fluctuations. They have not been disturbed by processes unrelated to storm activity, such as local anthropogenic activity (e.g. harbour dredging) or relative sea-level rise. Neither do they include astronomical tide influences (e.g. spring tide - neap tide cycle), which also induce a non storm-related signal.

4.1 Maxima analysis method

In paragraph 3.1, the maxima analysis method has been described within the context of getting insight into possible connections between sea-level, wave height and wind data (over the period 01-10-1964/31-12-1991). The analysis of maxima is however also very useful to detect and visualize trends and fluctuations in the data-sets itself.

4.1.1 Complete measurement period

In this paragraph, the results of applying the maxima analysis method to the (complete) sea-level data-sets and to the (complete) wind data-sets of Terschelling and Mike will be discussed. In Annex E these results are visualized, in combination with trend lines which have been calculated for each individual curve by means of linear regression. Table 4.1 shows some characteristics of the calculated trend lines in a numerical way, figure 4.1 in a graphical way (bar diagrams). In this figure, besides the calculated trend, also the percentage of significance of this trend is given for percentages above 95%.

It can be concluded that there are considerable fluctuations of the observed parameters on relative small time scales (see Annex E), which mainly can be attributed to the natural variability of the climate system.
Despite these fluctuations on relative small time scales, over the complete period there is almost no sign of a *significant* change (trend) in the selected sea-level and wind data-sets. Just in case of the wind data-set of Terschelling, most of the calculated trends turn out to be significant.

It should be noted that the results for Esbjerg show however a somewhat unrealistic picture, because the results over the period 1889/1890-1909/1910 differ considerably from the results over the remaining period. Striking feature is the lack of maximum values above 3 m. before 1910. The reason for this phenomenon is not known, but the abrupt jump about 1910 can not be attributed to natural circumstances. This is supported by the fact that the jump is not present in the maximum-5, maximum-10 and

table 4.1 Characteristics of trend lines (maxima analysis method)

	trend/100 year					student t-test				
	high-water set-up	high-water	daily maximum	day-light	wind	high-water set-up	high-water	daily maximum	day-light	wind
	[cm]	[cm]	[cm]	[cm]	[m/s]					
Newlyn										
maximum		3.0					0.44			
maximum-5		0.9					0.15			
maximum-10		-1.0					0.19			
maximum-20		10.9					1.95			
Southend										
maximum		-22.3					0.55			
maximum-5		20.6					1.89			
maximum-10		5.0					0.59			
maximum-20		-11.6					1,09			
Vlissingen										
maximum	-17.5	5.1				1.35	0.40			
maximum-5	-1.2	1.5				0.27	0.30			
maximum-10	-2.6	-4.5				0.96	1.07			
maximum-20	-4.7	-1.4				1.31	0.09			
Hoek van Holland										
maximum	-24.2	-16.0				1.50	1.03			
maximum-5	-2.3	2.3				0.45	0.40			
maximum-10	-3.2	0.0				0.88	0.00			
maximum-20	-3.9	-3.2				1.29	0.65			
Delfzijl										
maximum	-3.0	-4.5		-12.6		0.13	0.21		1.31	
maximum-5	13.0	20.8		-6.0		1.47	2.36		1.25	
maximum-10	4.0	9.1		-3.7		0.64	1.25		0.99	
maximum-20	3.6	8.0				0.77	1.47			
Cuxhaven										
maximum		3.7					0.28			
maximum-5		-1.3					0.24			
maximum-10		-1.2					0.33			
maximum-20		0.2					0.08			
Esbjerg (1911/1912-1993/1994)										
maximum			1.3					2.07		
maximum-5			22.0					2.11		
maximum-10			6.4					1.18		
maximum-20			-1.5					0.56		
Terschelling										
maximum					1.1					0.40
maximum-5					3.6					2.75
maximum-10					3.8					2.98
maximum-20					3.9					3.62
Mike										
maximum					-2.4					0.60
maximum-5					0.2					0.08
maximum-10					0.7					0.31
maximum-20					0.4					0.22

maximum-20 curves. Therefore the (trend) analysis for Esbjerg has been restricted to the period 1911-1912/1993-1994.

Looking more into detail at the results, it is worthwhile to mention that:

- Results, based on the high-water set-up data-sets (which purely reflect the storm-related water level fluctuations), indicate a distinction between the more southern stations Vlissingen and Hoek van Holland (decreasing trend in storminess) and the more northern station Delfzijl (increasing trend in storminess). This distinction is also visible when the variability on relative small time scales is taken into consideration. The results based on the data-sets of the more southern stations show a more moderate bi-annual variability.

- Just in case of the stations Vlissingen and Hoek van Holland (high-water set-up data), Delfzijl ('day-light' high-water data) and Terschelling (wind data), the sign of the calculated trends per data-set is similar. In case of wind station Terschelling, these trends are however different from the trends calculated for the sea-level stations, because:

  - the sign of these trends is upward instead of downward.
  - these trends are highly significant instead of not significant.

- In case of Delfzijl there is consistency in the sign of trends calculated on the basis of high-water set-up and 'complete' high-water data. The sign of trends calculated on the basis of the 'day-light' high-water data-set of this station is however opposite.

- With respect to

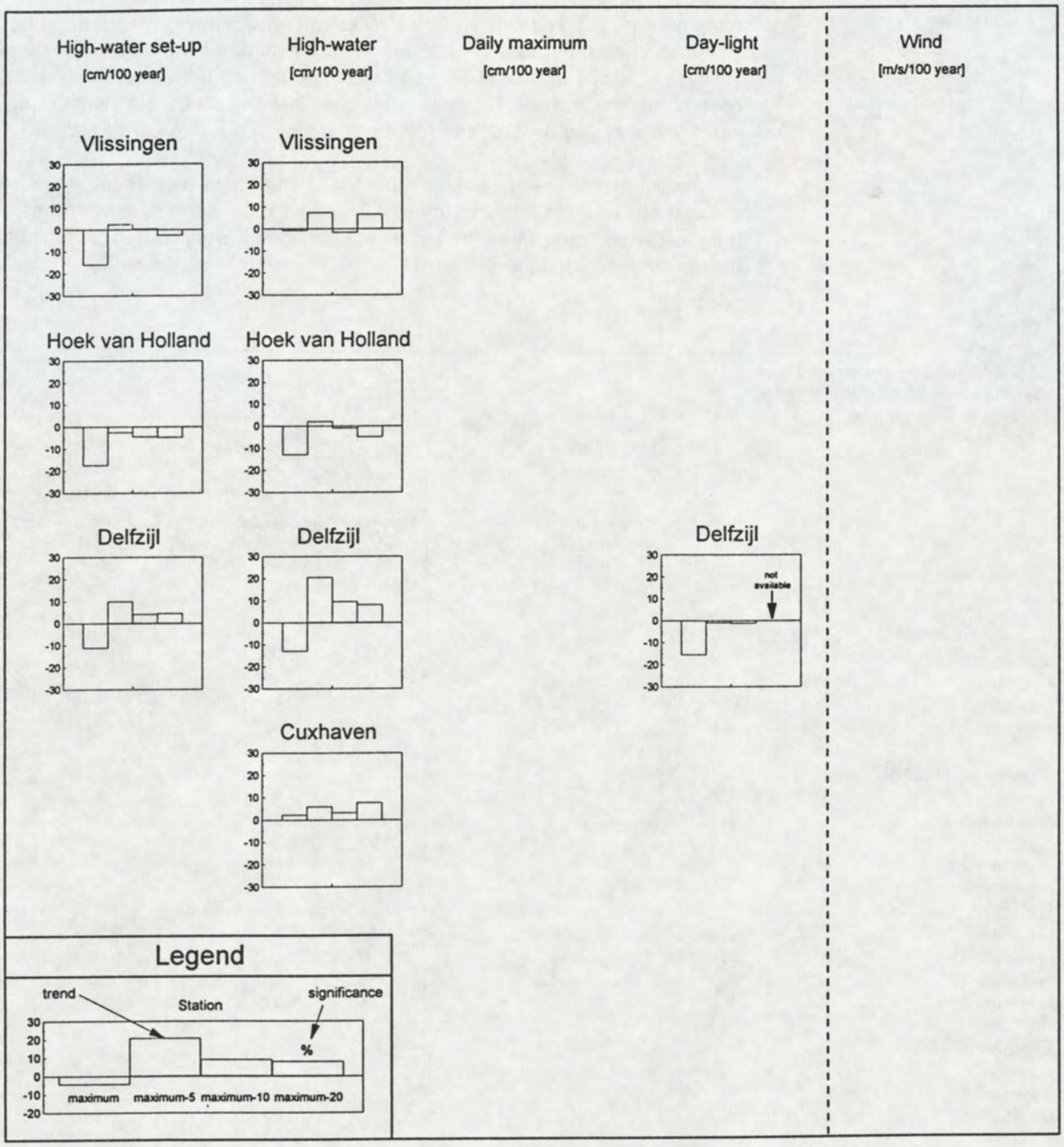
trends in the maxima:	38% is upward, 62% is downward.
trends in the maxima-5:	69% is upward, 31% is downward.
trends in the maxima-10:	50% is upward, 50% is downward.
the trends in the maxima-20:	45% is upward, 55% is downward.
trends in all quantities:	52% is upward, 48% is downward.

- The results based on the wind data-set of Terschelling reveal significant increasing trends in storminess. In fact, this wind data-set is the only data-set which shows significant (upward) trends; the sea-level data-sets do not show any significant trend. It should however be noticed that the time-span of this wind data-set is in fact to small to provide reliable information within the context of long-term trend calculations

Taking all results into account, general conclusion is that the calculated trends are both increasing and decreasing (not significantly), whereby:

a) high-water set-up data-sets (which purely reflect the storm-related water level fluctuations) indicate a distinction between the analysis results of the more southern stations (Vlissingen, Hoek van Holland), and the northern station (Delfzijl).
b) for trends in the maximum values there seems to be a tendency to decrease (62%). Trends in the maximum-5 values show however exactly the opposite, while trends in the maximum-10, maximum-20 values and in all quantities are equally increasing and decreasing.
c) there is no consistency in trends at stations where more than one type of data is available.
d) none of these trends differs significant from zero; except for the (possibly inhomogeneous) wind data-set of Terschelling.

figure 4.2 Characteristics of trend lines over the common measurement period (maxima analysis method)



4.1.2 Common measurement period

In the foregoing section, trend lines have been calculated on the basis of the complete measurement period of the data-sets. However, to compare the analysis results of various stations within an area, theoretically it is better to use a common measurement period.
Therefore in this paragraph, on the basis of the results of the maxima analysis method as visualized in Annex E, results of a trend analysis over a (common) period 1889/1890-1991/1992 will be discussed. This time-period has been chosen because on the one hand this period is quite long (order of 100 years), while on the other hand the majority of the (sea-level) data-sets covers this time-period. It implies however that the stations Newlyn, Southend, Esbjerg, Terschelling and Mike will not be taken into consideration.

The result of the trend analysis over the common measurement period is summarized in table 4.2 and figure 4.2, which show some characteristics of the calculated trend lines. In figure 4.2, besides the calculated trend, also the percentage of significance of this trend is given for percentages above 95%.

table 4.2 Characteristics of trend lines over the period 1889/1890-1991/1992 (maxima analysis method)

	trend/100 year					student t-test				
	high-water set-up [cm]	high-water [cm]	daily maximum [cm]	day-light [cm]	wind [m/s]	high-water set-up	high-water	daily maximum	day-light	wind
Vlissingen										
maximum	-16.0	-0.8				1.08	0.05			
maximum-5	2.5	7.3				0.55	1.41			
maximum-10	0.4	-1.7				0.15	0.38			
maximum-20	-2.5	6.6				0.63	0.39			
Hoek van Holland										
maximum	-17.5	-13.0				1.07	0.81			
maximum-5	-2.5	2.1				0.48	0.35			
maximum-10	-4.4	-1.0				1.21	0.21			
maximum-20	-4.8	-4.9				1.56	0.95			
Delfzijl										
maximum	-11.2	-13.0		-15.5		0.44	0.54		0.75	
maximum-5	10.0	20.6		-0.9		0.99	2.05		0.09	
maximum-10	4.1	9.6		-1.2		0.59	1.16		0.18	
maximum-20	4.6	8.2				0.86	1.32			
Cuxhaven										
maximum		2.3					1.01			
maximum-5		5.9					0.62			
maximum-10		3.3					0.52			
maximum-20		7.7					1.73			

On the basis of these results, it can be calculated that with respect to

- trends in the maxima: 13% is upward, 87% is downward.
- the trends in the maxima-5: 75% is upward, 25% is downward.
- trends in the maxima-10: 50% is upward, 50% is downward.
- trends in the maxima-20: 57% is upward, 43% is downward.
- trends in all quantities: 48% is upward, 52 % is downward.

These percentages show that (in general) there are no big differences between the sign of trends calculated over the complete measurement period of individual stations and the sign of trends over the common measurement period. In addition it is important to note that also in this case (common measurement period) none of the calculated trends is significant.

More specific it is worthwhile to mention that the results based on the 'complete' high-water data-set of Cuxhaven show a slight (not significant) upward trend for all calculated trend lines, while in case of the complete measurement period the trend lines show almost no trend. The sign of trends calculated on the basis of the 'complete' high-water and high-water set-up data-set of station Vlissingen also changes a bit as a result of using 2 different measurement periods.
With respect to the magnitude of the calculated trends, it is not possible to state general pronouncements within the context of using 2 different measurement periods. Theoretically it can be argued that the main differences have to appear in trends in the maximum values. However, in practice it turns out that also in case of the maximum-5, maximum-10 and maximum-20 values there are considerable differences in magnitude.

Summarizing statement is therefore that the sign of trends calculated over the common measurement period is more or less comparable to the sign of trends calculated over the complete measurement period. The magnitude of the calculated trends is however much more sensitive to the length of the measurement period which is used.

As described in the beginning of this paragraph, theoretically it is better to use a common measurement period in order to compare the analysis results of the various data-sets. A major disadvantage is however that this implies that

- useful data is not used because it does not fit within the common measurement period.
- some data-sets are omitted because their time-span is too short.

Because of these 2 reasons, despite the fact that there is some discrepancy between trends calculated over the complete measurement period and the common measurement period, in the concluding chapter 5 main emphasis will be stressed on results over the complete measurement period.

4.2 Quantile analysis method

4.2.1 Adjustment of the methodology

The second method which is used for trend analysis is the quantile analysis method. However, compared to the method described in paragraph 3.2, the methodology has been slightly adapted to the perspective of this chapter. In the remainder of this paragraph, the adjusted method will be outlined:

1) The first step is to split up a data-set into a number of succeeding sub-periods. The length of these periods has been set to 10 years, because in the second step of this method a threshold range '1/year - 5/year' is used. In order to be assured that this threshold range contains at least 10 threshold values (which is supposed to be the minimum number for this specific application of the quantile analysis method), if follows that sub-periods of at least 10 years are required.

2) The next step is to fit all the data of each 10-year period and of the complete period with the (conditional) 2-parameter Weibull frequency distribution which approximates exceedance frequency curves above a certain threshold value (see paragraph 3.2).
   The shape or curvature of this distribution is left unchanged for each of the 3 types of data; the threshold range which is used is however different. Instead of using 1 threshold range, 3 threshold ranges are used, whereby the bounds of each threshold range are determined by exceedance frequencies instead of concrete threshold values.

   The threshold ranges which have been taken into account are:

   1/year - 5/year; relative high threshold values.
   5/year - 10/year; medium threshold values.
   10/year - 15/year; by relative low threshold values.

3) The third step of the method is to calculate, for each of the 3 threshold ranges, the 10^{-4}-quantile value of both the 10-year periods and the complete period. The choice of this quantile value is mainly based on the fact that along the central coast of the Netherlands a safety standard has been agreed with a return period of 10000 years [de Ronde et al., 1995a).
   For each threshold range, many estimates of this quantile value are available (based on threshold values forming the threshold range which is taken into account). The mean of all these estimates is used as best quantile value.

4) The final part of the method involves the comparison of the 10^{-4}-quantile value of the complete period with the 10^{-4}-quantile value of a specific 10-year period. This provides as it were insight into the degree of storminess of this 10-year period (in relation to the complete measurement period). If for example the 10^{-4}-quantile value of a certain 10-year period is higher than the corresponding quantile value of the complete measurement period, than it can be argued that this 10-year period has been relative rough.
   To quantify this degree of storminess of each 10-year period, the difference between the 10^{-4}-quantile value of the 10-year period and the complete period has been taken (storminess factor). This means that a positive storminess factor denotes a relative rough 10-year period; a negative storminess factor a relative smooth period.

4.2.2 Complete measurement period

In this paragraph, the results of applying the adjusted quantile analysis method to the (complete) sea-level data-sets and to the (complete) wind data-sets of Terschelling and Mike will be described, whereby in case of station Esbjerg the data over the period 1889-1910 has been omitted (see paragraph 4.1.1).

In Annex F part 1, the results are visualized for decades which start at a plural of 10. In addition, for each curve of the stations Vlissingen, Hoek van Holland, Delfzijl, Cuxhaven and Esbjerg, trend lines have been calculated. Due to the (relative small) time-span which is covered by the data-sets of Newlyn, Southend, Terschelling and Mike, too little storminess factors could be generated to perform a reliable trend calculation.

figure 4.3 Characteristics of trend lines
(quantile analysis method)

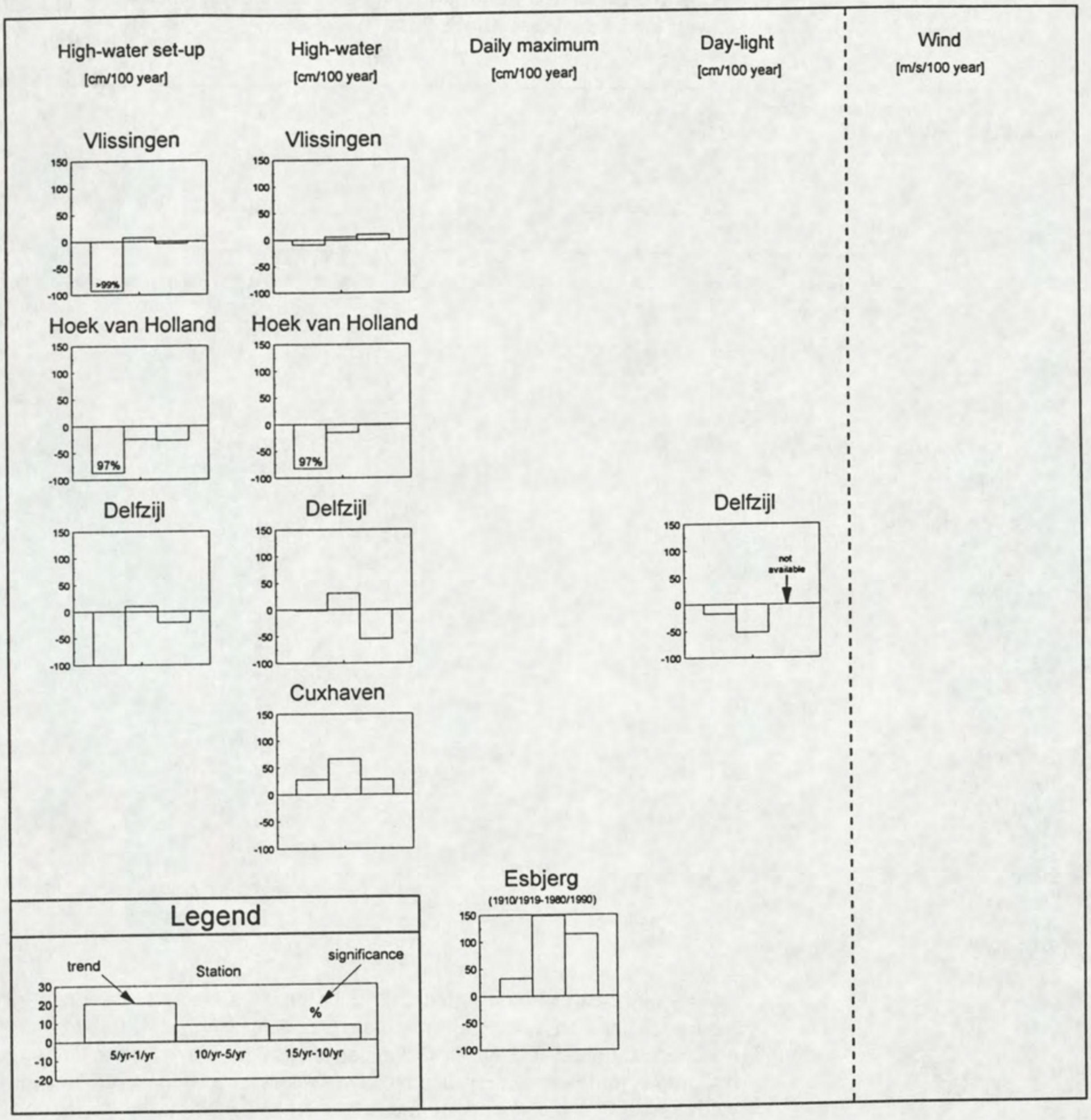


Table 4.3 shows some characteristics of the calculated trend lines in a numerical way; figure 4.3 in a graphical way (bar diagrams). In this figure, besides the calculated trend, also the percentage of significance of this trend is given for percentages above 95%.

table 4.3 Characteristics of trend lines (quantile analysis method)

	trend/100 year					student t-test				
	high-water set-up	high-water	daily maximum	day-light	wind	high-water set-up	high-water	daily maximum	day-light	wind
	[cm]	[cm]	[cm]	[cm]	[m/s]					
Vlissingen										
5/yr-1/yr	-92.3	-9.6				5.33	0.26			
10/yr-5/yr	7.6	5.8				0.24	0.16			
15/yr-10/yr	-3.9	9.9				0.14	0.24			
Hoek van Holland										
5/yr-1/yr	-86.9	-82.3				2.41	2.64			
10/yr-5/yr	-24.5	-14.8				0.86	0.49			
15/yr-10/yr	-26.6	-0.7				0.91	0.02			
Delfzijl										
5/yr-1/yr	-100.3	-54.8		-17.5		1.17	0.57		0.57	
10/yr-5/yr	10.7	31.4		-52.3		0.16	0.47		1.73	
15/yr-10/yr	-20.4	-1.5				0.33	0.02			
Cuxhaven										
5/yr-1/yr		27.8					0.48			
10/yr-5/yr		66.4					1.86			
15/yr-10/yr		27.8					0.70			
Esbjerg										
5/yr-1/yr			32.5					0.30		
10/yr-5/yr			148.5					1.40		
15/yr-10/yr			114.3					1.42		

In general, it can be concluded that the storminess factors show considerable fluctuations on a decadal time scale (see Annex F part 1), whereby more northern stations like Delfzijl, Cuxhaven or Esbjerg show larger fluctuations than more southern stations like Newlyn, Vlissingen or Hoek van Holland.
With respect to the results of the stations Newlyn, Southend, Terschelling and Mike it is however clear that the number of points (storminess factors) is in fact too small for reliable trend calculations.
In case of the analysis results of Terschelling, it is remarkable that all decadal storminess factors are negative, which means that all these decades are smooth compared to the complete measurement period. Explanation for this (strange) phenomenon is that the periods which are not covered by the decadal storminess factors (01-01-1948/31-12-1949 and 01-01-1990/31-12-1994) must have been rough. The latter is however not confirmed by the results of the maxima analysis method (Annex E) and the analysis results described in Annex F part 3 (see paragraph 4.2.5).

Looking more into detail at the results of this quantile analysis method, it is worthwhile to mention that (table 4.3, figure 4.3):

- Results, based on the high-water set-up data-sets (which purely reflect the storm-related water level fluctuations) show large decreasing trends for the threshold range which is formed by relative high threshold values. In contradiction to the maxima analysis method, these results do not indicate a distinction between the more southern stations (Vlissingen, Hoek van Holland) and the northern station Delfzijl.
  This distinction is however clearly visible when the variability on a decadal time scale is taken into consideration. The results based on the data-sets of the more southern stations clearly indicate a more moderate variability than the results based on the data-set of Delfzijl.

- In case of the stations Hoek van Holland ('complete' high-water and high-water set-up data), Delfzijl ('day-light' high-water data), Cuxhaven (high-water data) and Esbjerg ('daily maximum' high-water data), the sign of the calculated trend lines per data-set is similar. For Hoek van Holland and Delfzijl these trends are however downward, while Cuxhaven and Esbjerg show upward trends.

- With respect to trends calculated on the basis of both the 'complete' high-water data and the high-water set-up data of a certain measurement station, Hoek van Holland shows the best agreement. In addition, for both data-sets the (downward) trend, calculated on the basis of the 5/yr-1/yr threshold range, is significant.
  As stated above, station Vlissingen and station Delfzijl also show a large downward trend in case of the 5/yr-1/yr threshold range (high-water set-up data-set). This trend does however not appear in the 'complete' high-water data-sets of these stations.

- The magnitude of the calculated trends is considerably higher than in case of the maxima analysis method; station Esbjerg shows the largest upward trend (about 150 cm/100year), station Delfzijl the largest downward trend (about 100 cm/100year). Just in a few cases however, the calculated trends differ significantly from zero.
  Explanation for these large trends is that the in case of the quantile analysis method the trend calculation is based on quantile values with an exceedance frequency of 10^{-4}. This in contradiction to the maxima analysis method which involves a trend calculation on 2-year quantities with exceedance frequencies ranging from 1/year (maxima) to 20/year (maximum-20). Adjusting the quantile analysis method (step 3) to a calculation of quantile values with higher exceedance frequencies would show that the magnitude of trends calculated on the corresponding storminess factors is comparable to the trends based on the maxima analysis method.

- With respect to the trends, calculated on the basis of the

1/yr-5/yr threshold range:	22% is upward, 78% is downward.
5/yr-10/yr threshold range:	67% is upward, 33% is downward.
10/yr-15/yr threshold range:	38% is upward, 62% is downward.
combined threshold ranges:	46% is upward, 54% is downward.

Taking all results into account, general conclusion is that calculated trends are both increasing and decreasing (not significantly), whereby:

a) high-water set-up data-sets (which purely reflect the storm-related water level fluctuations) show large decreasing trends in storminess for the threshold range which is formed by relative high threshold values. In contradiction to the maxima analysis method, the calculated trends do

not indicate a distinction between the more southern stations (Vlissingen, Hoek van Holland) and the more northern station Delfzijl.
This distinction is however clearly noticeable when the variability on decadal time scale is taken into consideration.

b) for trends calculated on the basis of relative high threshold values there seems to be a tendency to decrease (78%). Trends calculated on the basis of relative low threshold values support this finding (62%), but trends calculated on the basis of medium threshold values show a tendency in opposite direction. In addition, when all calculated trends are taken into account, the percentage of increasing and decreasing trends turns out to be equal.

4.2.3 Common measurement period

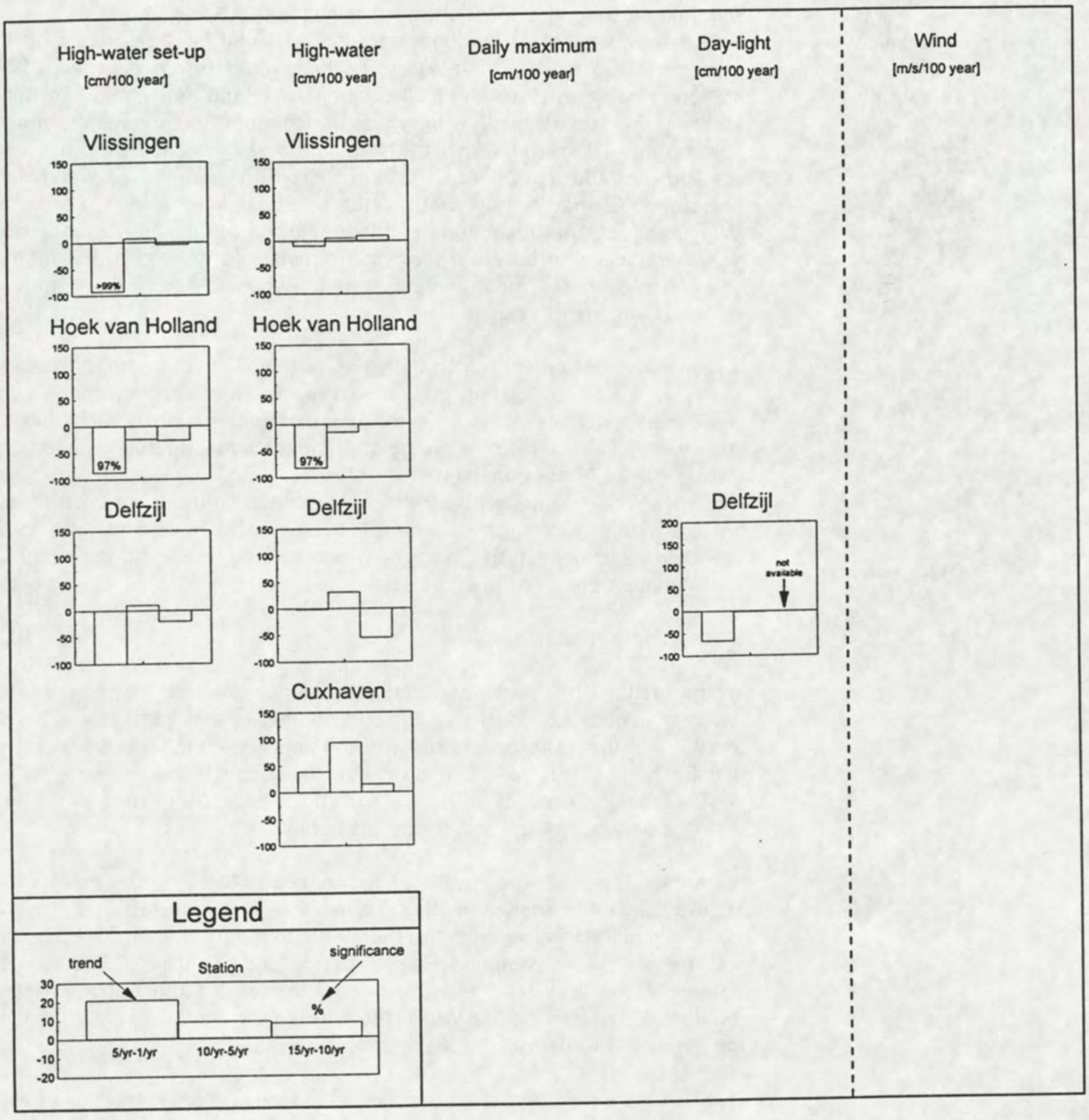
As described in paragraph 4.1.2, to compare trends in data-sets of various stations, theoretically it is better to use a common measurement period. Therefore in this paragraph, on the basis of the results of the adjusted quantile analysis method as visualized in Annex F part 1, the results of a trend analysis over the (common) period 1890/1899-1980/1989 will be discussed. As outlined in paragraph 4.1.2, this implies that the data-sets of the stations Newlyn, Southend, Esbjerg, Terschelling and Mike will be omitted.

The result of this trend analysis is summarized in table 4.4 and figure 4.4, which show some characteristics of the calculated trend lines. In figure 4.4, besides the calculated trend, also the percentage of significance of this trend is given for percentages above 95%.

table 4.4 Characteristics of trend lines over the period 1890/1899-1980/1989 (quantile analysis method)

	trend/100 year					student t-test				
	high-water set-up	high-water	daily maximum	day-light	wind	high-water set-up	high-water	daily maximum	day-light	wind
	[cm]	[cm]	[cm]	[cm]	[m/s]					
Vlissingen										
5/yr-1/yr	-92.3	-9.6				5.33	0.26			
10/yr-5/yr	7.6	5.8				0.24	0.16			
15/yr-10/yr	-3.9	9.9				0.14	0.24			
Hoek van Holland										
5/yr-1/yr	-86.9	-82.3				2.41	2.64			
10/yr-5/yr	-24.5	-14.8				0.86	0.49			
15/yr-10/yr	-26.6	-0.7				0.91	0.02			
Delfzijl										
5/yr-1/yr	-100.3	-54.8		-66.6		1.17	0.57		0.97	
10/yr-5/yr	10.7	31.4		-0.9		0.16	0.47		0.85	
15/yr-10/yr	-20.4	-1.5				0.33	0.02			
Cuxhaven										
5/yr-1/yr		38.8					0.35			
10/yr-5/yr		94.1					1.40			
15/yr-10/yr		15.3					0.30			

figure 4.4 Characteristics of trend lines over the period 1890/1899-1980/1989 (quantile analysis method)



On the basis of these results, it can be concluded that with respect to the sign of the calculated trends, no differences can be detected between the method using the complete measurement period of individual stations and the method using the common measurement period.
This is however not astonishing, because the trend lines calculated on the basis of the 'complete' high-water and high-water set-up data-sets of the stations Vlissingen, Hoek van Holland and Delfzijl did not change. For these stations, the 10-year periods in which the common measurement period is split up equal those in which the complete measurement period has been split up. Just the trend lines of station Delfzijl ('day-light' high-water data) and station Cuxhaven (high-water data) have been adjusted.
With respect to the magnitude of these adjusted trends, for station Cuxhaven there seems to be an increase in storminess (compared to the method using the complete measurement period), while station Delfzijl shows a drastic change per threshold range.

Summarizing statement of this section is therefore that the discrepancy between trends calculated over the complete measurement period and trends calculated over the common measurement period is such that the disadvantages as a result of using the common measurement period (see paragraph 4.1.2) are dominant.
This means that, although theoretically it is better to use a common measurement period (to compare the analysis results of various data-sets), in the remaining sections of this paragraph use will be made of the complete measurement period of the data-sets.

4.2.4 Time-shift variant

In this section, the sensitivity of the adjusted quantile analysis method to the 10-year periods in which the complete data-sets are split up will be discussed. For that purpose, a variant of the adjusted quantile analysis method has been used. This variant involves that the complete data-sets are split up into succeeding decades which, compared to the decades used in the foregoing 2 paragraphs, are shifted 5 years in time.

In Annex F part 2, the results of applying this (time-shift) variant of the adjusted quantile analysis method to the sea-level data-sets and the wind data-sets of Terschelling and Mike are visualized. In addition, for each curve of the stations Vlissingen, Hoek van Holland, Delfzijl, Cuxhaven and Esbjerg, trend lines have been calculated. In case of the stations Newlyn, Southend, Terschelling and Mike, too little points (storminess factors) could be generated to perform a reliable trend analysis.

Table 4.5 shows some characteristics of the calculated trend lines in a numerical way; figure 4.5 in a graphical way (bar diagrams). In this figure, besides the calculated trend, also the percentage of significance of this trend is given for percentages above 95%.

On the basis of these results, it can be concluded that also the time-shift variant of the quantile analysis method shows considerable fluctuations of the 10-year storminess factor (see Annex F part 2), whereby the more northern stations show larger fluctuations than the more southern stations. For the stations Newlyn, Southend, Terschelling and Mike it is however clear that the number of points (storminess factors) is in fact too small for reliable pronouncements.

figure 4.5 Characteristics of trend lines (time-shift variant quantile analysis method)

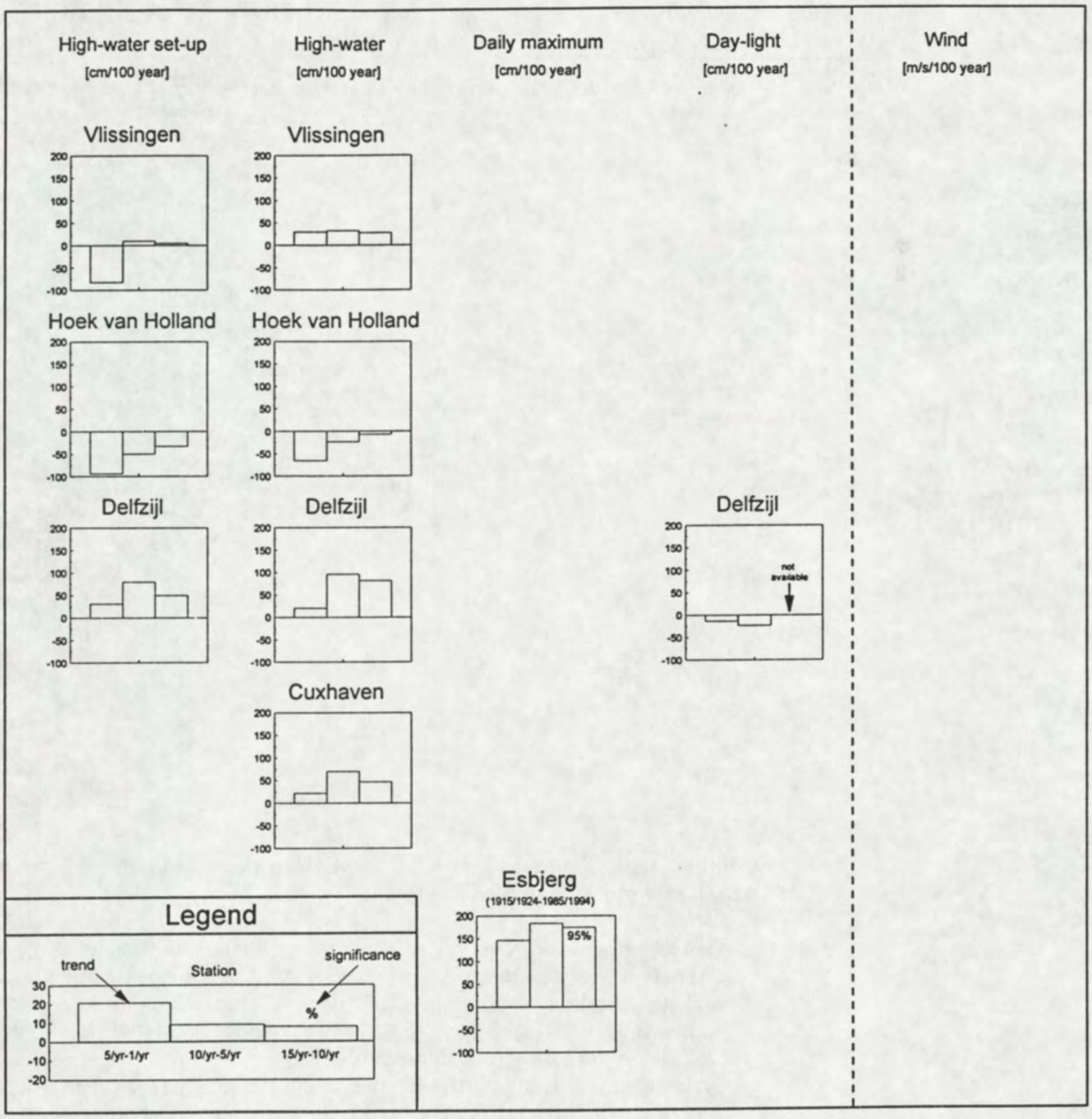


table 4.5 Characteristics of trend lines (time-shift variant quantile analysis method)

	trend/100 year					student t-test				
	high-water set-up [cm]	high-water [cm]	daily maximum [cm]	day-light [cm]	wind [m/s]	high-water set-up	high-water	daily maximum	day-light	wind
Vlissingen										
5/yr-1/yr	-82.8	30.0				1.43	0.51			
10/yr-5/yr	9.7	32.3				0.24	1.44			
15/yr-10/yr	4.6	27.8				0.20	0.79			
Hoek van Holland										
5/yr-1/yr	-94.1	-65.9				1.46	1.07			
10/yr-5/yr	-50.6	-23.6				1.09	0.50			
15/yr-10/yr	-33.3	-7.4				1.08	0.12			
Delfzijl										
5/yr-1/yr	31.2	20.1		-13.2		0.38	0.26		0.40	
10/yr-5/yr	79.7	96.3		-22.8		0.87	1.00		0.86	
15/yr-10/yr	50.1	82.4				0.65	1.02			
Cuxhaven										
5/yr-1/yr		22.3					0.45			
10/yr-5/yr		69.8					1.45			
15/yr-10/yr		47.1					1.07			
Esbjerg										
5/yr-1/yr			146.3					1.40		
10/yr-5/yr			183.8					2.09		
15/yr-10/yr			175.1					2.39		

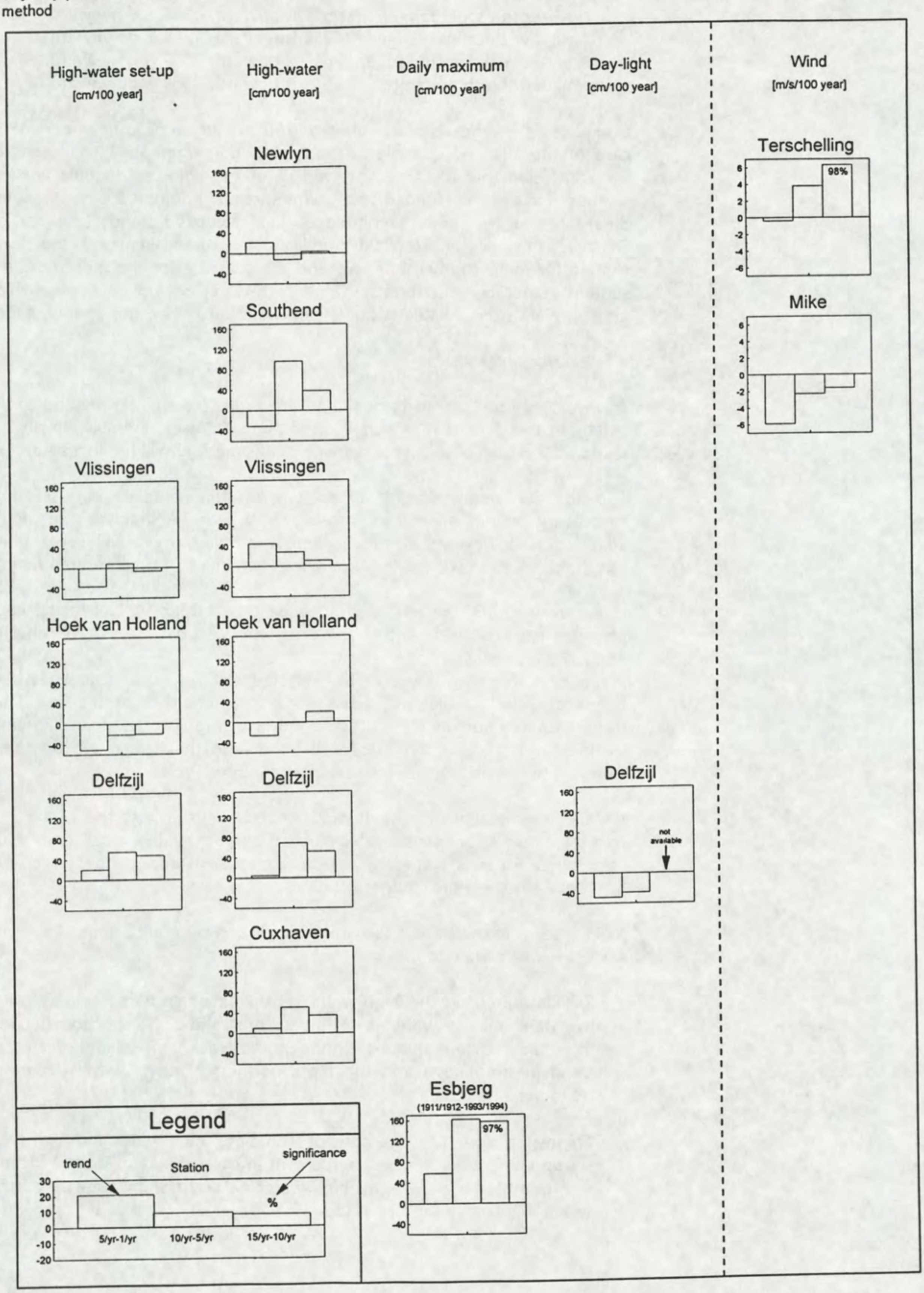
With respect to the trend lines which have been calculated (table 4.5, figure 4.5), it is worthwhile to mention that:

- Results, based on the high-water set-up data-sets clearly show a distinction between the southern stations (Vlissingen, Hoek van Holland) and the northern station Delfzijl. Trends, calculated for the more southern stations are decreasing, while trends calculated for station Delfzijl are increasing (not significantly).
  This dichotomy is supported by the analysis results based on the data-sets of Cuxhaven and Esbjerg, which all show increasing trends in storminess.

- For nearly all data-sets, the sign of the calculated trend lines per data-set is similar.

- With respect to trends calculated on the basis of 'complete' high-water and high-water set-up data, station Hoek van Holland and station Delfzijl show the best agreement. For Hoek van Holland these trends are decreasing, while for Delfzijl all trends turn out to be increasing.
  The sign of trends, calculated on the basis of the 'day-light' high-water data-set of Delfzijl, is however opposite.

figure 4.6 Characteristics of trend lines (2-yearly period variant quantile analysis method



- With respect to the trends, calculated on the basis of the

1/yr-5/yr threshold range:	55% is upward, 45% is downward.
5/yr-10/yr threshold range:	67% is upward, 33% is downward.
10/yr-15/yr threshold range:	75% is upward, 25% is downward.
combined threshold ranges:	65% is upward, 35% is downward.

Comparing these points of attention with those which have been derived in case of the adjusted quantile analysis method (paragraph 4.2.1), leads to the conclusion that the time-shift variant of the adjusted quantile analysis method induces no fundamental differences. Although there are some differences in sign and magnitude of the calculated trends (e.g. station Delfzijl), in essence the results also indicate a small weakening of the storm climate for more southern stations and a worsening for the more northern stations. Especially the results of the high-water set-up data-sets (which purely reflect storm-related water level fluctuations) show this phenomenon.

4.2.5 Periods of 2 year

To investigate the sensitivity of the adjusted quantile analysis method to the length of the periods in which the complete data-sets are split up, in this section the results of a '2-year' variant of this method will be discussed.

The adaption simply consists of splitting up the complete data-sets into succeeding periods of 2 years instead of 10 years. A disadvantage of this adaption is however that the applied threshold ranges will contain less threshold values as wished (especially the '1/year - 5/year' threshold range).

In Annex F part 3, the results of applying this '2-year' variant to the complete sea-level data-sets and to the complete wind data-sets of Terschelling and Mike are visualized.
In addition, for each curve of the selected stations, also trend lines have been calculated. Table 4.6 shows some characteristics of the calculated trend lines in a numerical way; figure 4.6 in a graphical way (bar diagrams). In this figure, besides the calculated trend, also the percentage of significance of this trend is given for percentages above 95%.

On the basis of these results, it can be concluded that also the 2-year storminess factors show considerable fluctuations on relative small time scales (see Annex F part 3), whereby the more northern stations show larger fluctuations than the more southern stations.

With respect to the trend lines which have been calculated (table 4.6, figure 4.6), it is worthwhile to mention that:

- Results, based on the high-water set-up data-sets (which purely reflect the storm-related water level fluctuations) show a distinction between the more southern stations Vlissingen and Hoek van Holland (decreasing trend in storminess) and the more northern station Delfzijl (increasing trend in storminess).

- Trends, calculated on the basis of 'complete' high-water and high-water set-up data, show the best agreement in case of station Delfzijl (decreasing trends). The 'day-light' high-water data-sets shows however trends which are exactly the opposite.

- Results, based on the wind data-sets of Terschelling and Mike, show opposite trends in storminess. Station Terschelling shows increasing trends, while station Mike indicates decreasing trends in storminess. This weakening of the storm climate does not fit within the observed concept of a (not significant) small worsening of the storm climate for the more northern stations.
  It should however be noticed that these (possibly inhomogeneous) wind data-sets cover a time-span which is considerably smaller than the time-span which is covered by the (more homogeneous) sea-level data-sets.

table 4.6 Characteristics of trend lines (2-yearly variant quantile analysis method)

	trend/100 year					student t-test				
	high-water set-up [cm]	high-water [cm]	daily maximum [cm]	day-light [cm]	wind [m/s]	high-water set-up	high-water	daily maximum	day-light	wind
Newlyn										
5/yr-1/yr		21.9					0.68			
10/yr-5/yr		-12.4					0.32			
15/yr-10/yr		3.6					0.09			
Southend										
5/yr-1/yr		-31.1					0.27			
10/yr-5/yr		97.0					1.16			
15/yr-10/yr		38.4					0.55			
Vlissingen										
5/yr-1/yr	-36.1	44.9				0.93	1.18			
10/yr-5/yr	8.6	28.0				0.28	0.94			
15/yr-10/yr	-6.7	11.3				0.27	0.38			
Hoek van Holland										
5/yr-1/yr	-50.8	-26.0				1.09	0.53			
10/yr-5/yr	-21.7	-1.2				0.59	0.03			
15/yr-10/yr	-20.1	20.4				0.63	0.60			
Delfzijl										
5/yr-1/yr	20.6	4.5		-48.7		0.25	0.06		1.38	
10/yr-5/yr	54.9	69.1		-38.4		0.83	1.08		1.47	
15/yr-10/yr	48.1	52.3				0.86	0.91			
Cuxhaven										
5/yr-1/yr		9.8					0.19			
10/yr-5/yr		51.3					1.22			
15/yr-10/yr		35.1					0.19			
Esbjerg										
5/yr-1/yr			57.7					0.56		
10/yr-5/yr			162.0					2.02		
15/yr-10/yr			157.2					2.33		
Terschelling										
5/yr-1/yr					-0.4					0.11
10/yr-5/yr					3.8					1.50
15/yr-10/yr					6.3					2.67
Mike										
5/yr-1/yr					-5.9					1.05
10/yr-5/yr					-2.3					0.47
15/yr-10/yr					-1.6					0.37

- With respect to the trends, calculated on the basis of the

1/yr-5/yr threshold range:	46% is upward, 54% is downward.
5/yr-10/yr threshold range:	62% is upward, 38% is downward.
10/yr-15/yr threshold range:	75% is upward, 25% is downward.
combined threshold ranges:	60% is upward, 40% is downward.

Comparing the results and points of attention of this 2-year variant with those of (the foregoing variants of) the adjusted quantile analysis method, leads however to the conclusion that:

a) the '2-year' variant of the adjusted quantile analysis method induces no fundamental differences. Although there are differences in sign and magnitude of the calculated trends (e.g. station Delfzijl), in essence the results are comparable. Especially the results of the high-water set-up data-sets (which purely reflect storm-related water level fluctuations) support this conclusion.
b) the observed large fluctuations of the storminess factors cannot be attributed to the length of the periods in which the complete data-sets were split up (decades). As concluded in section 4.1.1, most likely explanation is therefore that these fluctuations are due to the natural variability of the climate system.

4.2.6 Mean variant

In this paragraph, the results of the last variant of the adjusted quantile analysis method will be discussed. This variant has been developed in order to generate more generalized results. The adaption simply involves that the output of the adjusted quantile analysis method (10-year storminess factors per threshold range) is averaged over the 3 threshold ranges in question.

In Annex F part 4, the results of applying this variant to the sea-level data-sets and to the wind data-sets of Terschelling and Mike are visualized. For each curve of the stations Vlissingen, Hoek van Holland, Delfzijl, Cuxhaven and Esbjerg, also trend lines have been calculated. In case of the stations Newlyn, Southend, Terschelling and Mike, too little points (storminess factors) could be generated for a reliable trend calculation.

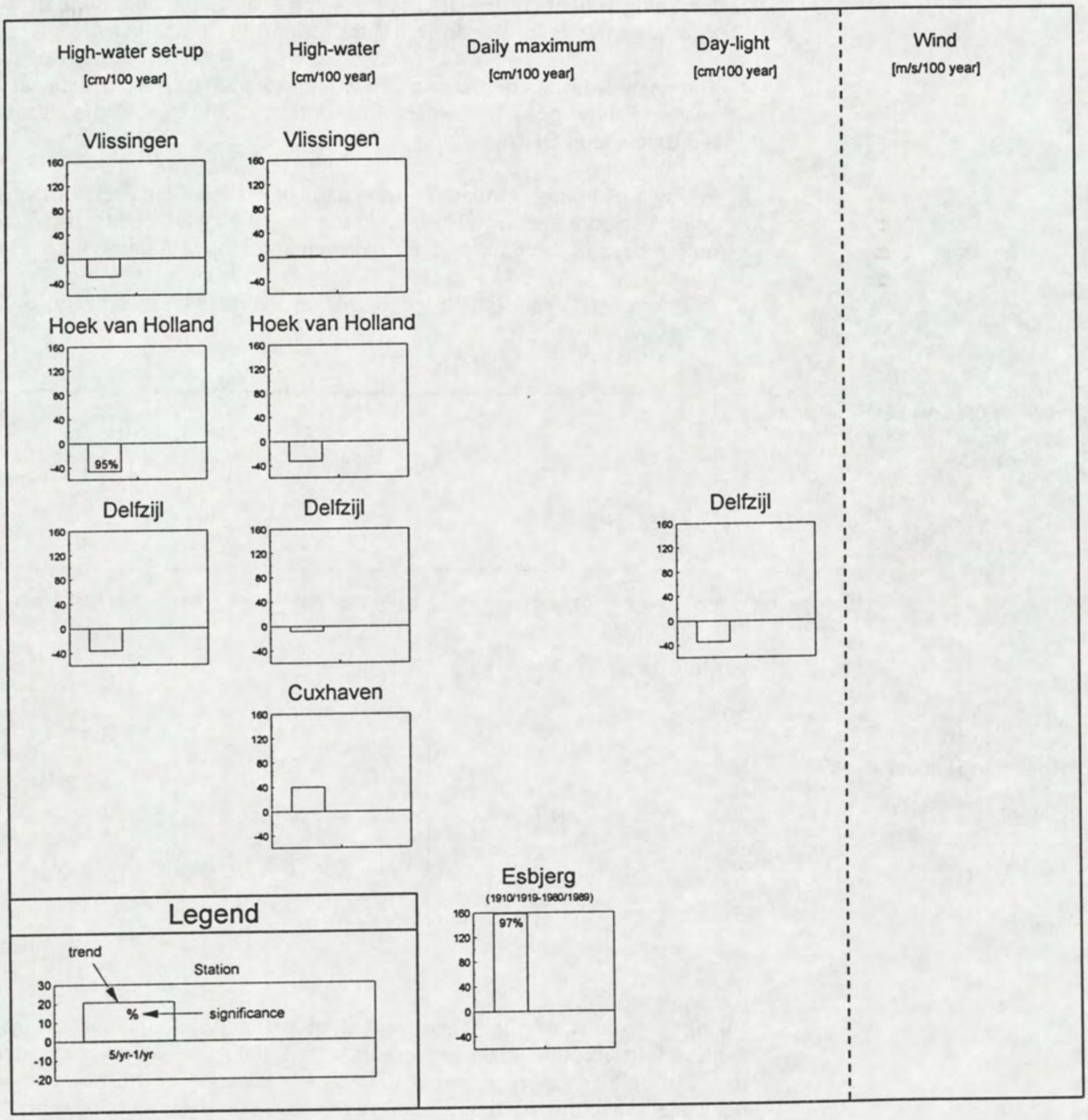
Table 4.7 shows some characteristics of the calculated trend lines in a numerical way; figure 4.7 in a graphical way (bar diagrams). In this figure, besides the calculated trend, also the percentage of significance of this trend is given for percentages above 95%.

On the basis of these results, also for the mean variant of the adjusted quantile analysis method it can be concluded that the more northern stations like Delfzijl, Cuxhaven and Esbjerg show a more enhance variability than the more southern stations (see Annex F part 4). As a result of the averaging procedure, in general the magnitude of these fluctuations has reduced considerably.

With respect to the trend lines which have been calculated (table 4.7, figure 4.7), it is worthwhile to mention that:

- Results, based on the high-water set-up data-sets (which purely reflect storm-related fluctuations) show a tendency towards a weakening of the storm climate. This result does not completely fit with the results of the

figure 4.7 Characteristics of trend lines (mean variant quantile analysis method)



foregoing variants, which indicate a distinction between the southern stations (Vlissingen, Hoek van Holland) and the northern station Delfzijl. It should however be emphasized that, both in this variant and in the foregoing variants of the adjusted quantile analysis method, none of the calculated trends for station Delfzijl turned out to be significant.

- The analysis results of stations where more than 1 (sea-level) data-set is available show good agreement with respect to the sign of the calculated trends (e.g. Delfzijl).

- The sign of trends calculated on the basis of sea-level data-sets of Dutch coastal stations (downward) is opposite to the sign of trends calculated on the basis of the data-sets of Cuxhaven and Esbjerg (upward).

- With respect to the sign of the calculated trends, 33% is upward; 67% is downward.

table 4.7 Characteristics of trend lines (mean variant quantile analysis method)

	trend/100 year					student t-test				
	high-water set-up	high-water	daily maximum	day-light	wind	high-water set-up	high-water	daily maximum	day-light	wind
	[cm]	[cm]	[cm]	[cm]	[m/s]					
Vlissingen	-29.6	2.0				1.30	0.06			
Hoek van Holland	-46.0	-32.6				2.15	1.121			
Delfzijl	-36.7	-8.3		-34.9		0.61	0.12		1.28	
Cuxhaven		40.7					1.08			
Esbjerg			158.8					2.60		

Taking all results of the mean variant of the adjusted quantile analysis method into account, main impression is that along the Dutch coast there seems to be a tendency apparent towards a weakening of the storm climate, while the more northern stations Cuxhaven and Esbjerg indicate the opposite.

4.3 Frequency and Intensity

The quantile analysis method described in the foregoing paragraph is in essence based on the fact that exceedance frequencies are approximated by means of a conditional 2-parameter Weibull frequency distribution. In this paragraph a different approach will be outlined, based on some properties of the exponential distribution.

4.3.1 Exponential distribution

The most simple form of a Weibull frequency distribution is

$$P[x>a] = e^{-(\frac{a}{\sigma})^{\alpha}}$$

where: α is the parameter which determines the shape or curvature of the frequency distribution and σ is the parameter which determines the scale of the frequency distribution.

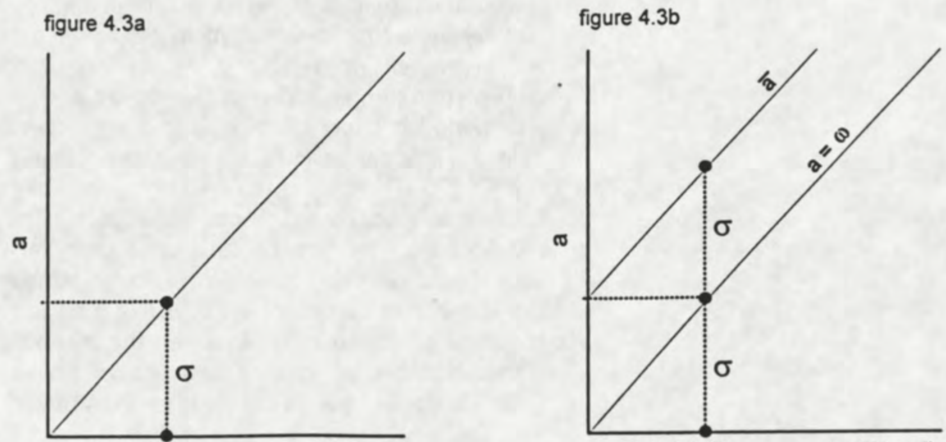
As described in paragraph 3.2, for sea-level data-sets a fixed α is used, whereby $\alpha = 1$ has turned out to be the best estimate. This implies that the Weibull frequency distribution in that case changes into a pure exponential distribution:

$$P[x>a] = e^{-(\frac{a}{\sigma})}$$

On log scale, this distribution can be depicted as a straight line with inclination σ (figure 4.8a).

The first property of this exponential distribution which is important within the aim of this chapter, is that the mean of all a-values equals σ. A second relevant property is that a sub-set of a-values (above a certain threshold value ω) also makes up an exponential distribution.
Combining these 2 properties implies that the mean of all a-values $(\bar{a})$ above a certain threshold ω amounts to $\sigma + \omega$. So, using every a-value as a (variable) threshold value ω, the course of the mean of a-values above threshold value ω can be visualized as depicted in figure 4.8b [van der Made et al., 1984].

figure 4.8 Properties of the exponential distribution



4.3.2 Frequency-intensity analysis method

As described in the foregoing section, for sea-level data-sets the (conditional) 2 parameter Weibull frequency distribution can be regarded as a (conditional) 1 parameter exponential distribution.

In addition it was derived that:

- For a complete (sea-level) data-set, the mean of all values indicates the inclination of its exponential distribution ($\bar{a} = \sigma$).
- For a subset of a (sea-level) data-set above a certain threshold value ω, the mean of this sub-set also indicates the inclination of its exponential distribution ($\bar{a} = \sigma + \omega$).

These derivations form the basis of the third and final method which is used for trend analysis in this chapter. The methodology is as follows:

- The first step is to spit up a sea-level data-set into succeeding periods of 10 years, whereby each period starts at a plural of 10.
- The second step involves the calculation of the mean value of the data of each 10-year period and of the complete period for a number of (increasing) threshold values. In addition, for each threshold value also the average number of storms per year is calculated for both the 10-year periods and the complete period.
- The third step is to visualize (for each threshold value) the mean value and the average number of storms per year of the 10-year periods in relation to those of the complete period.

Main idea behind this methodology is that the mean value of data over a specific period is in fact an indicator of the inclination of the exponential distribution which can be used to approximate the exceedance frequencies.

So, assuming that the number of storms per year of a specific 10-year period equals the number of storms per year of the complete period, it can be argued that a comparison between the mean value of a 10-year period and the complete period provides insight into the degree of storminess of the 10-year period which is taken into account.

If for example the mean value of the 10-year period is higher than the corresponding value of the complete period, than it can be argued that this 10-year period has been relative rough; since in that case the inclination of the (hypothetical) frequency distribution of the 10-year period is higher than of the complete period (see figure 4.8). If this mean value of the 10-year period is lower than the corresponding value of the complete period, than this 10-year period has been relative smooth.

Because in most cases the number of storms per year of the 10-year period will not equal the number of storms per year of the complete period, the above described derivations have to be handled with care. If for example the number of storms of a 10-year period is substantial lower than of the complete period, than, even when the mean value of the 10-year period is higher that the corresponding value of the complete period, it is possible that this 10-year period is smoother than the complete period.

So, to draw correct conclusions from the results of this method, both the mean value of data and the number of storms per time-period has to be taken into consideration.

figure 4.9 Characteristics of trend lines (intensity/frequency analysis method)

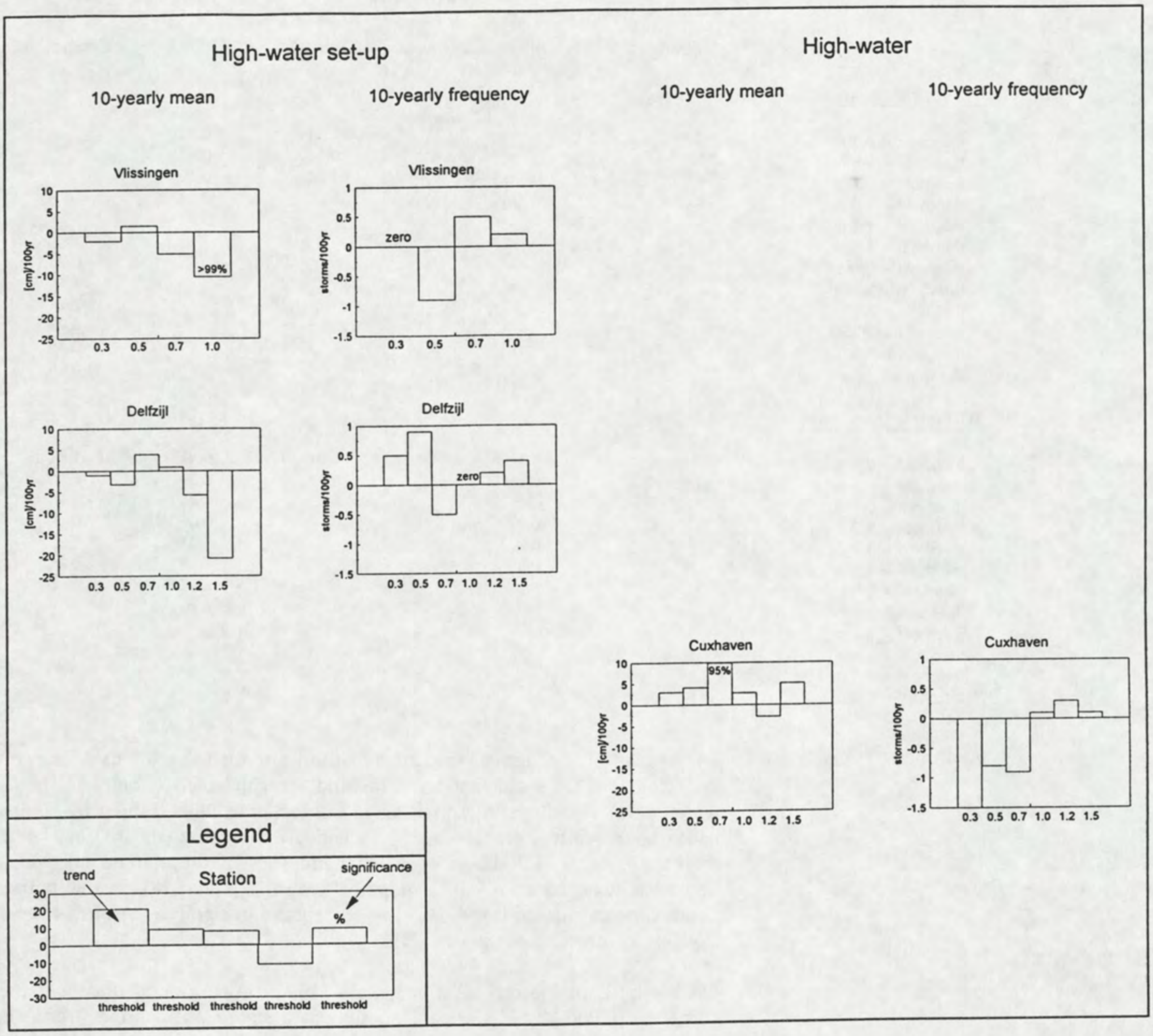


table 4.8 Characteristics of trendlines (intensity/frequency analysis method)

	trend/100 year			student t-test		
	Vlissingen	Delfzijl	Cuxhaven	Vlissingen	Delfzijl	Cuxhaven
10-yearly mean	[cm]	[cm]	[cm]			
threshold = 0.3 m	-2.1	-1.1		0.84	0.18	
threshold = 0.5 m	1.5	-3.2		0.56	0.57	
threshold = 0.7 m	-5.1	3.9		1.53	0.60	
threshold = 1.0 m	-10.5	0.9		5.80	0.18	
threshold = 1.2 m		-5.8			0.83	
threshold = 1.5 m		-20.8			2.11	
threshold = 2.0 m			3.0			0.73
threshold = 2.25m			4.1			1.14
threshold = 2.5 m			9.9			2.21
threshold = 2.75m			2.8			0.49
threshold = 3.0 m			-2.8			0.35
threshold = 3.5 m			5.1			0.66
10-yearly frequency						
threshold = 0.3 m	0.0	0.5		0.01	0.47	1.54
threshold = 0.5 m	-0.9	0.9		0.97	0.99	0.80
threshold = 0.7 m	0.5	-0.5		0.83	0.43	0.98
threshold = 1.0 m	0.2	0.0		0.40	0.05	0.15
threshold = 1.2 m		0.2			0.31	0.80
threshold = 1.5 m		0.4			1.52	0.31
threshold = 2.0 m			-1.5			
threshold = 2.25m			-0.8			
threshold = 2.5 m			-0.9			
threshold = 2.75m			0.1			
threshold = 3.0 m			0.3			
threshold = 3.5 m			0.1			

The results of the above described method are for the stations Vlissingen and Delfzijl (high-water set-up data) and for Cuxhaven ('complete' high-water data) visualised in Annex G, in combination with trend lines which have been calculated for each individual curve by means of linear regression. Table 4.8 shows some characteristics of these trend lines in a numerical way, figure 4.9 in a graphical way (bar diagrams). In this figure, besides the calculated trend, also the percentage of significance of this trend is given for percentages above 95%.

On the basis of these results, in general it can be concluded that over the complete period there is almost no sign of a *significant* change (trend) in the sea-level data-sets which have been taken into account. Just in 2 cases the calculated trends turn out to be significant.

Looking more into detail at these results, it is remarkable that (per threshold value), all 3 stations show a trend in the 10-yearly mean which is nearly always opposite to the trend in the 10-yearly frequency. This implies the following 2 situations:

- An increasing trend in the 10-yearly mean, which stands for a growing roughness of the 10-yearly periods, is accompanied by a decreasing trend in the 10-yearly frequency (which counterbalances this effect). This can be explained by a growing tendency towards a situation with less storms with relative more extremes.

- A decreasing trend in the 10-year mean, which stands for a fading roughness of the 10-year periods, is accompanied by a increasing trend in the 10-year frequency (which counterbalances this effect). This can be explained by a growing tendency towards a situation with more storms with relative less extremes.

5. Discussion and conclusions

The aim of the present study is to investigate the question whether there is any sign of (man-induced) climate change apparent in data-sets of sea-level, wave height and wind. In this final chapter, some discussion and concluding remarks will be made on the basis of subjects which play an important role in this study.

Data

To detect any sign of (man-induced) climate change in the data-sets, extreme value statistics and trend analysis have been applied. To perform these techniques, it is however necessary that

a) the elements of the data-sets are mutually independent.
b) the elements of the data-sets belong to the same statistical distribution.

The sea-level, wave height and wind data-sets which are used in this study (chapter 2) do not satisfy these requirements. Therefore, a threshold value, a storm season selection and a (D-S-*i*) selection in the time domain have been applied; the threshold value to provide the same peak-over-threshold distribution, the storm season selection to obtain elements of the same (common) distribution and the D-S-*i* selection to suppress autocorrelation.

In principle, a large number of long-term observational records is available for all 3 types of data. Most of these records suffer however from inhomogeneity, especially those of wave height and wind. Main reasons are registration gaps, change of observation method, measurement equipment, etc. Except for the high-water set-up data-sets, the observed records of sea-level data also reflect the impacts of more external factors like the effect of harbour works or dredging activities on the astronomical tide, relative sea-level rise, etc. As a result, the number of long observational records which purely reflect storm-related fluctuations of observed parameters is in fact quite small.
The records used in this study have been corrected as much as possible for the above described factors influencing the homogeneity in a negative way. Main attention has been paid to the high-water set-up data-sets, because these data-sets just purely reflect the storm-related water level fluctuations. Compared to the other data-sets available, these data-sets have not been disturbed by processes unrelated to storm activity and do not reflect the unwished variety due to astronomical influences. Within the perspective of the present study these data-sets are therefore of main interest.

Connection

Two methods have been applied in an attempt to extend the (small) time-horizon of the wave height and wind data-sets:

- Maxima analysis method (paragraph 3.1). This method turns out to be not useful in getting a better insight into possible connections between sea-level, wave height and wind data (both for directional and omni-directional data). The method in itself however, is very suitable for trend-analysis.

- Quantile analysis method (paragraph 3.2). Main conclusion of applying this method is that (with a stable and robust method like the quantile analysis method) it is possible to demonstrate possible connections between sea-level, wave height and wind data. It is however necessary to investigate and test this method in a more detailed way, before the analysis results can be used in a quantitative way.

In addition to these 2 methods, also a statistical technique to downscale storm surge statistics (based on more than 100 year data) to wave height statistics (based on 30 year data) was successfully applied to various combinations of sea-level and wave height data-sets (paragraph 3.3). The results show (under the assumption that storm maxima of sea-level and wave height data are strongly dependent) that extending the time-horizon of wave height statistics into the past, slightly increases the estimated 10^{-2}-quantile value of wave height maxima. This increase is however smaller than the standard deviation, which implies that this slight increase of this quantile is not significant.

<u>Trends and fluctuations</u>
To detect any sign of (man-induced) climate change in data-sets, 3 (main) methods have been applied:

- Maxima analysis method (paragraph 4.1)
- Quantile analysis method (paragraph 4.2)
- Frequency and intensity method (paragraph 4.3)

For detailed discussion and conclusions of the results of these methods, one is referred to the appropriate paragraphs. In the following, a more general (area-averaged) overview will be given, whereby main attention will be paid to:

- results based on the sea-level data-sets of the Dutch coastal stations, Cuxhaven and Esbjerg, because the remainder of the data-sets covers a time-period which is too small to perform a reliable trend analysis (especially in case of the quantile analysis method).
- the results based on high-water set-up data-sets, because these data-sets purely reflect the storm-related water level fluctuations.
- results based on the quantile analysis method, because this relative stable and robust method takes all data available into account. This in contrast to the maxima analysis method which takes just 4 quantities into account.

The results of the maxima analysis and the quantile analysis method (and variants of these methods) show both increasing and decreasing trends in storminess. In table 5.1, a summarizing overview is shown, whereby for both methods the results of all variants have been combined (except for the mean variant of the quantile analysis method).

A '-' or '+' means that the calculated trend of all variants was downward resp. upward, while a '*' indicates that the various variants show trends in opposite directions. In addition, 'high', 'medium' and 'low' stand for the 5/yr-1/yr, 10/yr-5/yr and 15/yr-10/yr threshold range. Furthermore it should be emphasized that in this table just the sign of the calculated trends is taken into consideration; the magnitude and possible significance of the individual trends did not play a role.

On the basis of this table, in combination with all other results obtained in this study, the following conclusions can be drawn:

1) Local
Detailed discussion of the results obtained in this study, reveals that there is not always consistency in sign and magnitude of the calculated trends per station (when more than 1 data-set is available). Another point is that some data-sets show differences in sign and magnitude of trends calculated on the basis of the maxima analysis method and the quantile analysis method. Possible explanation could be that most of these data-sets still contain unwished astronomical influences, which mask the signal which is of main interest in this study. The latter is supported by the fact that the analysis result of the high-water set-up data-sets of the Dutch coastal stations, which only reflect storm-related water level fluctuations, are more consistent.
Besides that, the majority of the calculated trends is not significant, which in fact implies that trends are fluctuating.

2) Area-averaged
In general the analysis results show that, although there is considerable natural variability on relative short time scales, over the complete measurement period of the investigated records no sign of a significant increase in storminess over north-west Europe can be detected.
The results also indicate similar features for stations in the south-western North Sea, this in opposition to the more northern stations in the German Bight. In this area, all results show a small to moderate natural variability on relative small time scales (biannual to decadal). In the German Bight, this variability is clearly more enhanced. This 'distinction' between the southern and northern stations is also noticeable when the results of the trend calculation are taken into consideration. Especially the high-water set-up data-sets, which have not been disturbed by processes unrelated to storm activity, do show this feature.
Although sign and magnitude of the calculated trends is not entirely unequivocal, for sea-level stations in the south-western North Sea there seems to be tendency towards a small weakening of the storm climate over the past 100 year. This is supported by the fact that on the basis of the (sea-level) data-sets of these stations the only significant (downward) trends of this study have been calculated. Trends, calculated on the basis of data-sets of the more northern stations in the German Bight show however no indication towards a weakening of the storm climate. Though not significantly, in fact they show most increasing trends.

General conclusion is that the storm climate over North-west Europe has not systematically worsened in the past 100 year, but that there is considerable natural variability on smaller time scales.

table 5.1 Summarizing overview of trends in storminess

A '-' or '+' means that the calculated trend of all variants was downward resp. upward, while a '•' indicates that the various variants show trends in opposite directions. In addition, 'high', 'medium' and 'low' stand for the 5/yr-1/yr, 10/yr-5/yr and 15/yr-10/yr threshold range. Furthermore it should be emphasized that in this table just the sign of the calculated trends is taken into consideration; the magnitude and possible significance of the individual trends did not play a role.

	high-water set-up		high-water		daily-maximum		day-light high-water		wind	
	Maxima analysis	Quantile analysis	Maxima analysis	Quantile analysis	Maxima analysis	Quantile analysis	Maxima analysis	Quantile analysis	Maxima analysis	Quantile analysis
Newlyn			maximum: + maximum-5: + maximum-10: - maximum-20: +	high: + medium: - low: +						
Southend			maximum: - maximum-5: + maximum-10: + maximum-20: -	high: - medium: + low: +						
Vlissingen	maximum: - maximum-5: • maximum-10: - maximum-20: -	high: - medium: + low: •	maximum: • maximum-5: + maximum-10: - maximum-20: •	high: • medium: + low: +						
Hoek van Holland	maximum: - maximum-5: - maximum-10: - maximum-20: -	high: - medium: - low: -	maximum: - maximum-5: + maximum-10: - maximum-20: -	high: - medium: - low: •						
Delfzijl	maximum: - maximum-5: + maximum-10: + maximum-20: +	high: • medium: + low: •	maximum: - maximum-5: + maximum-10: + maximum-20: +	high: + medium: + low: •			maximum: - maximum-5: - maximum-10: - maximum-20:	high: - medium: - low:		
Cuxhaven			maximum: + maximum-5: • maximum-10: • maximum-20: +	high: + medium: + low: +						
Esbjerg					maximum: + maximum-5: + maximum-10: + maximum-20: -	high: + medium: + low: +				
Terschelling									maximum: + maximum-5: + maximum-10: + maximum-20: +	high: - medium: + low: +
Mike									maximum: - maximum-5: + maximum-10: + maximum-20: +	high: - medium: - low: -

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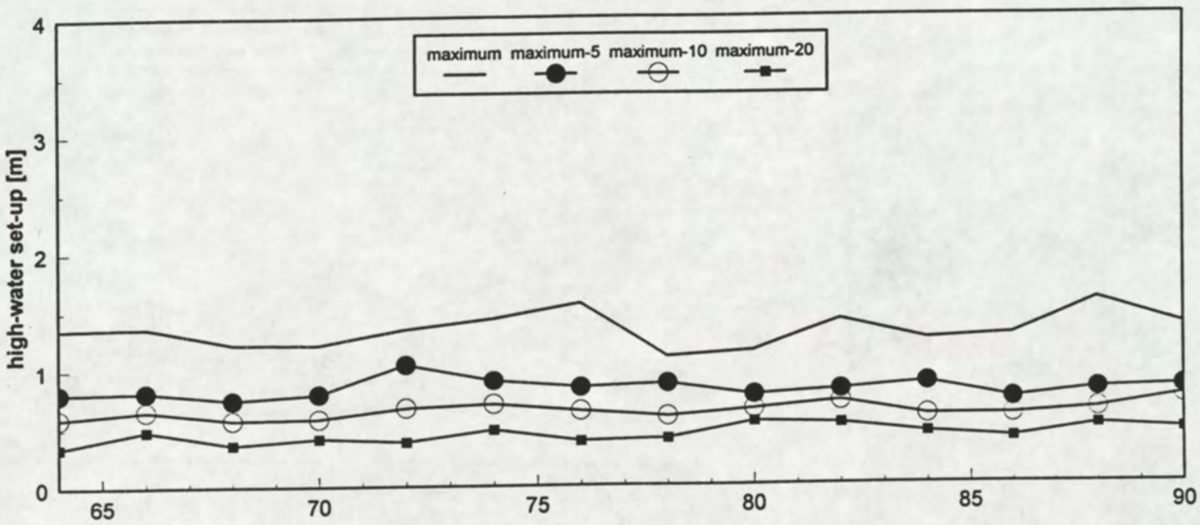
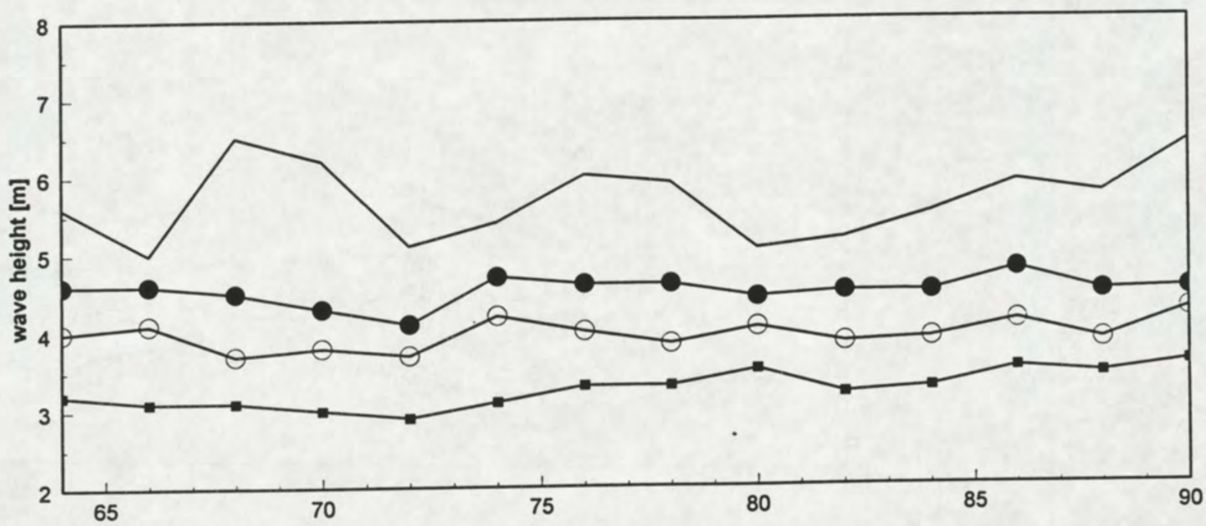
Annex A, part 1

In this part of Annex A, the result of the maxima analysis method is shown for various combinations of sea-level, wave height and wind stations.

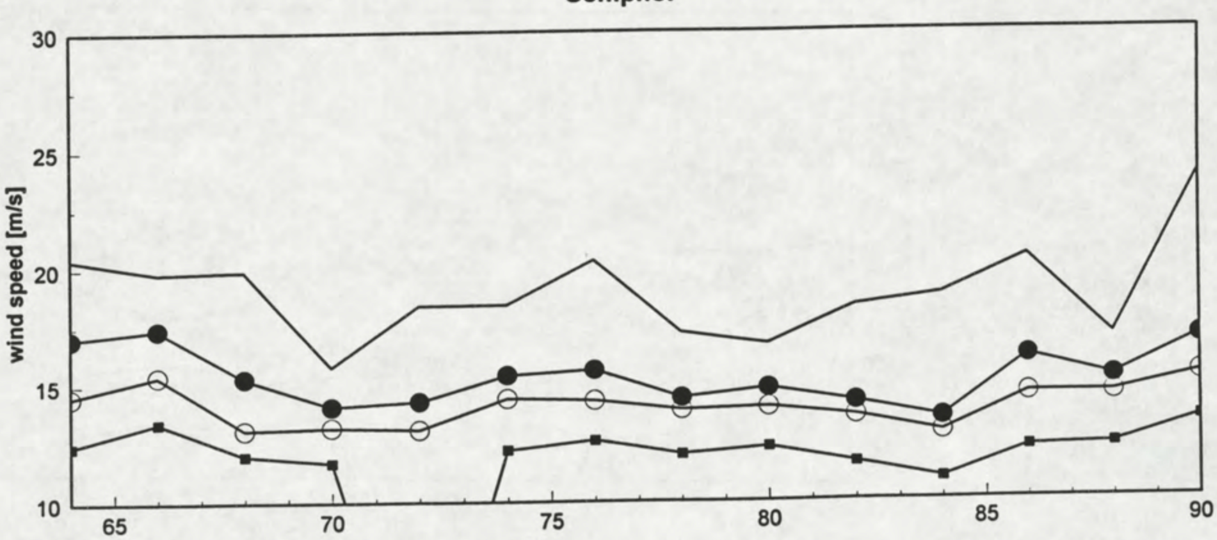
Vlissingen

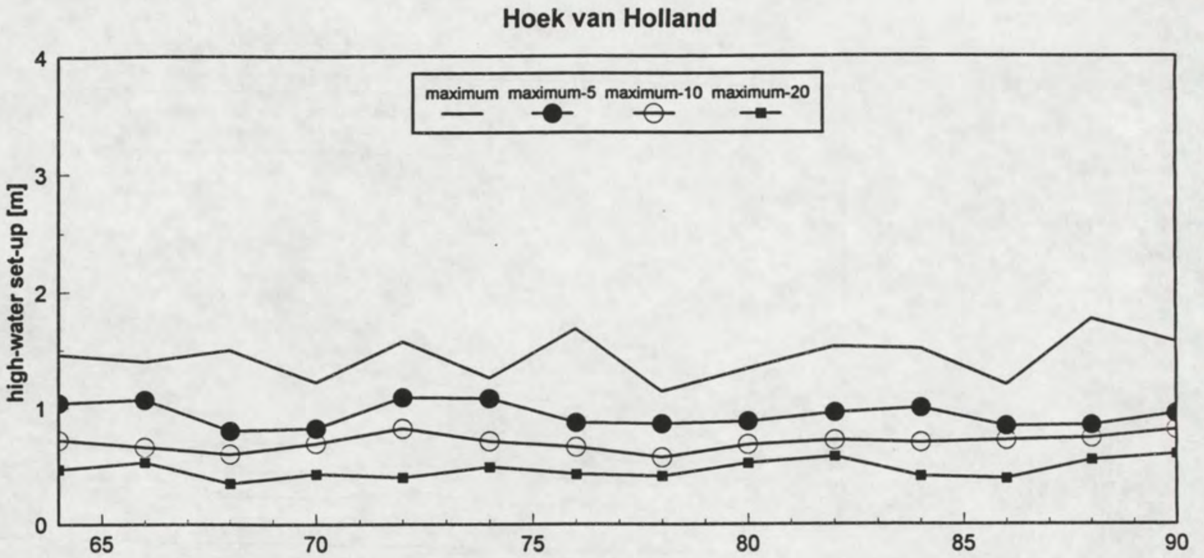


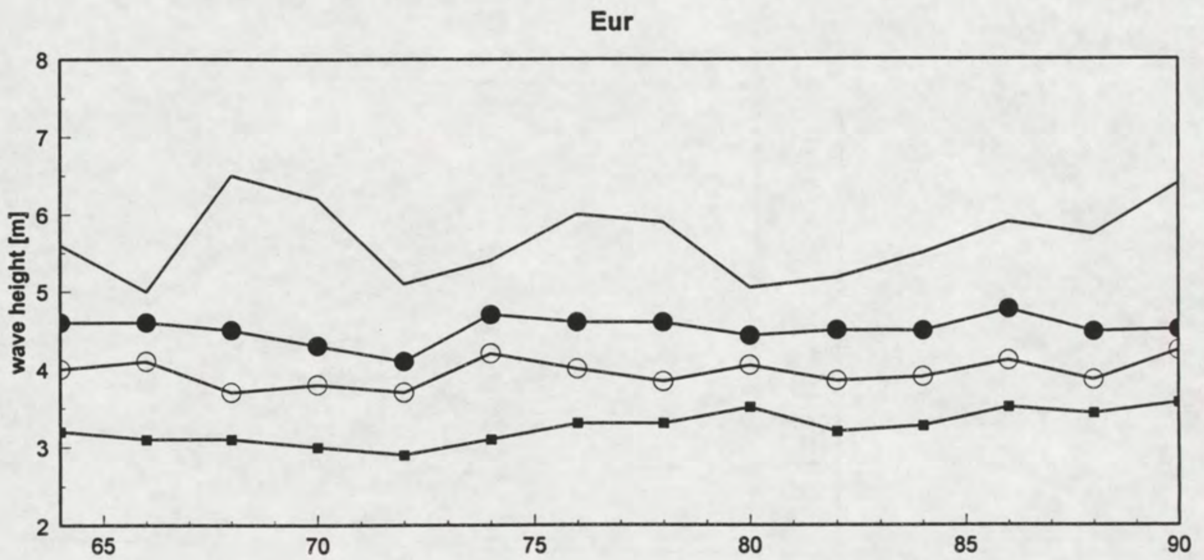
Eur

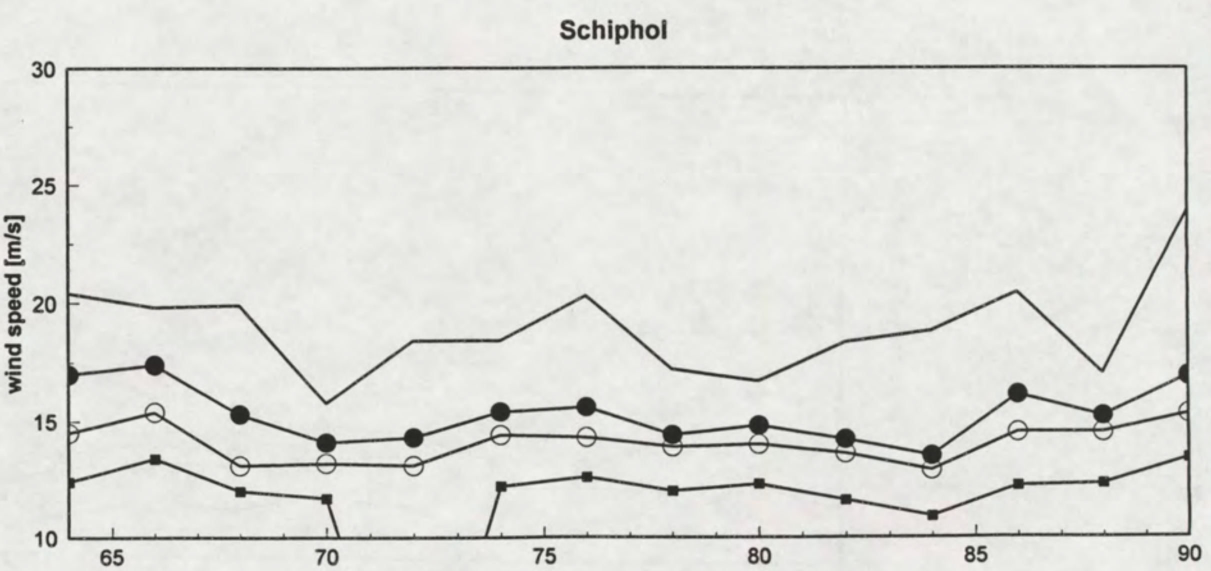


Schiphol

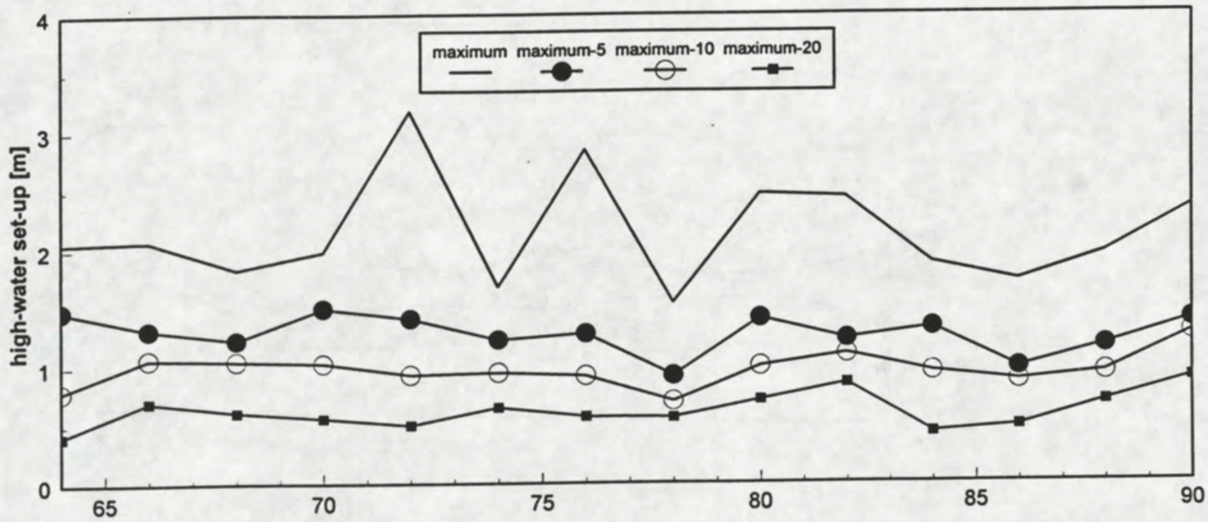



Hoek van Holland
maximum
maximum-5
maximum-10
maximum-20
high-water set-up [m]
0
1
2
3
4
65
70
75
80
85
90

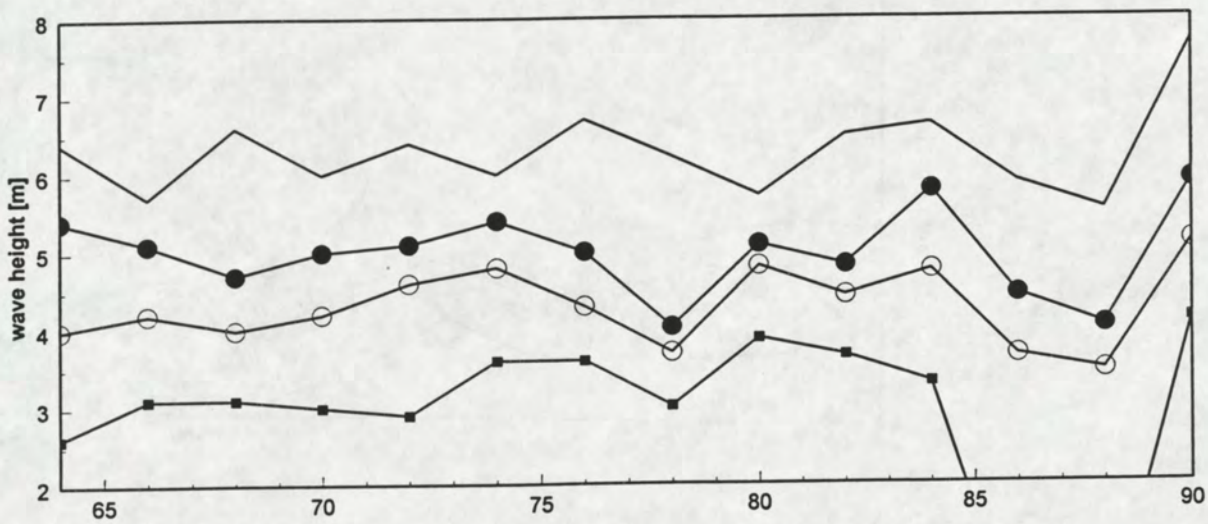

Eur
wave height [m]
2
3
4
5
6
7
8
65
70
75
80
85
90


Schiphol
wind speed [m/s]
10
15
20
25
30
65
70
75
80
85
90

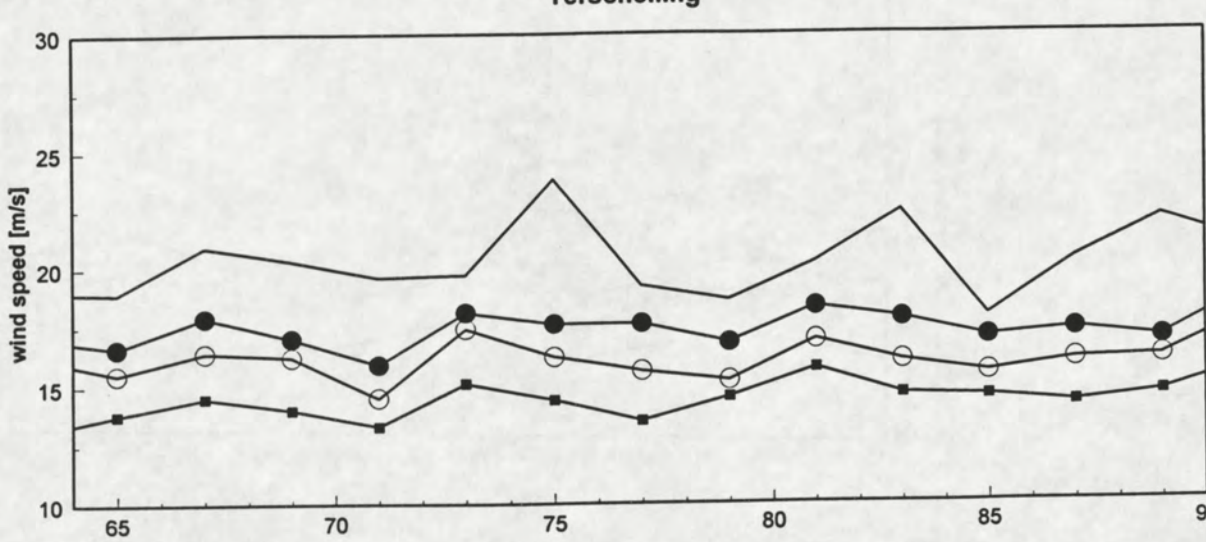
Delfzijl



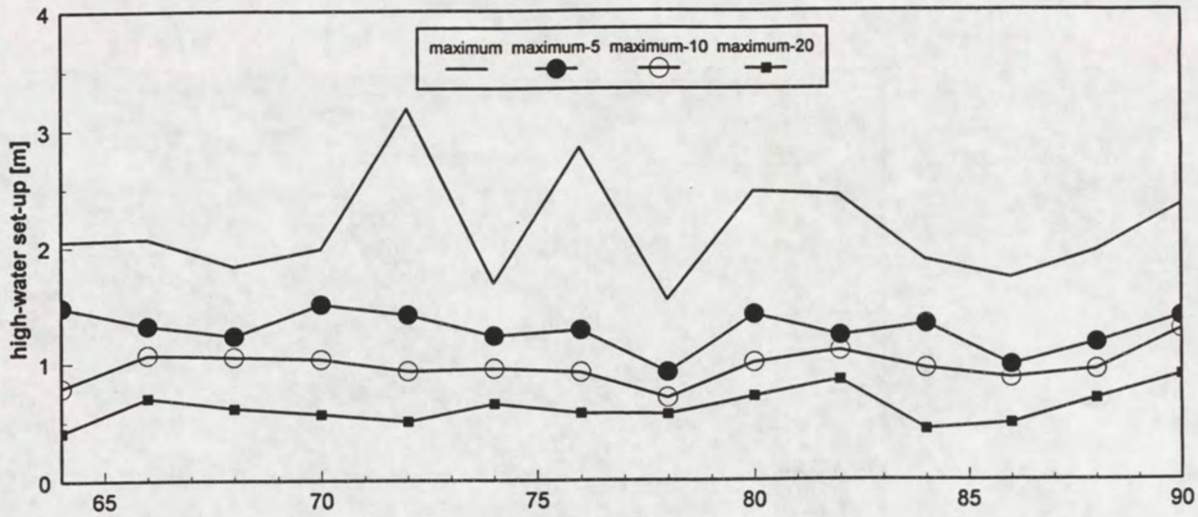
Eld



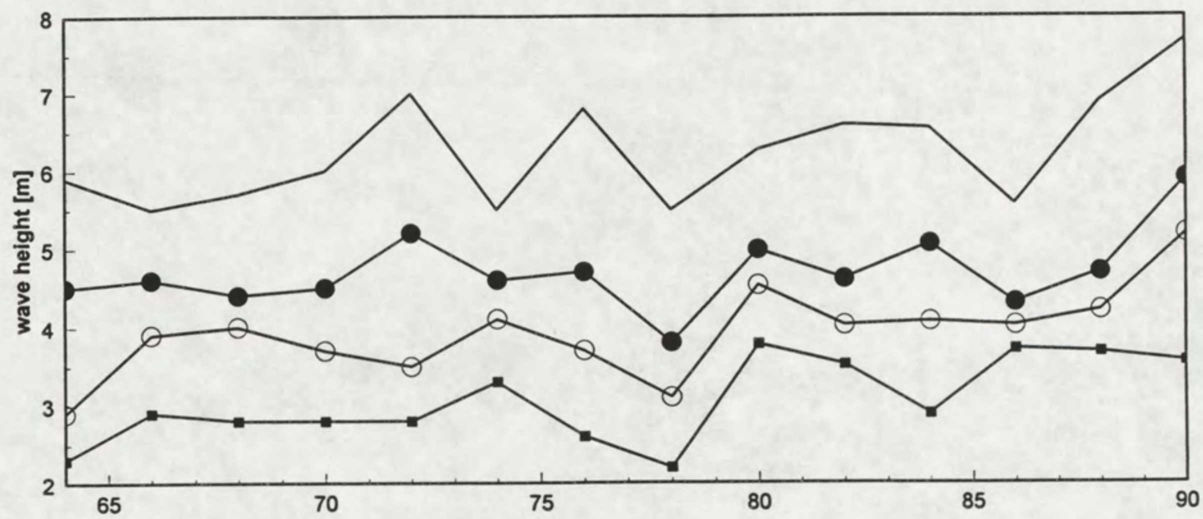
Terschelling



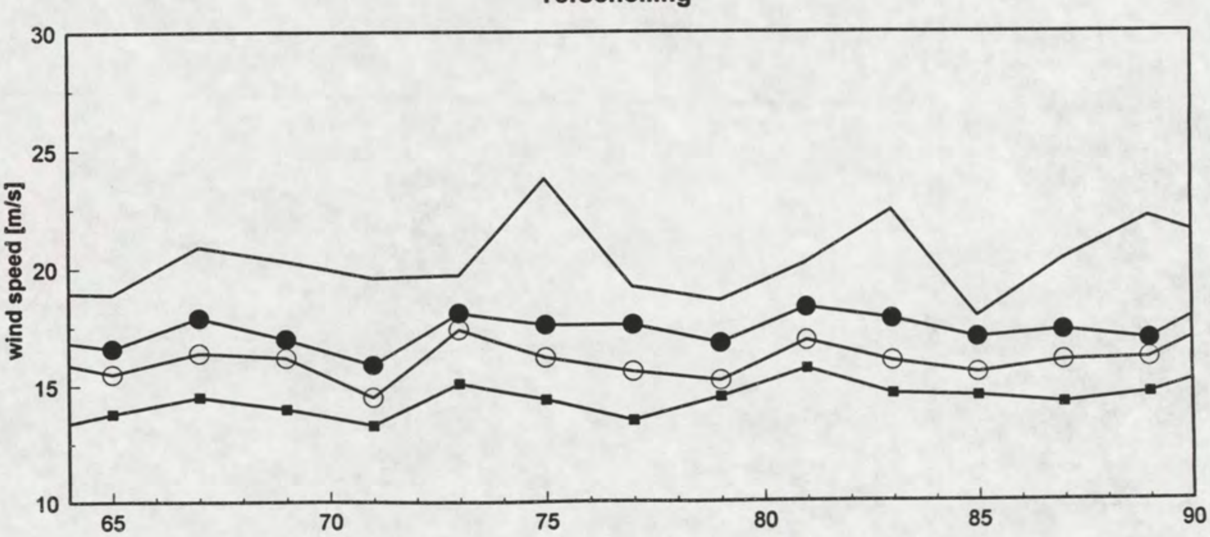
Delfzijl



Son

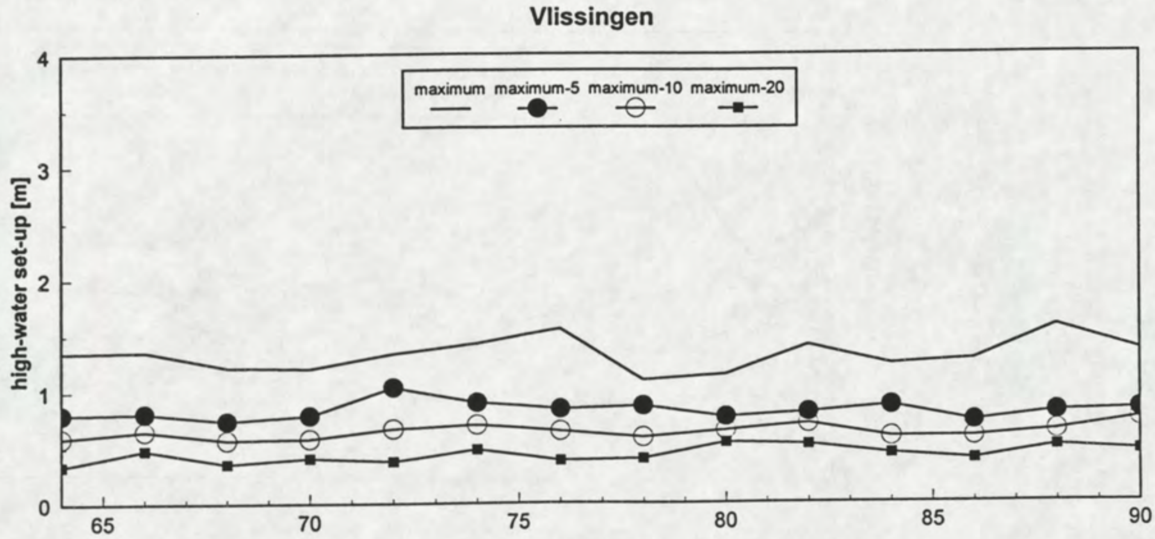


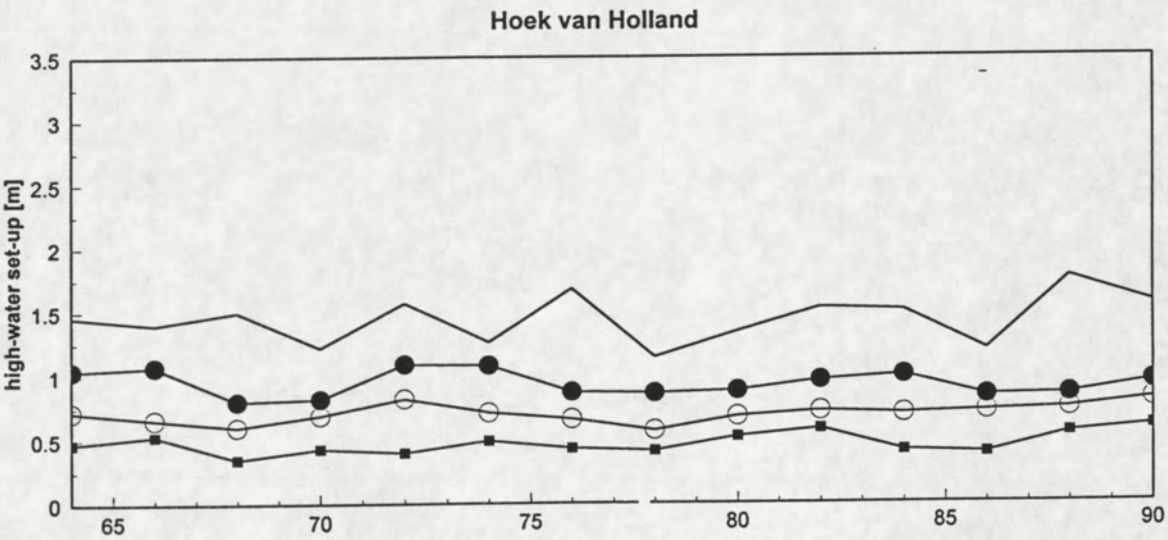
Terschelling

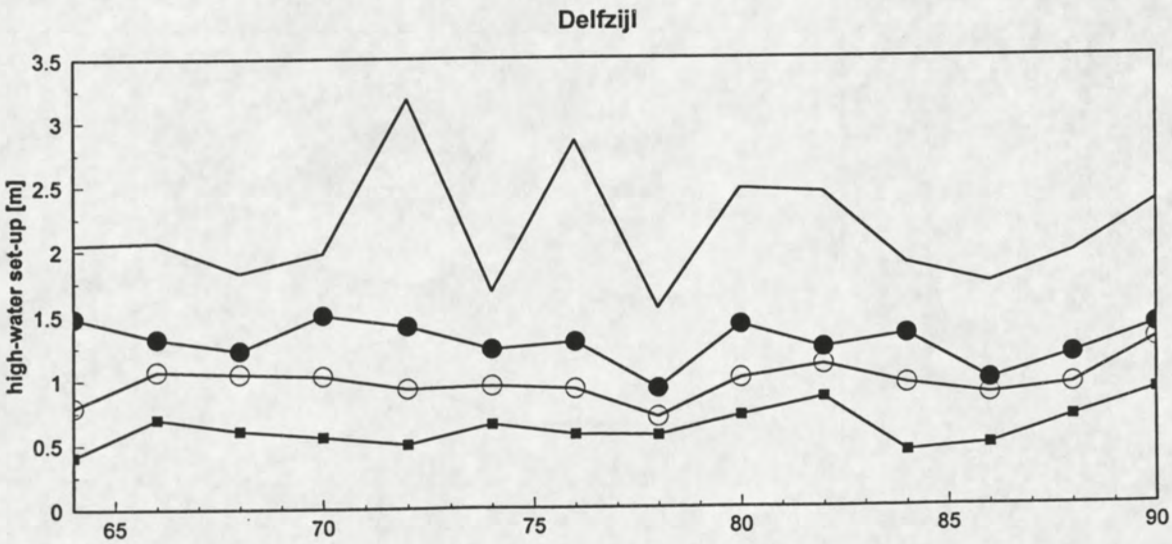


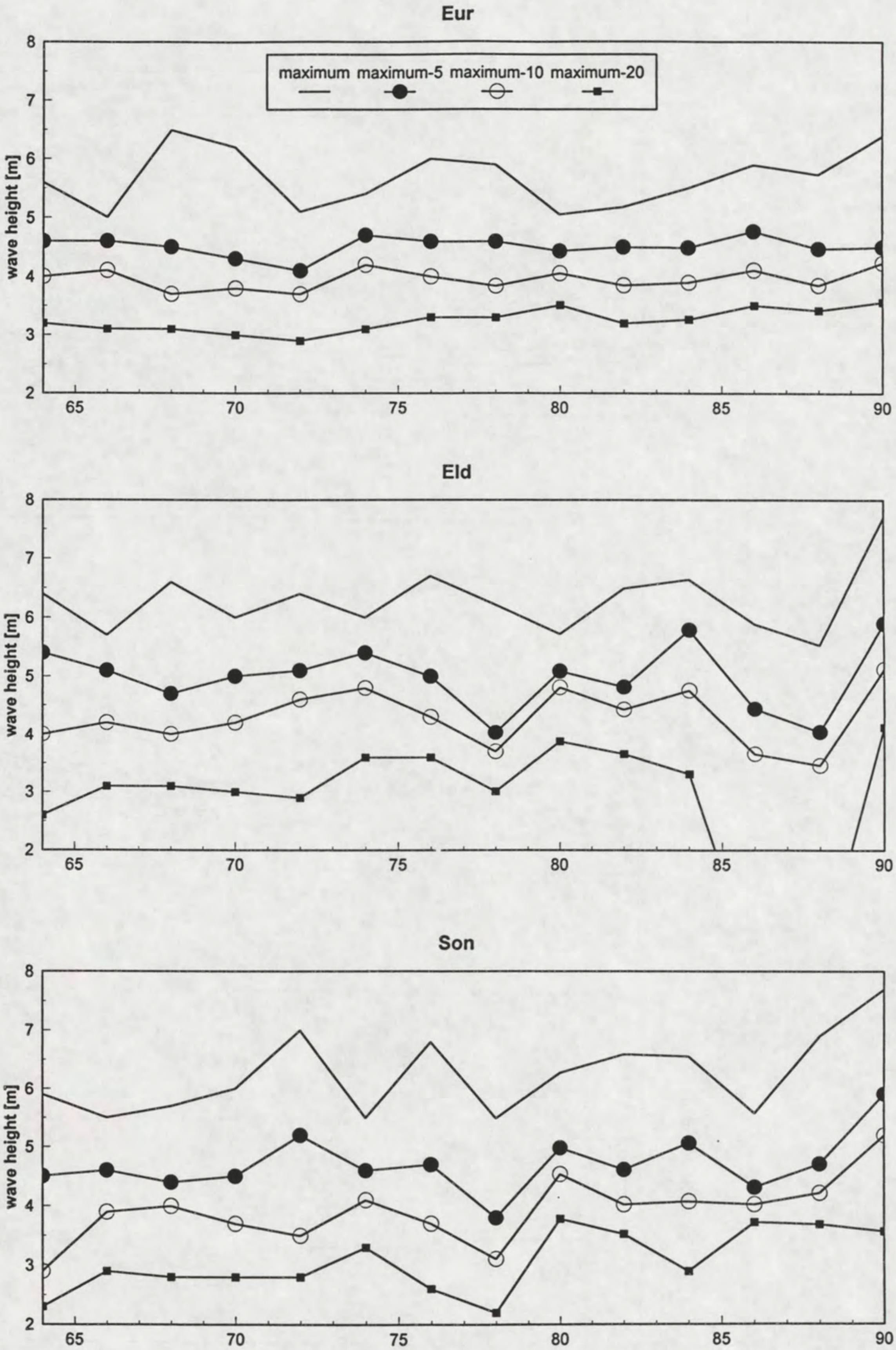
Annex A, part 2

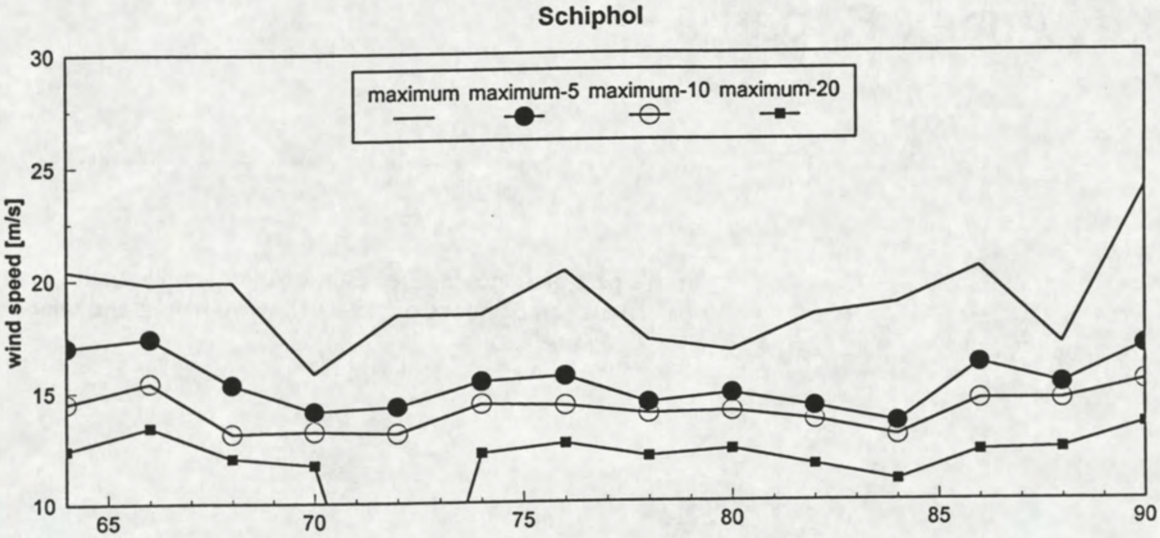
In this part of Annex A, the result of the maxima analysis method is shown for sea-level, wave height and wind stations separately.


Vlissingen
maximum
maximum-5
maximum-10
maximum-20
high-water set-up [m]
0
1
2
3
4
65
70
75
80
85
90

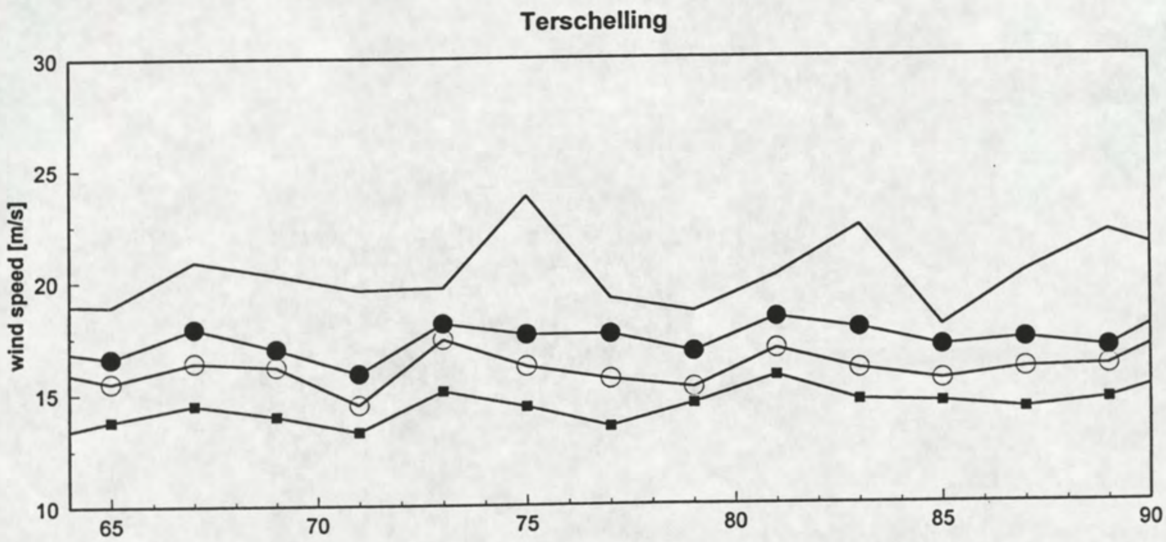

Hoek van Holland
high-water set-up [m]
0
0.5
1
1.5
2
2.5
3
3.5
65
70
75
80
85
90


Delfzijl
high-water set-up [m]
0
0.5
1
1.5
2
2.5
3
3.5
65
70
75
80
85
90


Eur
maximum maximum-5 maximum-10 maximum-20
wave height [m]
8
7
6
5
4
3
2
65
70
75
80
85
90
Eld
wave height [m]
8
7
6
5
4
3
2
65
70
75
80
85
90
Son
wave height [m]
8
7
6
5
4
3
2
65
70
75
80
85
90



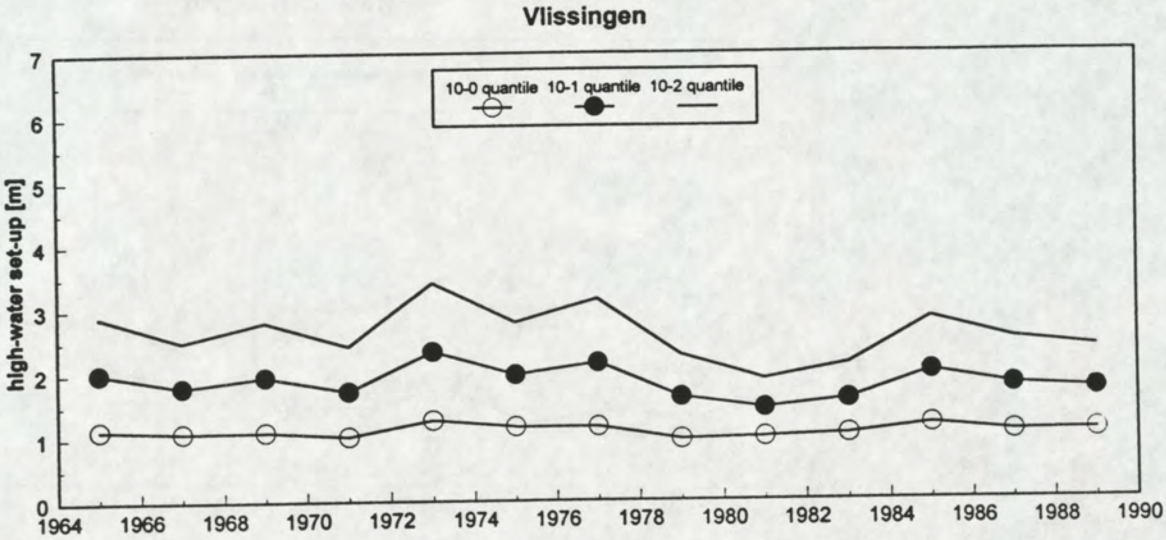
Schiphol
maximum maximum-5 maximum-10 maximum-20
wind speed [m/s]
30
25
20
15
10
65
70
75
80
85
90

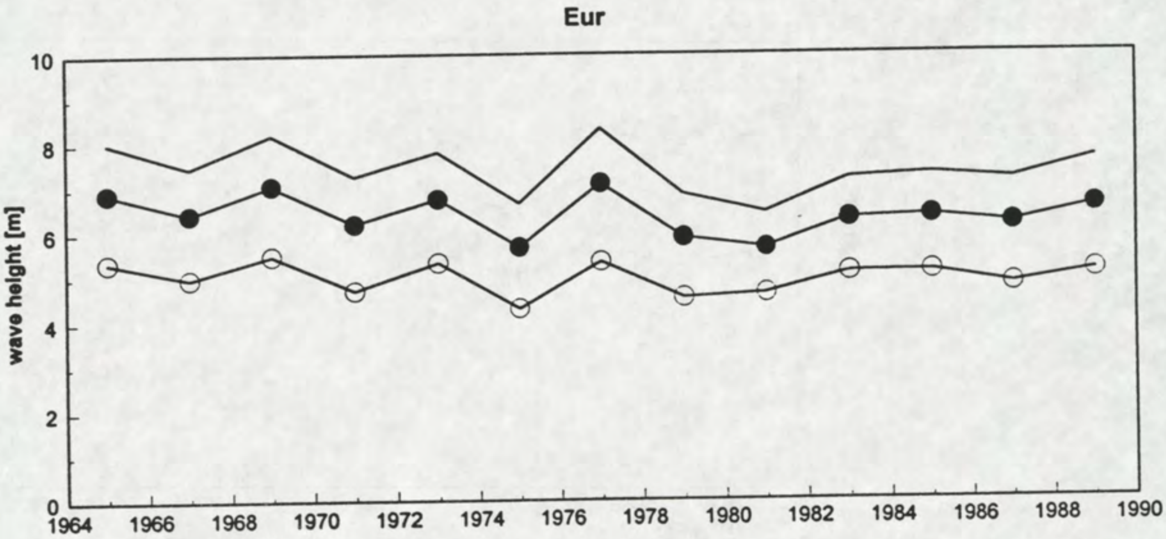


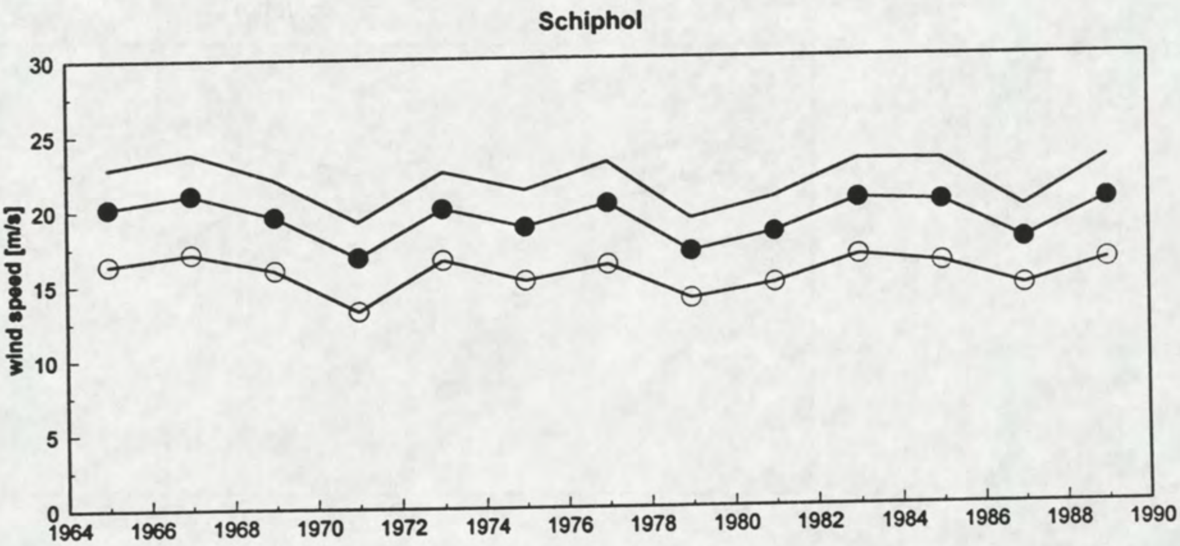
Terschelling
wind speed [m/s]
30
25
20
15
10
65
70
75
80
85
90

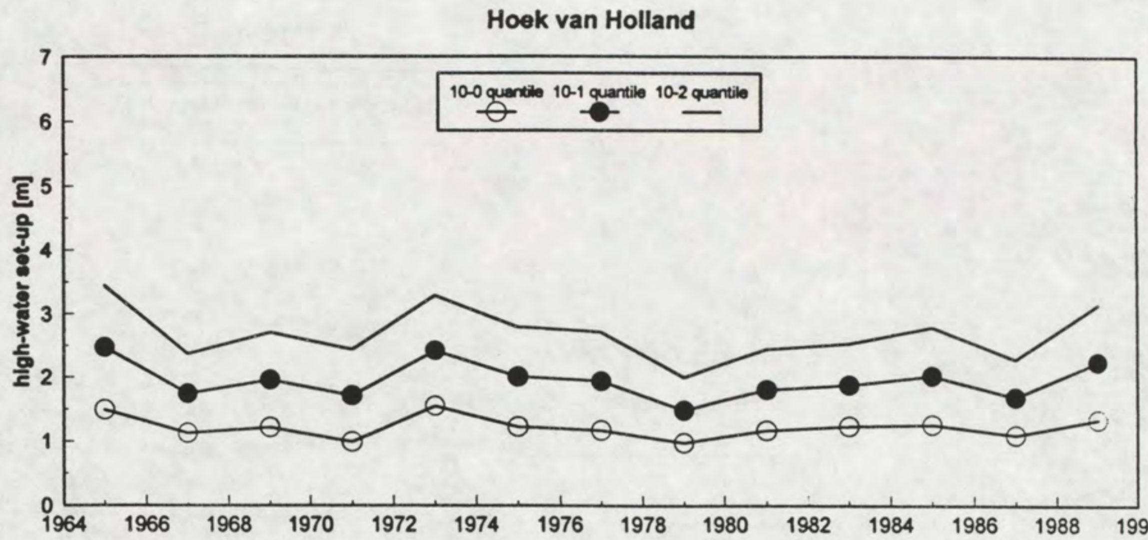
Annex B, part 1

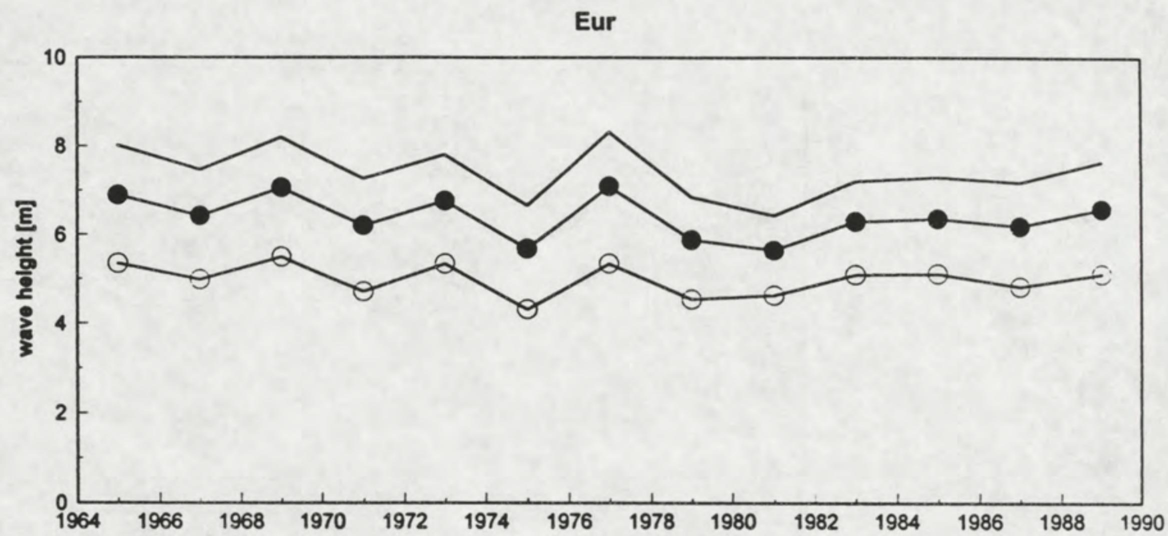
In this part of Annex B, the result of the quantile analysis method is shown for various combinations of sea-level, wave height and wind stations.

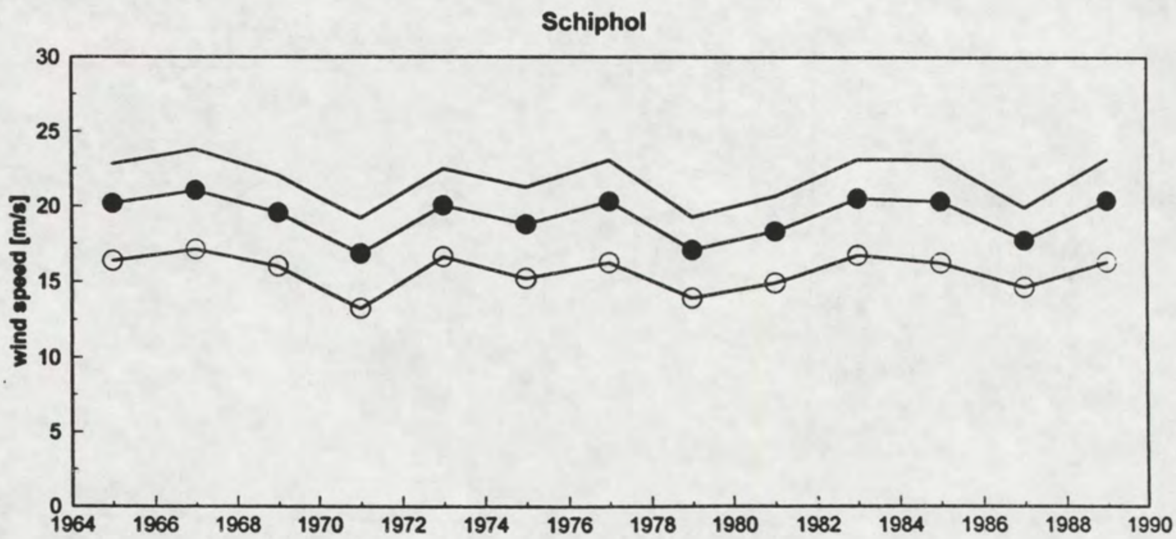

Vlissingen
10-0 quantile
10-1 quantile
10-2 quantile
high-water set-up [m]
0
1
2
3
4
5
6
7
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990

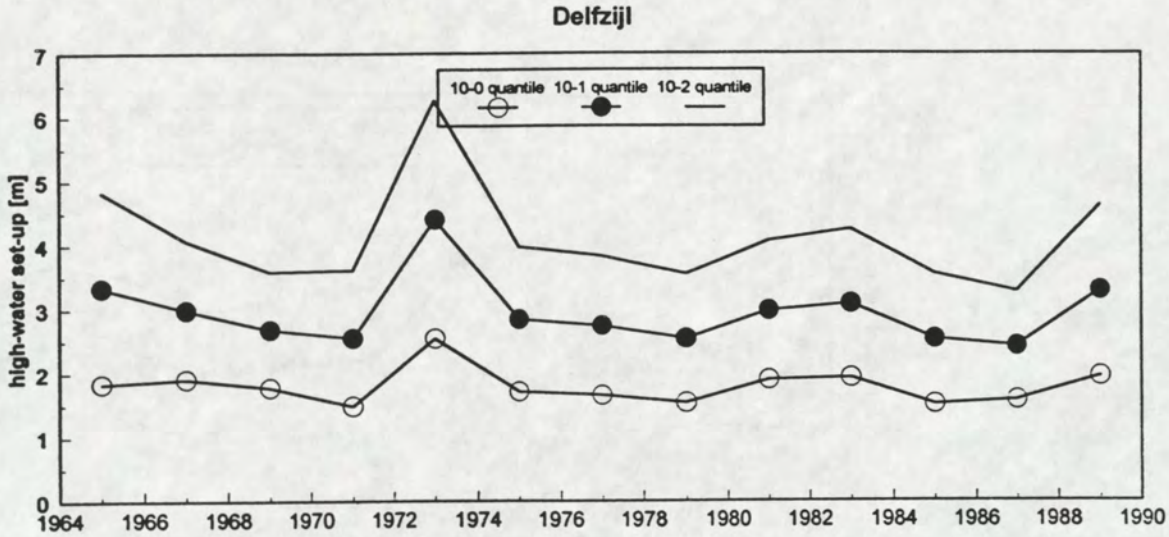

Eur
wave height [m]
0
2
4
6
8
10
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990

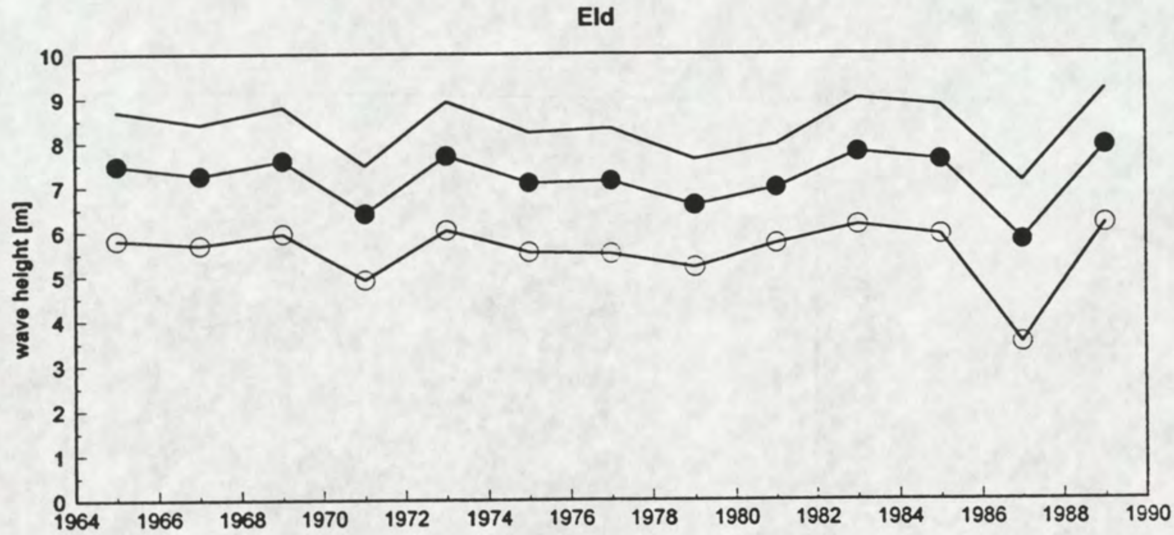

Schiphol
wind speed [m/s]
0
5
10
15
20
25
30
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990

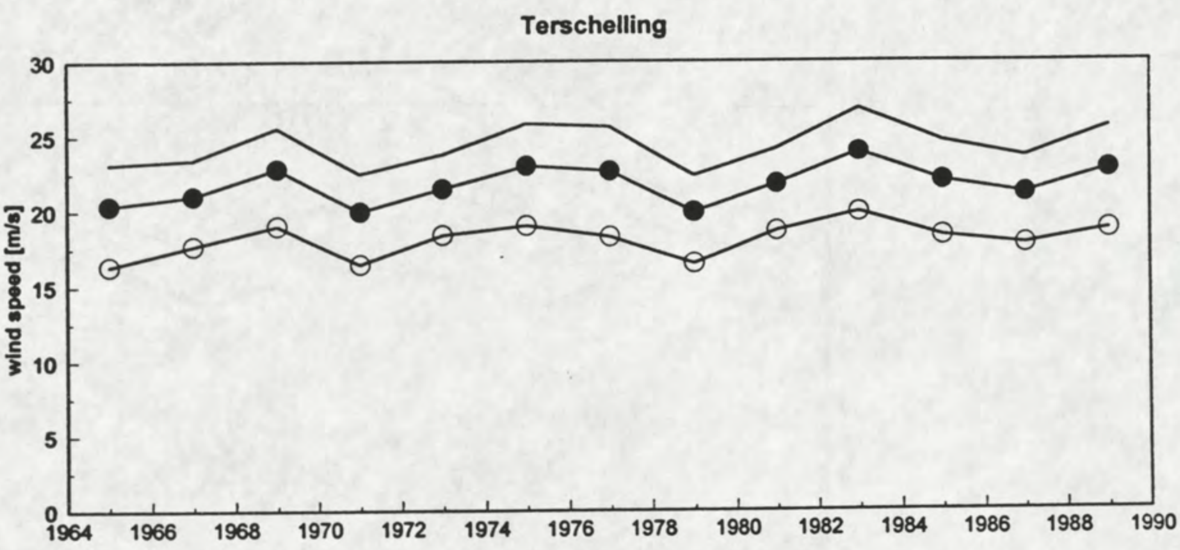

Hoek van Holland
high-water set-up [m]
10-0 quantile
10-1 quantile
10-2 quantile
0
1
2
3
4
5
6
7
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990

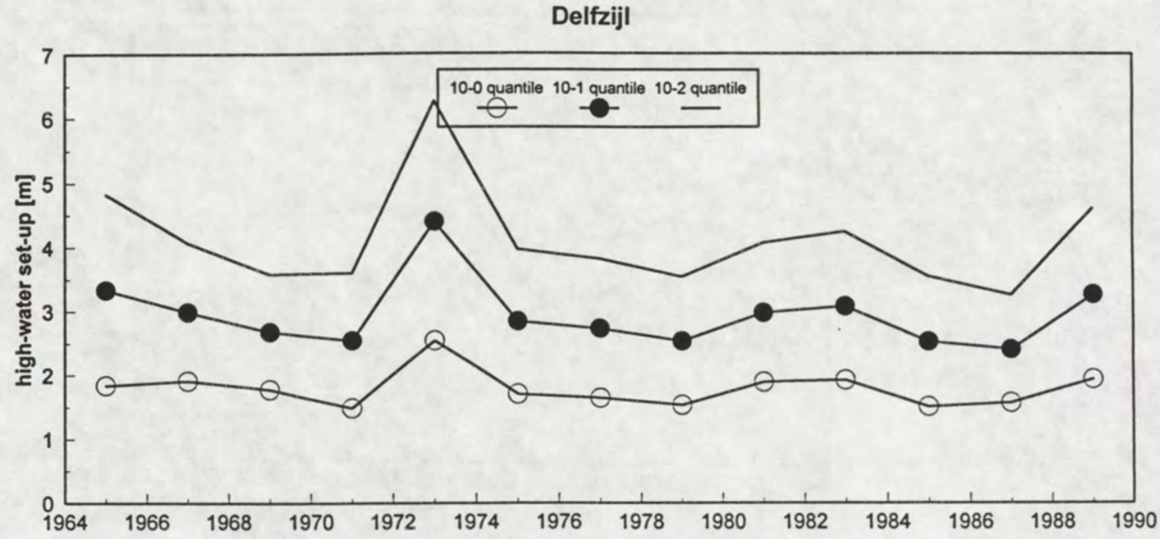

Eur
wave height [m]
0
2
4
6
8
10
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990

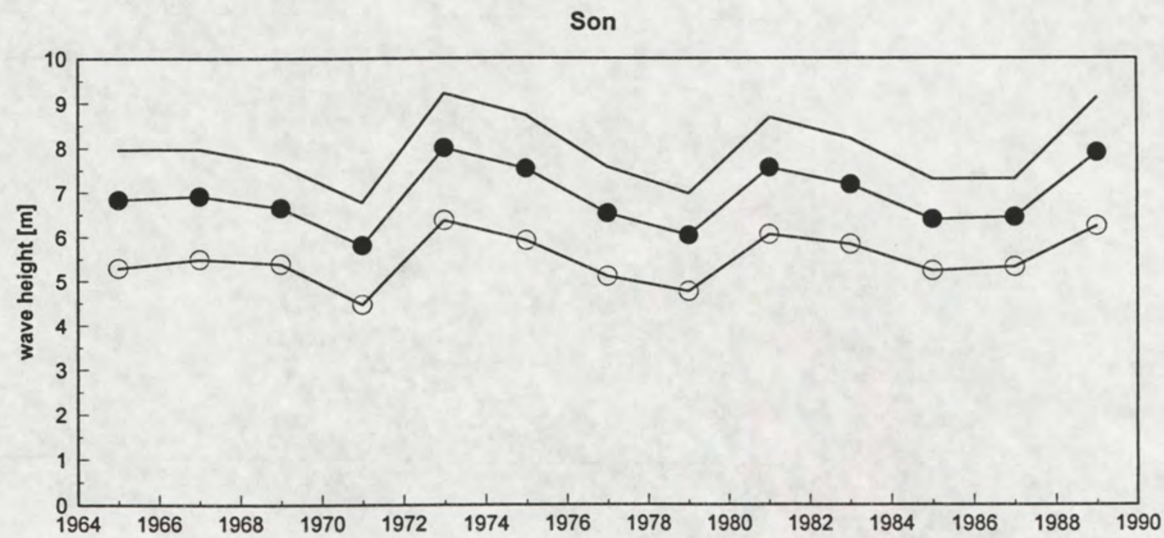

Schiphol
wind speed [m/s]
0
5
10
15
20
25
30
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990

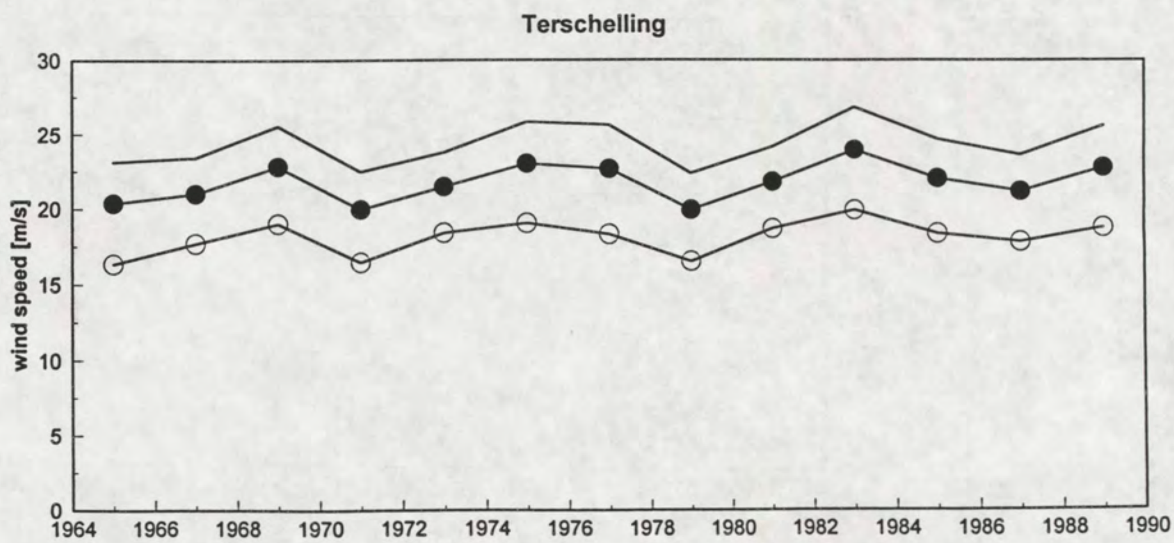

Delfzijl
10-0 quantile
10-1 quantile
10-2 quantile
high-water set-up [m]
0
1
2
3
4
5
6
7
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990

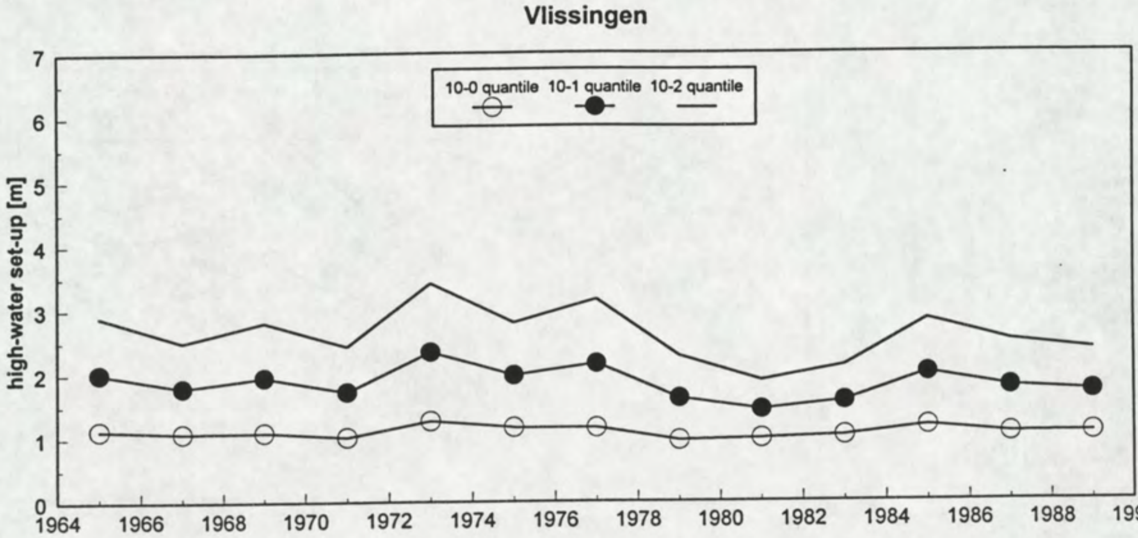

Eld
wave height [m]
0
1
2
3
4
5
6
7
8
9
10
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990


Terschelling
wind speed [m/s]
0
5
10
15
20
25
30
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990

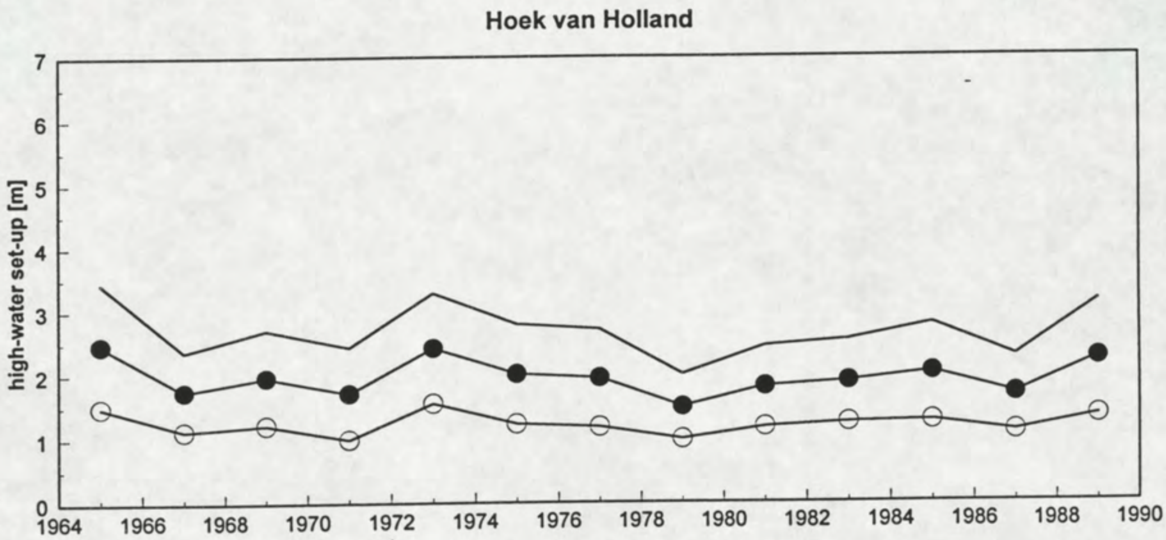

Delfzijl
10-0 quantile
10-1 quantile
10-2 quantile
high-water set-up [m]
0
1
2
3
4
5
6
7
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990


Son
wave height [m]
0
1
2
3
4
5
6
7
8
9
10
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990

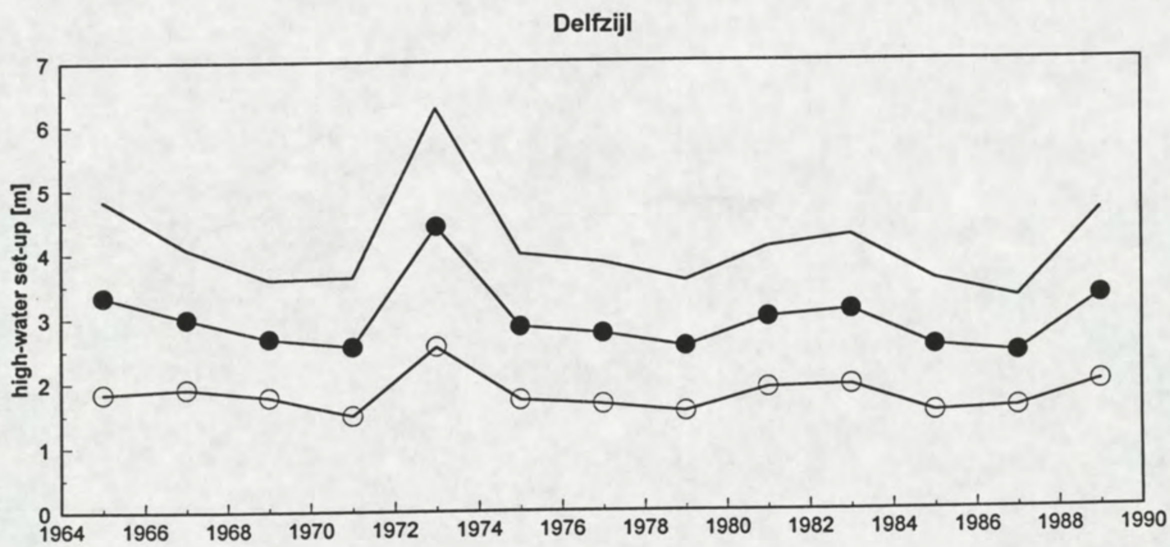

Terschelling
wind speed [m/s]
0
5
10
15
20
25
30
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990



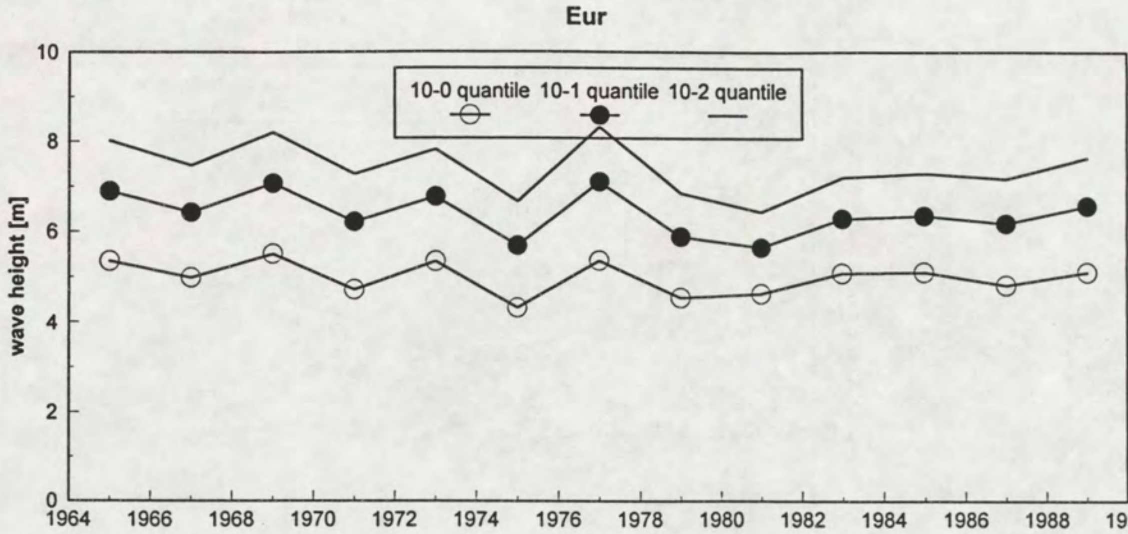
Vlissingen
10-0 quantile
10-1 quantile
10-2 quantile
high-water set-up [m]
0
1
2
3
4
5
6
7
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990

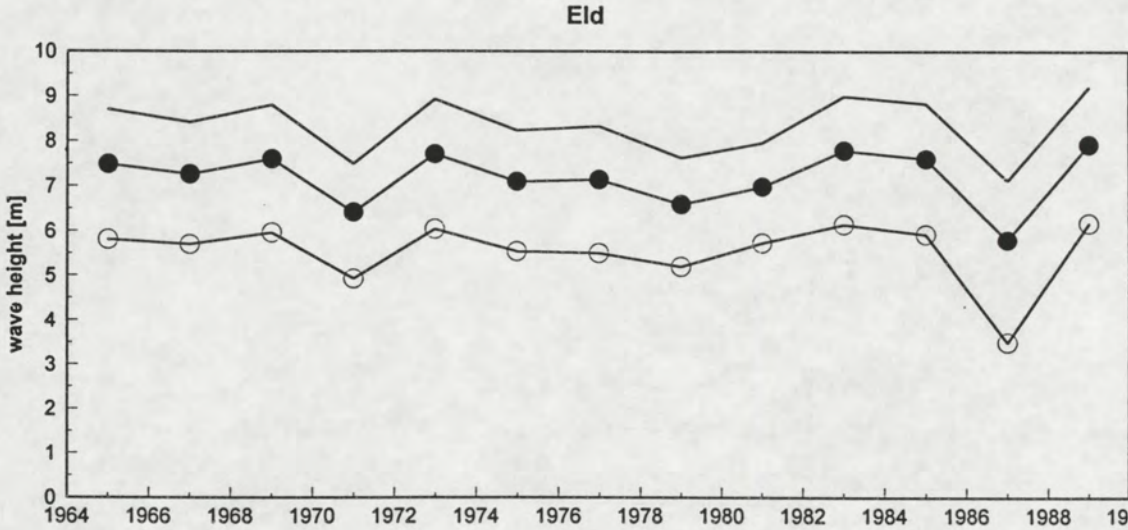


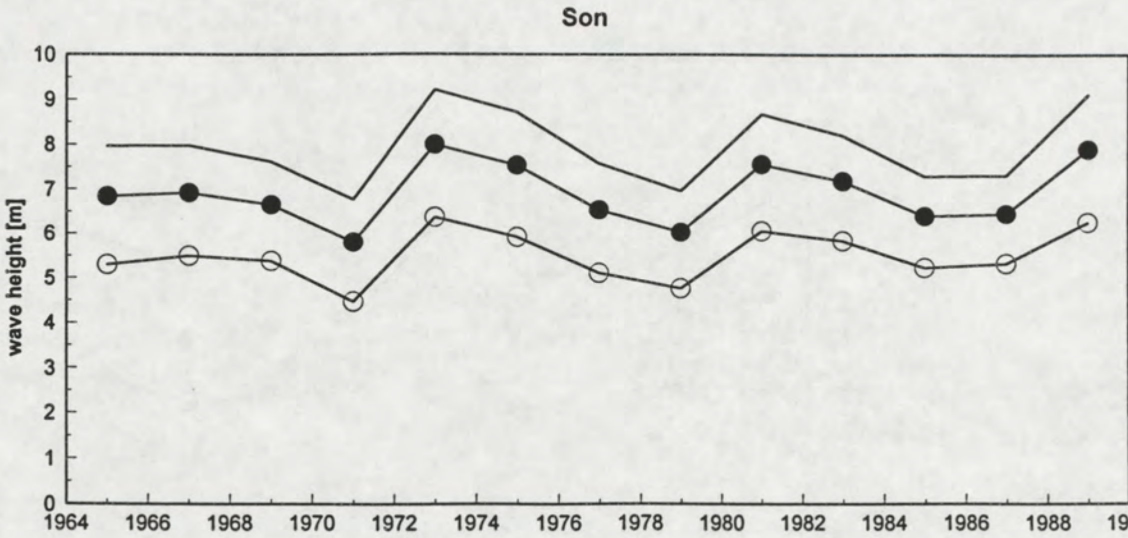
Hoek van Holland
high-water set-up [m]
0
1
2
3
4
5
6
7
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990

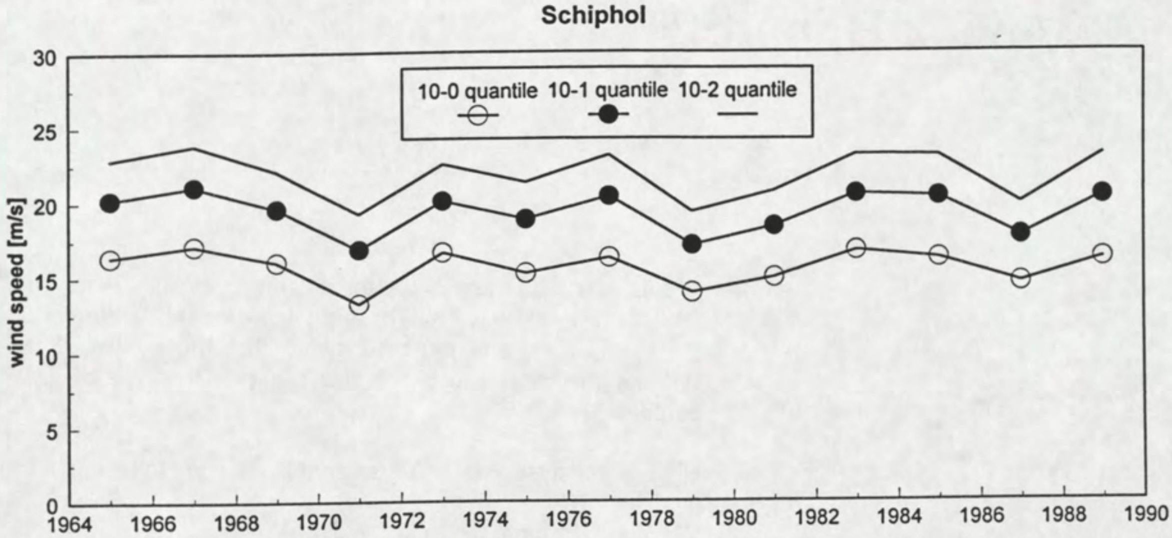


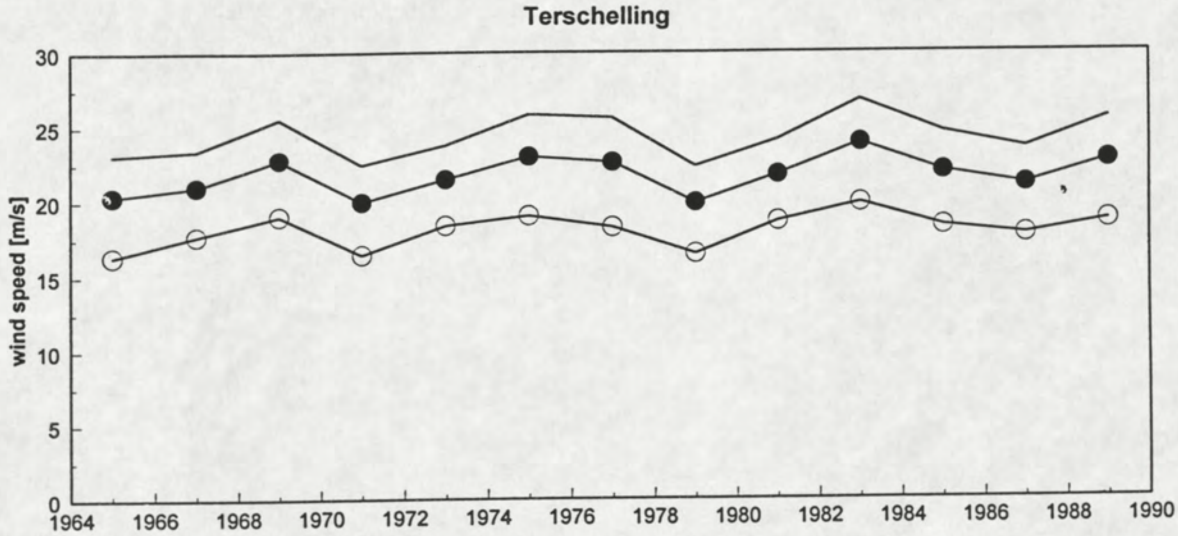
Delfzijl
high-water set-up [m]
0
1
2
3
4
5
6
7
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990


Eur
10-0 quantile
10-1 quantile
10-2 quantile
wave height [m]


Eld
wave height [m]


Son
wave height [m]

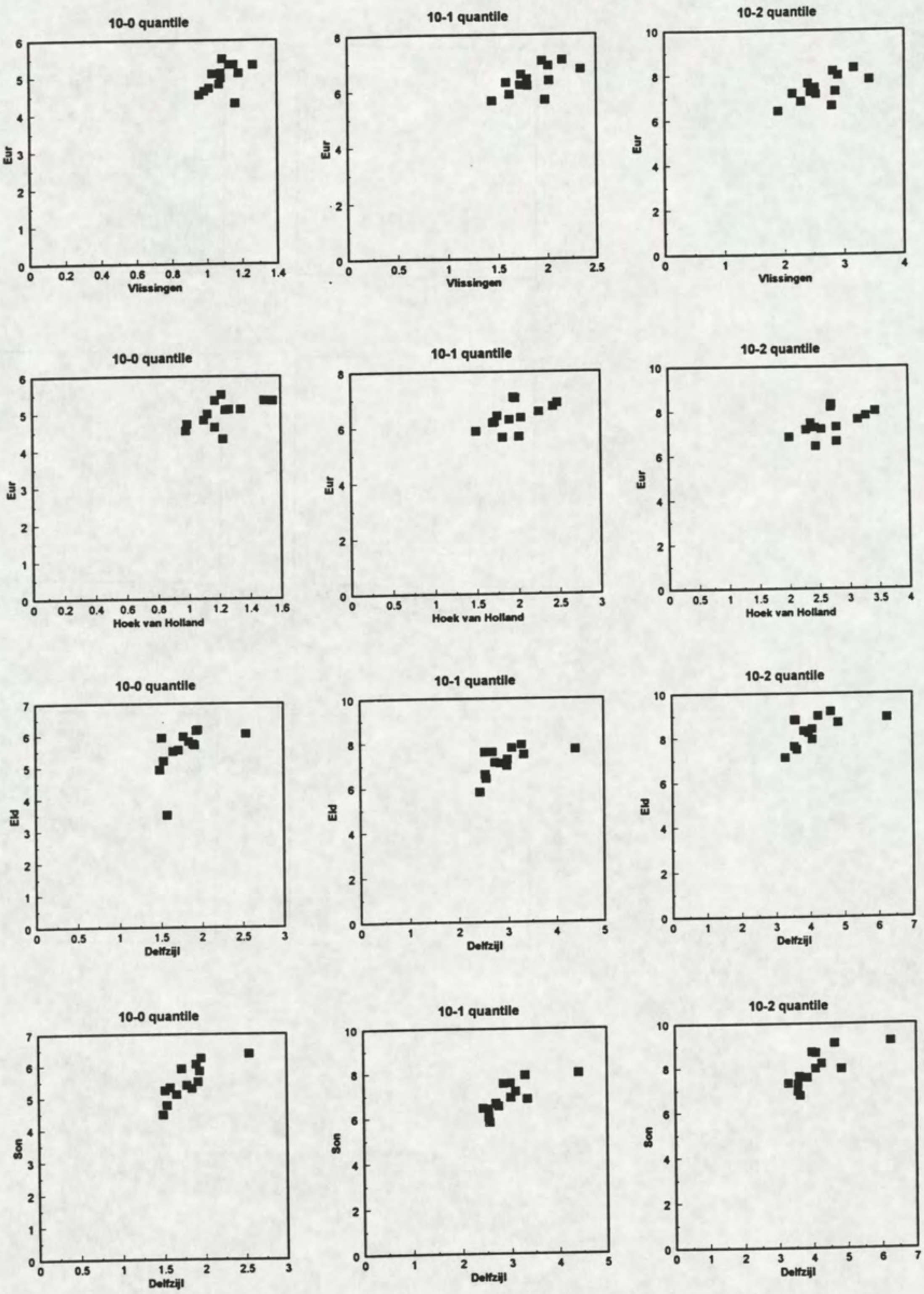

Schiphol
10-0 quantile
10-1 quantile
10-2 quantile
wind speed [m/s]
0
5
10
15
20
25
30
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990

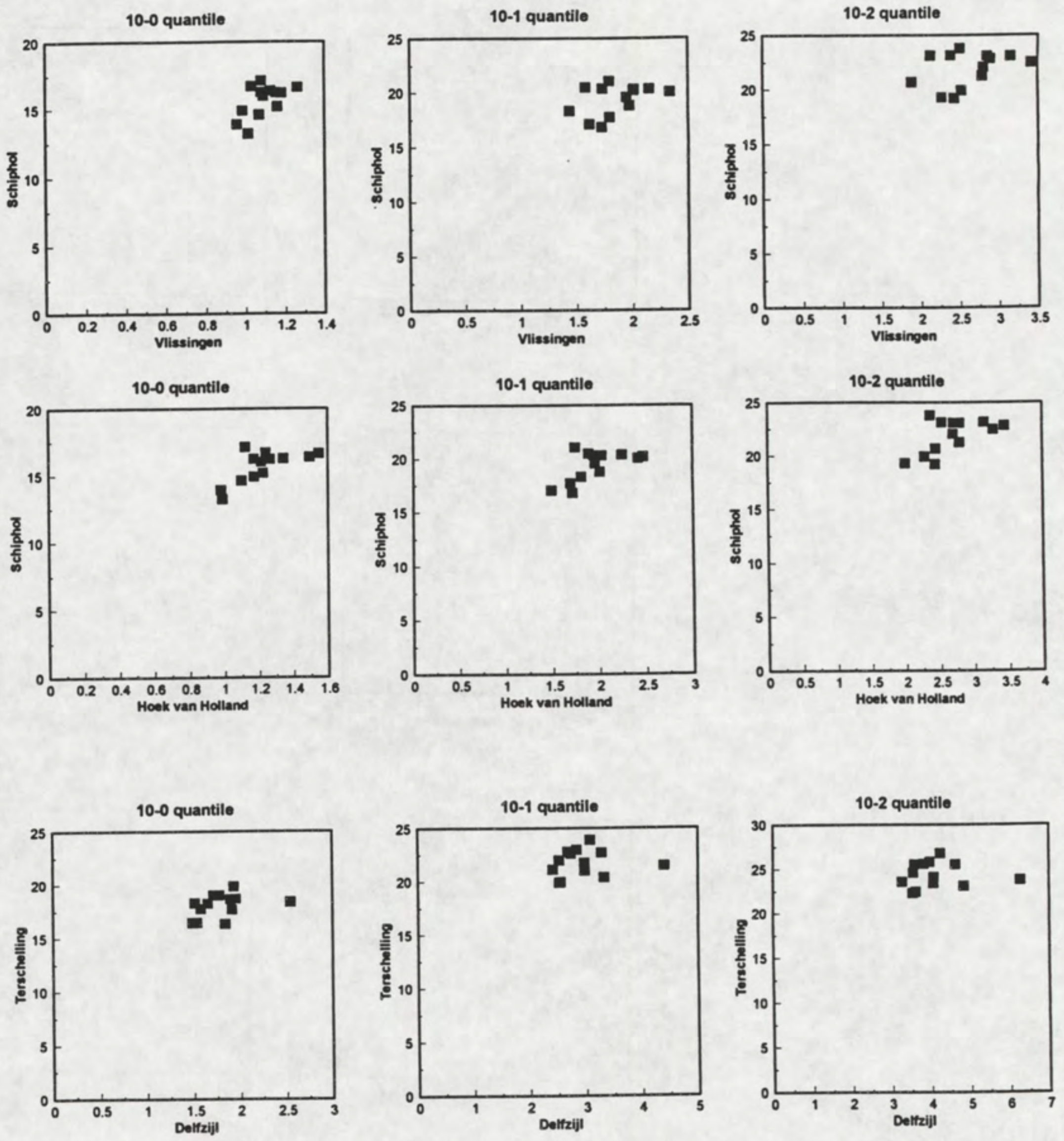

Terschelling
wind speed [m/s]
0
5
10
15
20
25
30
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990

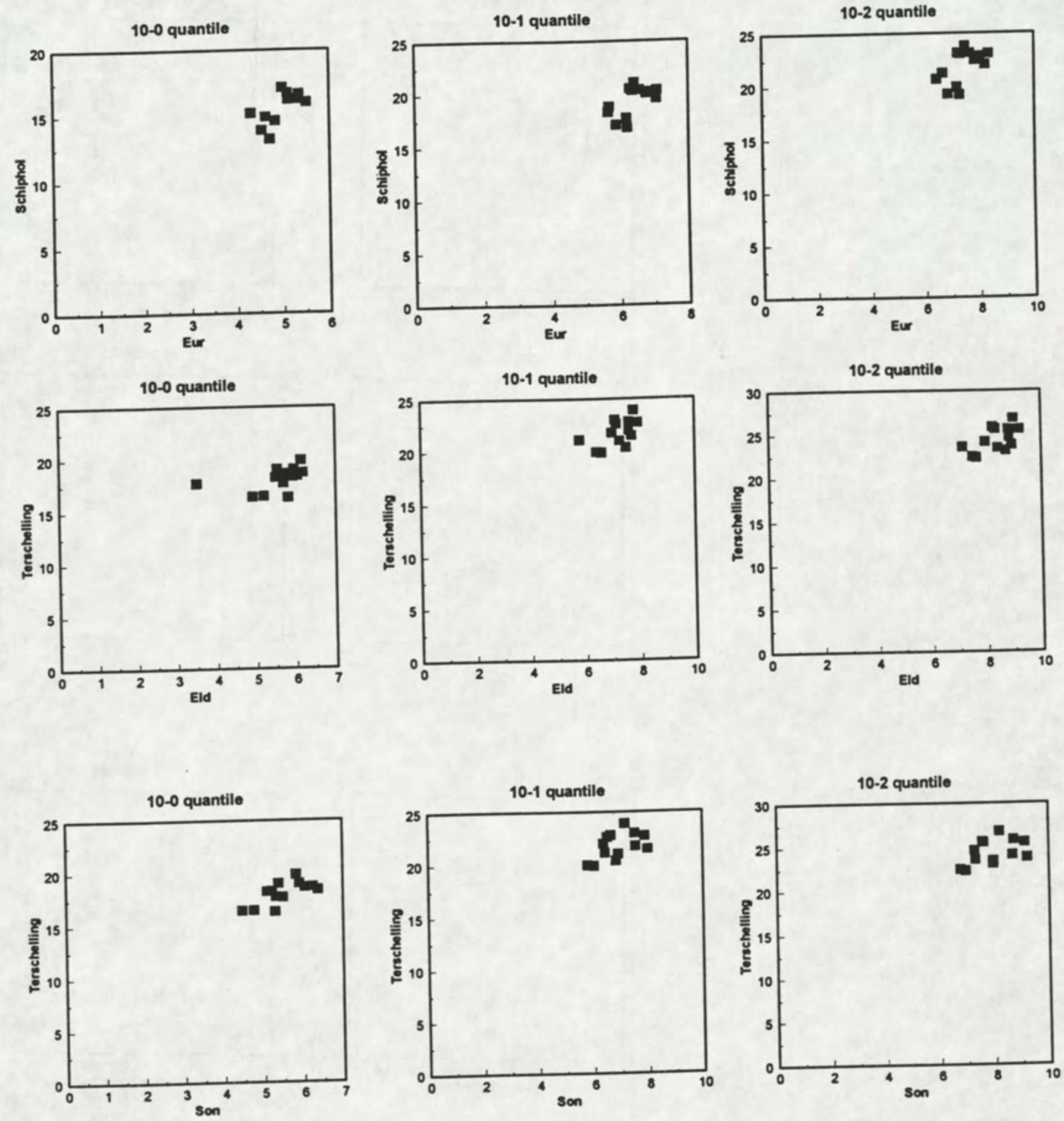
Annex B, part 2

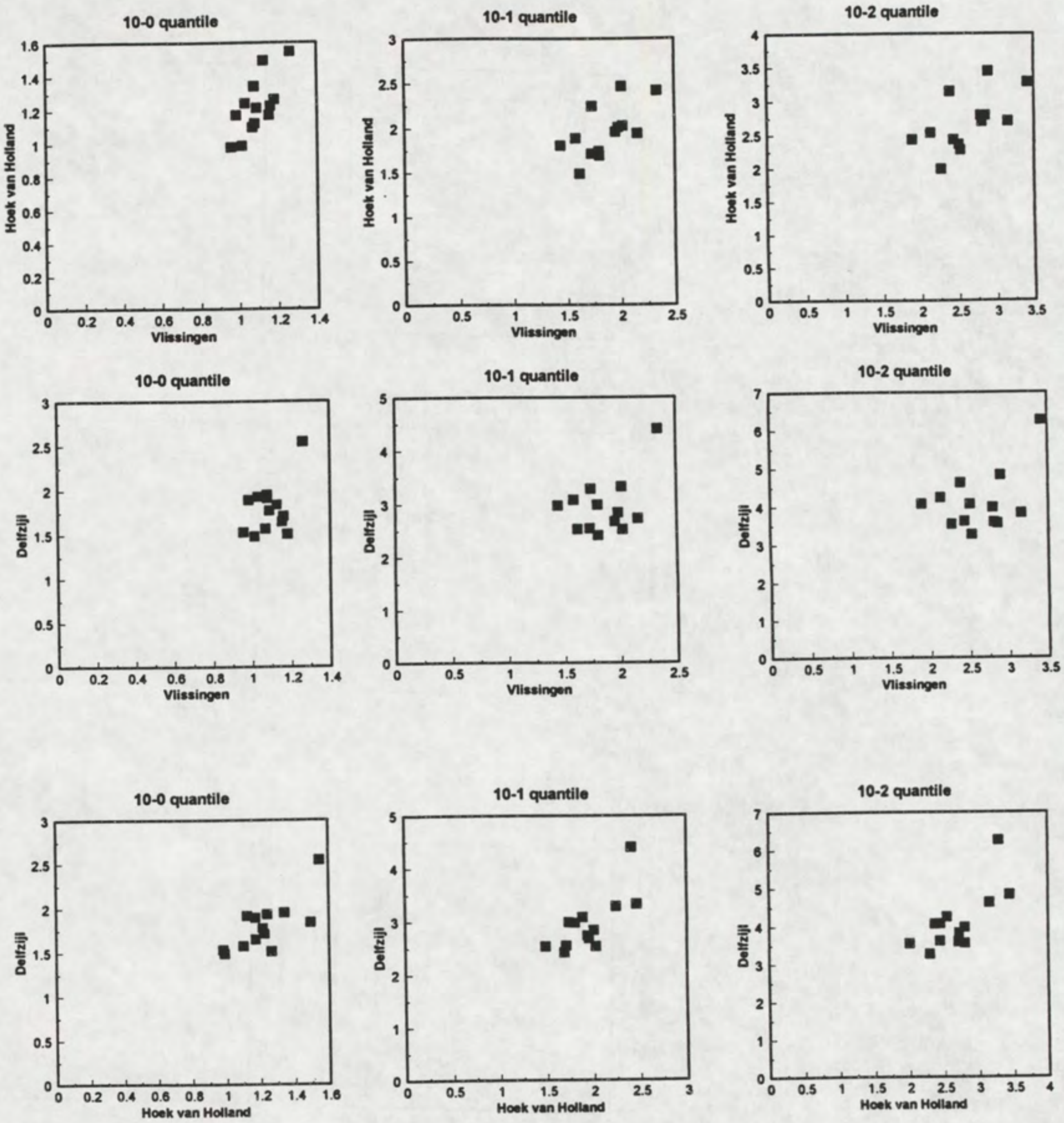
In this part of Annex B, scatter diagrams are shown for various combinations of sea-level, wave height and wind data. For a correct understanding of these diagrams, one must be aware that the names of the measurement stations on the x- and y-axis also implicate the type of data which is compared:

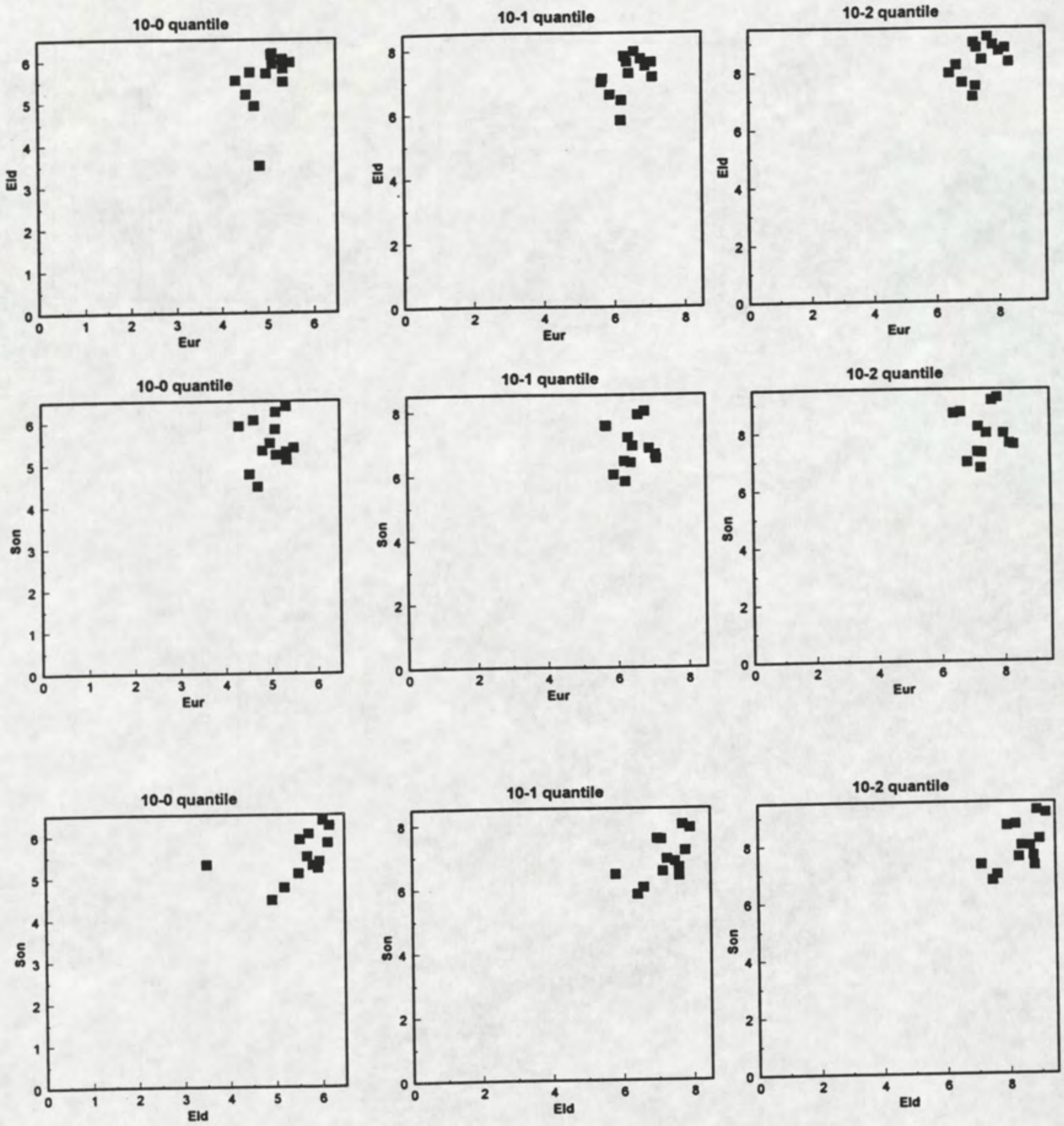
High-water set-up data:	Vlissingen, Hoek van Holland, Delfzijl
Wave height data:	Eur, Eld, Son
Wind data:	Schiphol, Terschelling

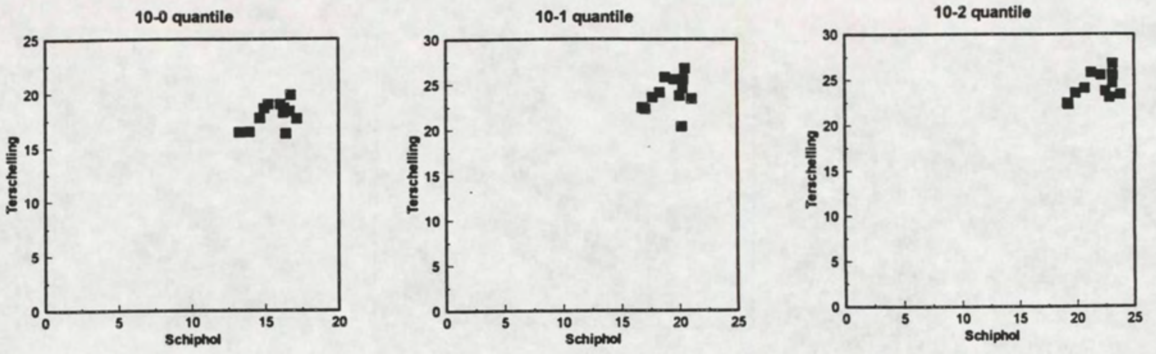

10-0 quantile
Eur
Vlissingen
10-1 quantile
Eur
Vlissingen
10-2 quantile
Eur
Vlissingen
10-0 quantile
Eur
Hoek van Holland
10-1 quantile
Eur
Hoek van Holland
10-2 quantile
Eur
Hoek van Holland
10-0 quantile
Eld
Delfzijl
10-1 quantile
Eld
Delfzijl
10-2 quantile
Eld
Delfzijl
10-0 quantile
Son
Delfzijl
10-1 quantile
Son
Delfzijl
10-2 quantile
Son
Delfzijl


10-0 quantile
Schiphol
Vlissingen
10-1 quantile
Schiphol
Vlissingen
10-2 quantile
Schiphol
Vlissingen
10-0 quantile
Schiphol
Hoek van Holland
10-1 quantile
Schiphol
Hoek van Holland
10-2 quantile
Schiphol
Hoek van Holland
10-0 quantile
Terschelling
Delfzijl
10-1 quantile
Terschelling
Delfzijl
10-2 quantile
Terschelling
Delfzijl


10-0 quantile
Schiphol
Eur
10-1 quantile
Schiphol
Eur
10-2 quantile
Schiphol
Eur
10-0 quantile
Terschelling
Eld
10-1 quantile
Terschelling
Eld
10-2 quantile
Terschelling
Eld
10-0 quantile
Terschelling
Son
10-1 quantile
Terschelling
Son
10-2 quantile
Terschelling
Son

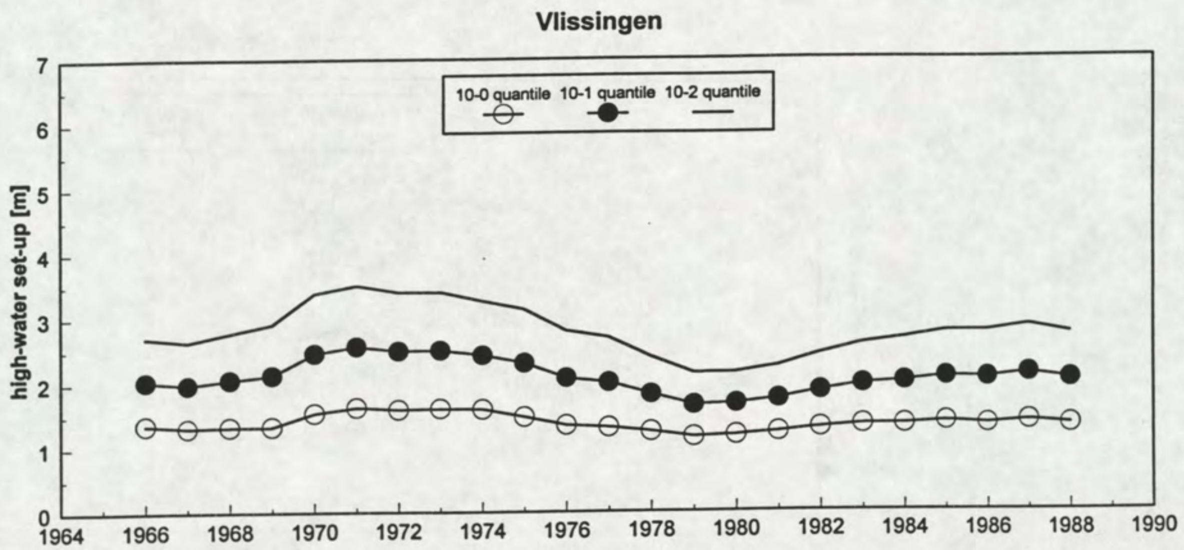

10-0 quantile
Hoek van Holland
Vlissingen
10-1 quantile
Hoek van Holland
Vlissingen
10-2 quantile
Hoek van Holland
Vlissingen
10-0 quantile
Delfzijl
Vlissingen
10-1 quantile
Delfzijl
Vlissingen
10-2 quantile
Delfzijl
Vlissingen
10-0 quantile
Delfzijl
Hoek van Holland
10-1 quantile
Delfzijl
Hoek van Holland
10-2 quantile
Delfzijl
Hoek van Holland

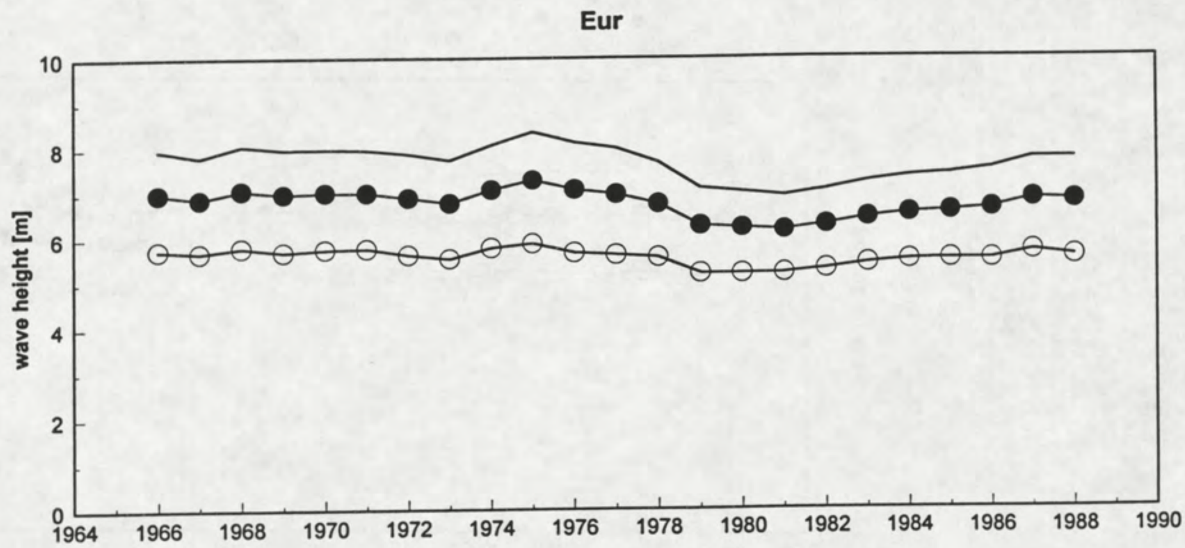

10-0 quantile
10-1 quantile
10-2 quantile
Eld
Eur
10-0 quantile
10-1 quantile
10-2 quantile
Son
Eur
10-0 quantile
10-1 quantile
10-2 quantile
Son
Eld

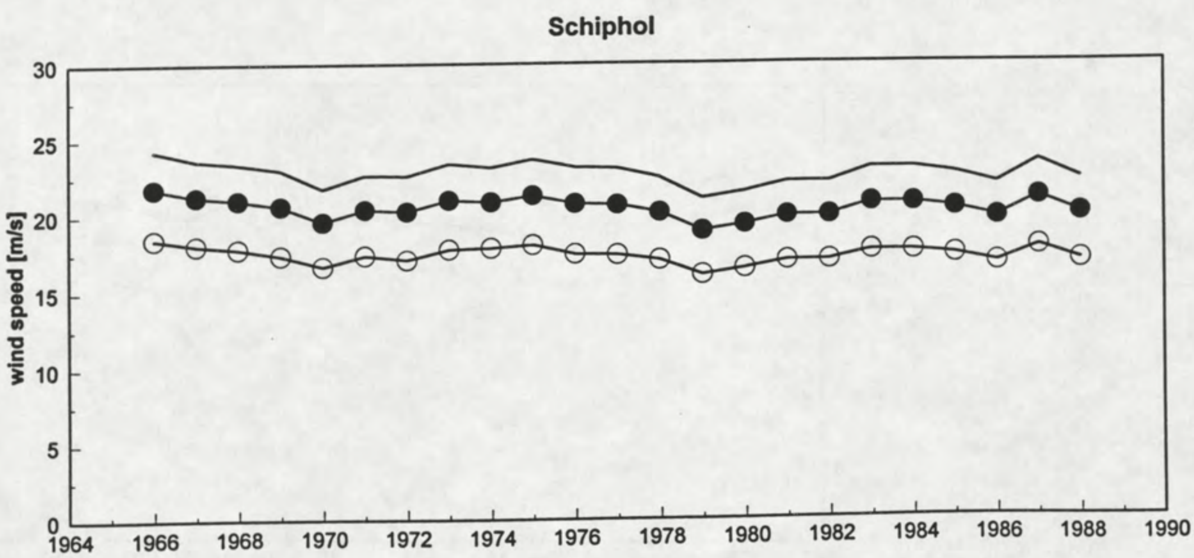

10-0 quantile
Terschelling
Schiphol
0
5
10
15
20
25
10-1 quantile
Terschelling
Schiphol
30
10-2 quantile
Terschelling
Schiphol

Annex C, part 1

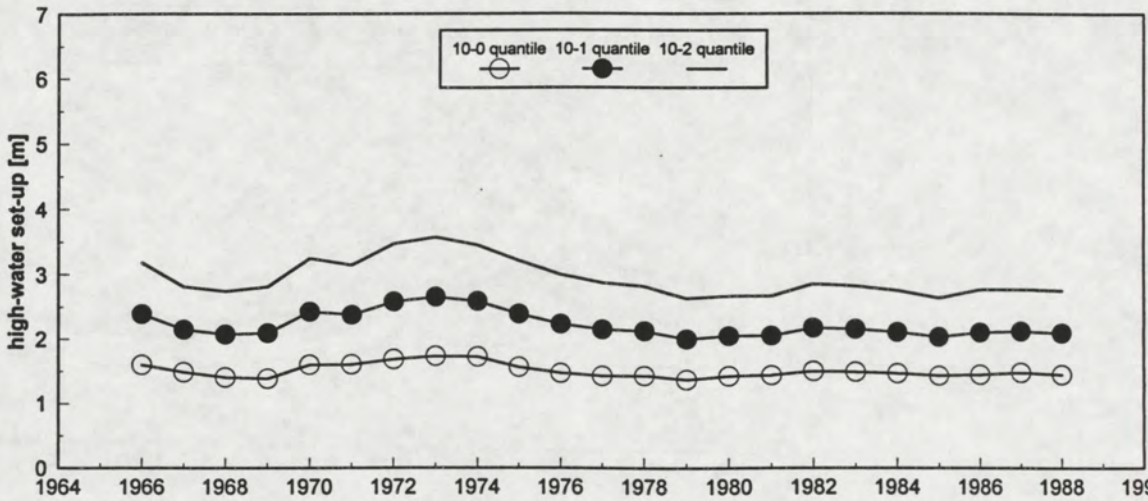
In this part of Annex C, the result of a variant of the quantile analysis method is shown for various combinations of sea-level, wave height and wind stations.
This variant has been applied to investigate the sensitivity of the quantile analysis method to the length of the periods in which the complete datasets are split up and to the number of elements involved in the Weibull fit procedure. A complete description of this variant is given at page 17.


Vlissingen
10-0 quantile
10-1 quantile
10-2 quantile
high-water set-up [m]
0
1
2
3
4
5
6
7
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990

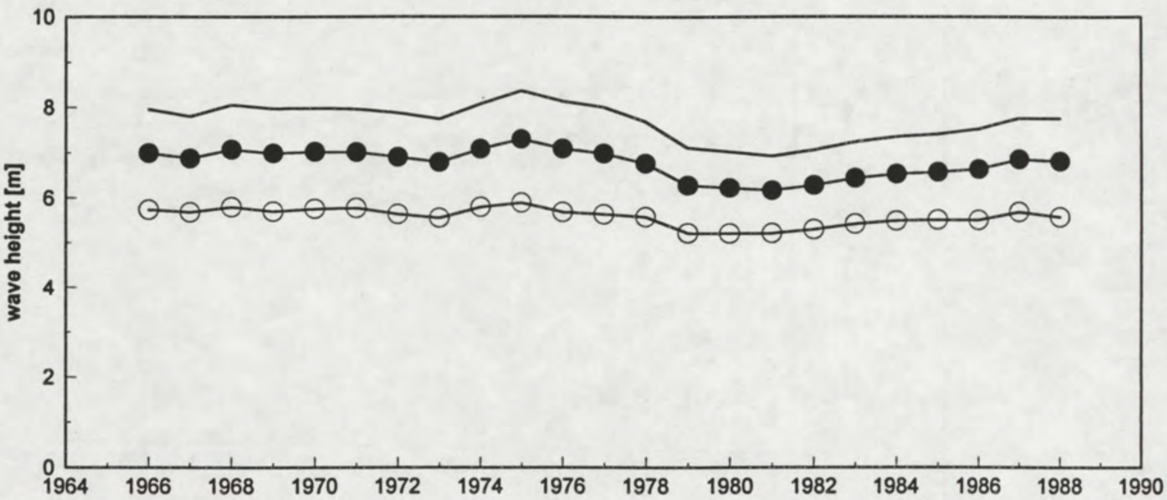

Eur
wave height [m]
0
2
4
6
8
10
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990


Schiphol
wind speed [m/s]
0
5
10
15
20
25
30
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990

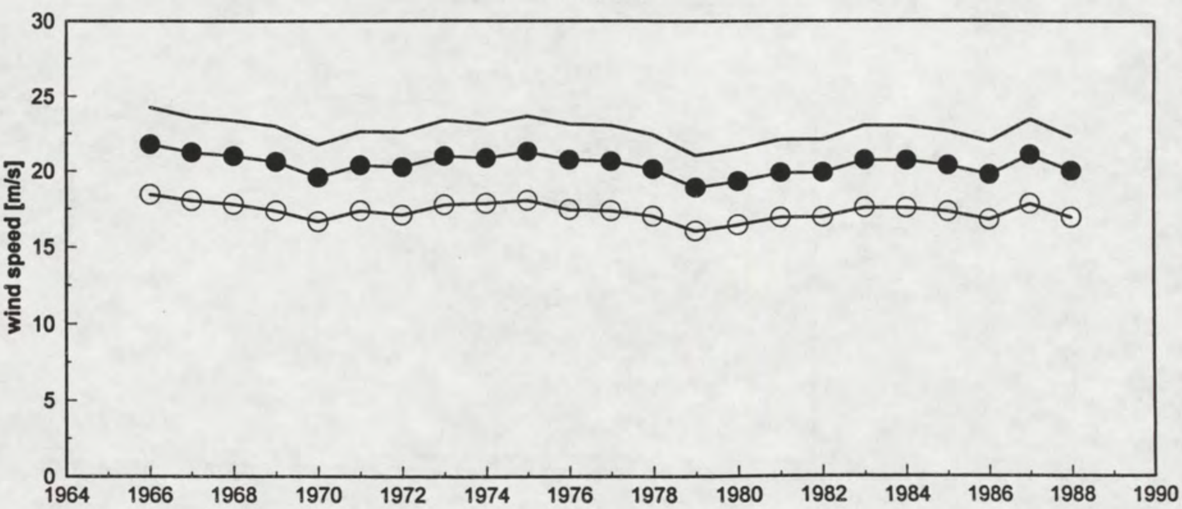
Hoek van Holland

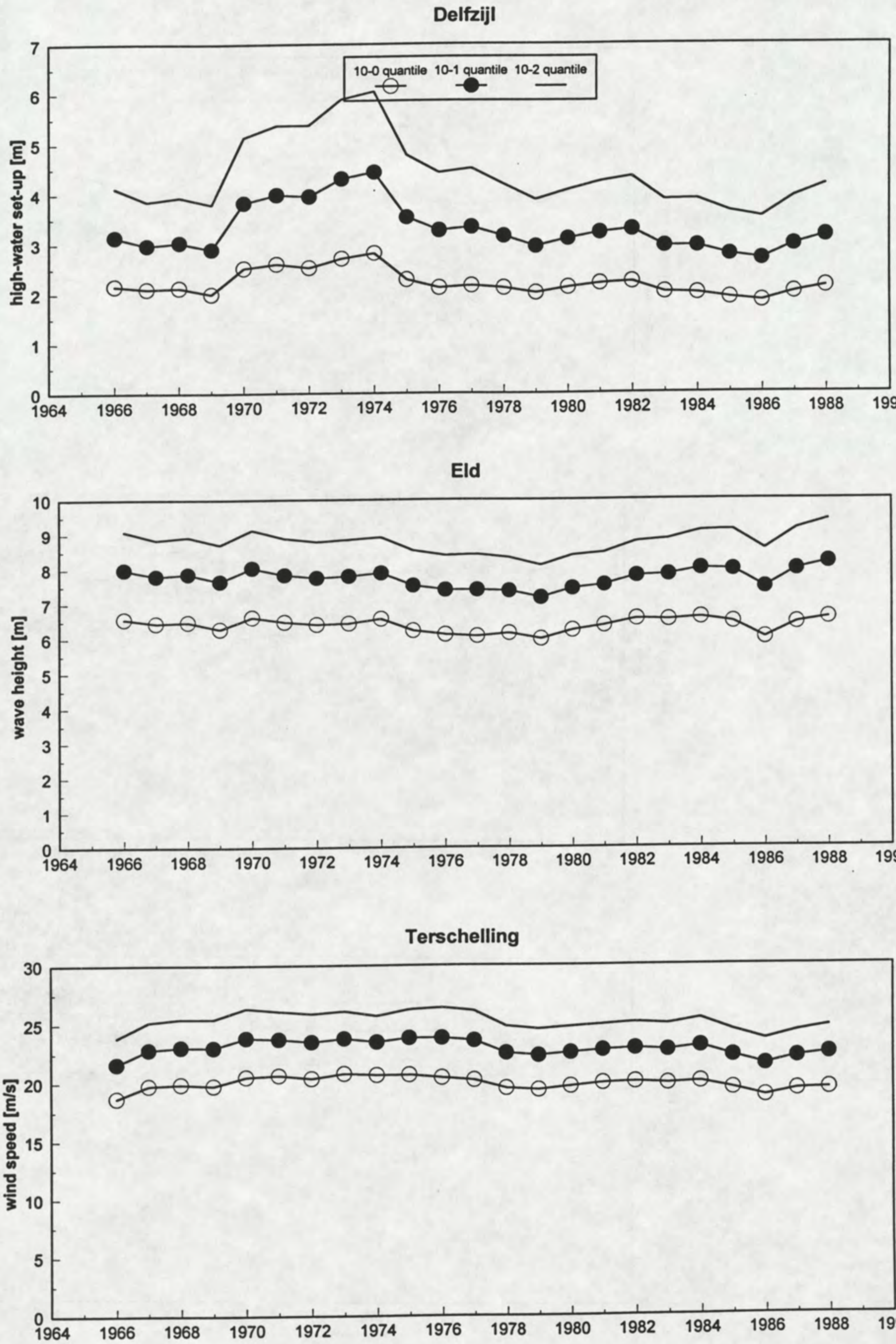


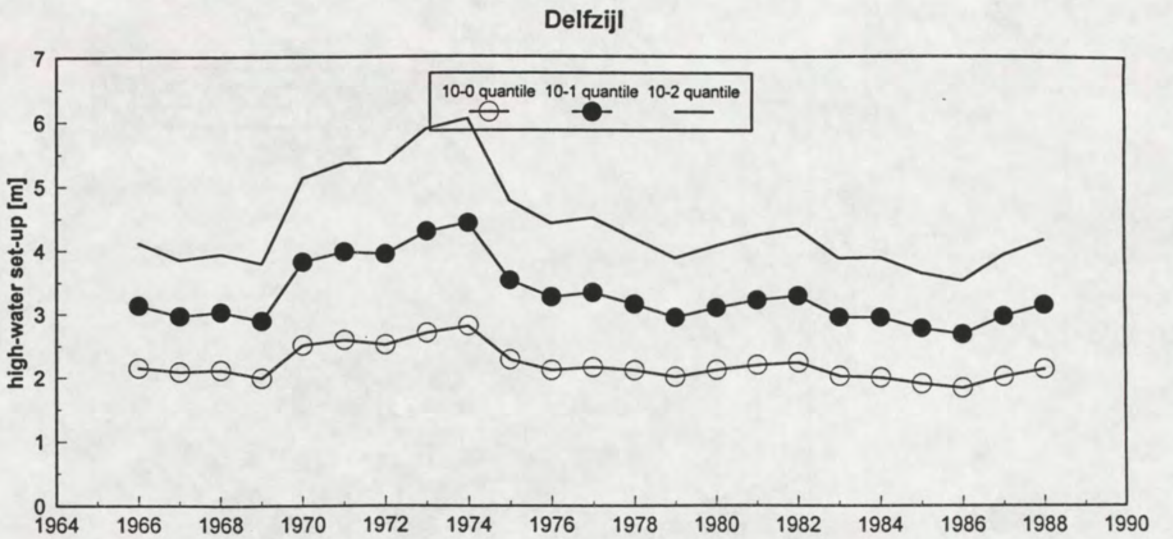
Eur

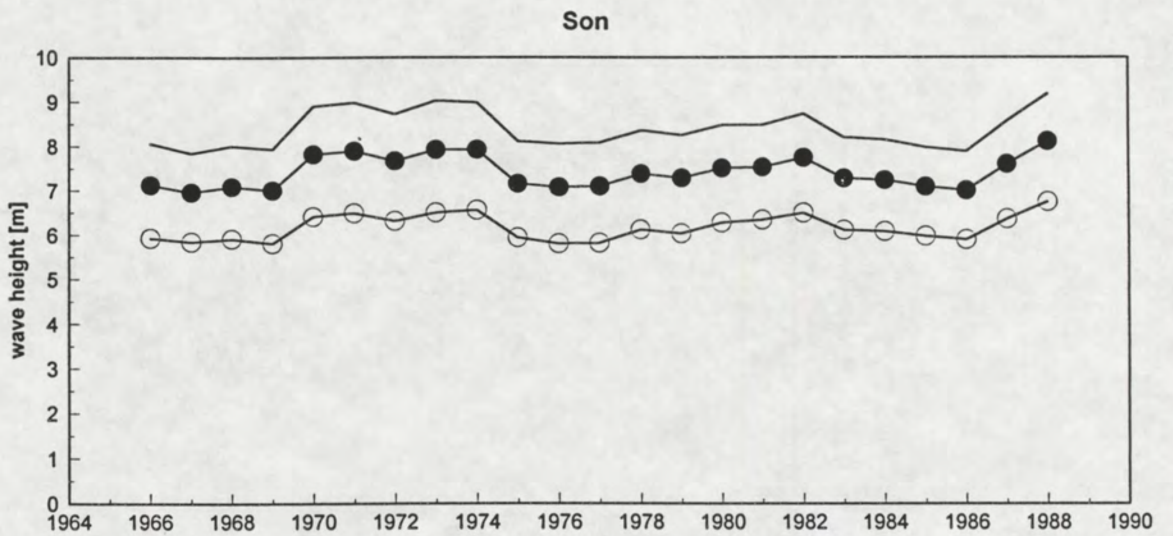


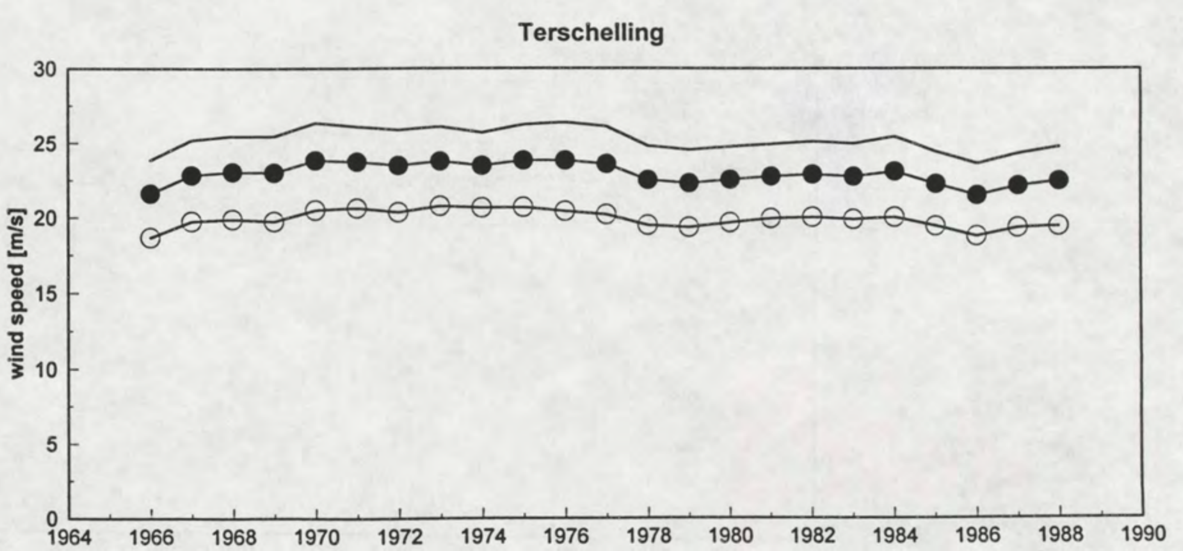
Schiphol

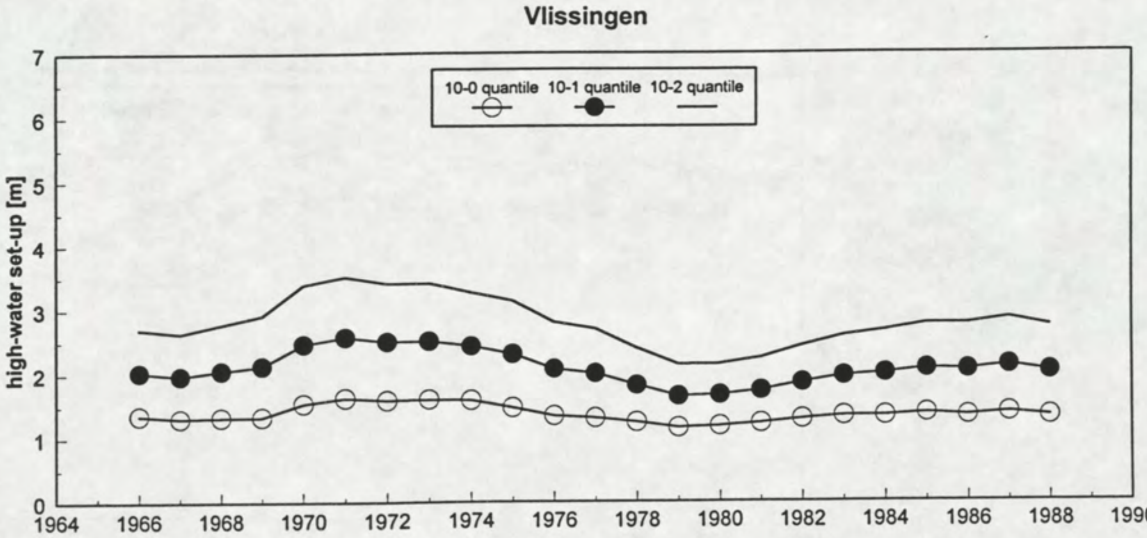


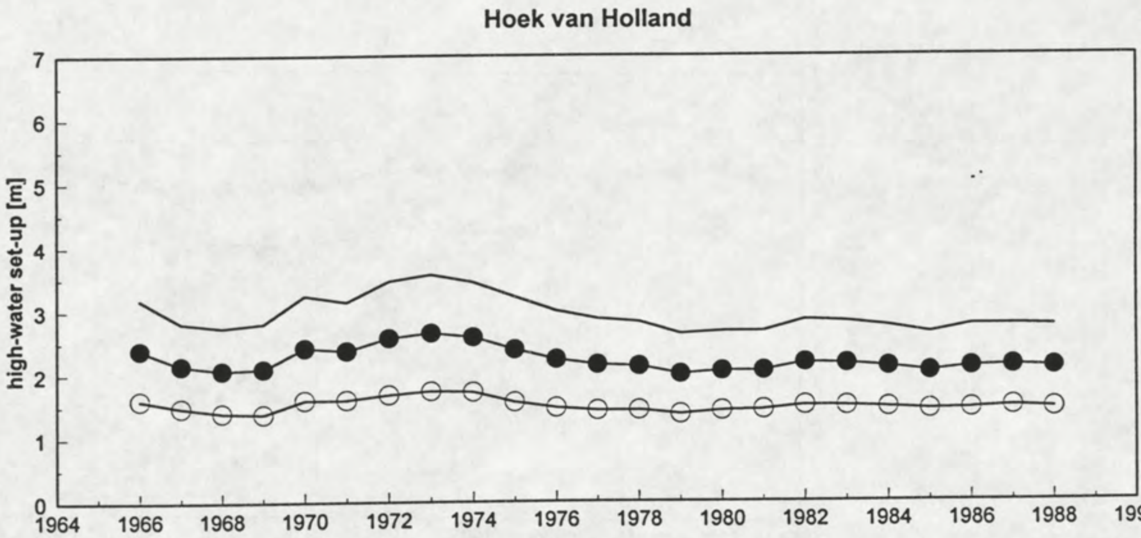

Delfzijl
10-0 quantile
10-1 quantile
10-2 quantile
high-water set-up [m]
0
1
2
3
4
5
6
7
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
Eld
wave height [m]
0
1
2
3
4
5
6
7
8
9
10
Terschelling
wind speed [m/s]
0
5
10
15
20
25
30

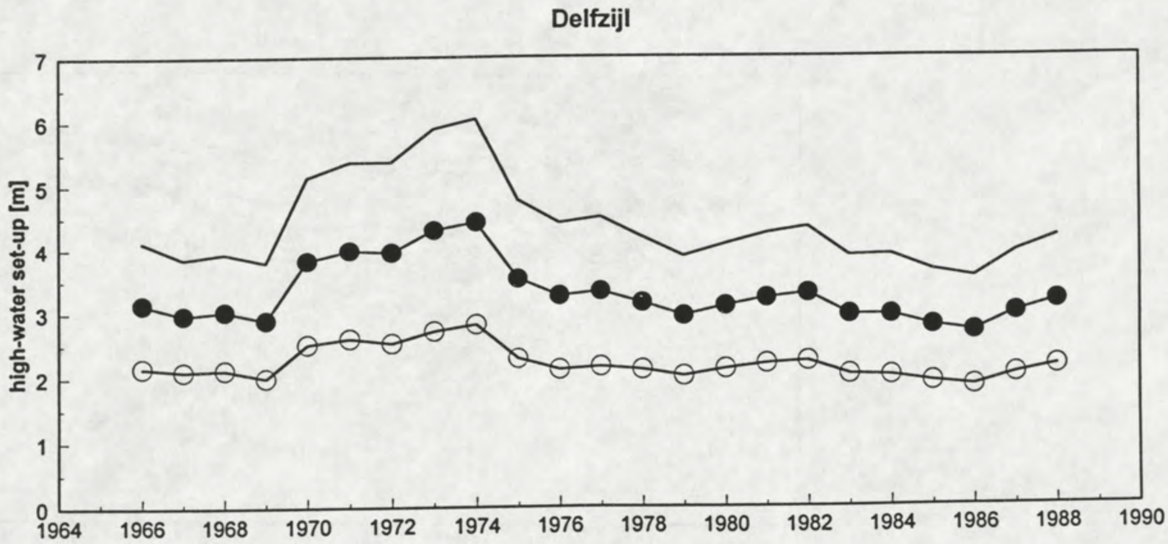

Delfzijl
10-0 quantile
10-1 quantile
10-2 quantile
high-water set-up [m]
0
1
2
3
4
5
6
7
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990

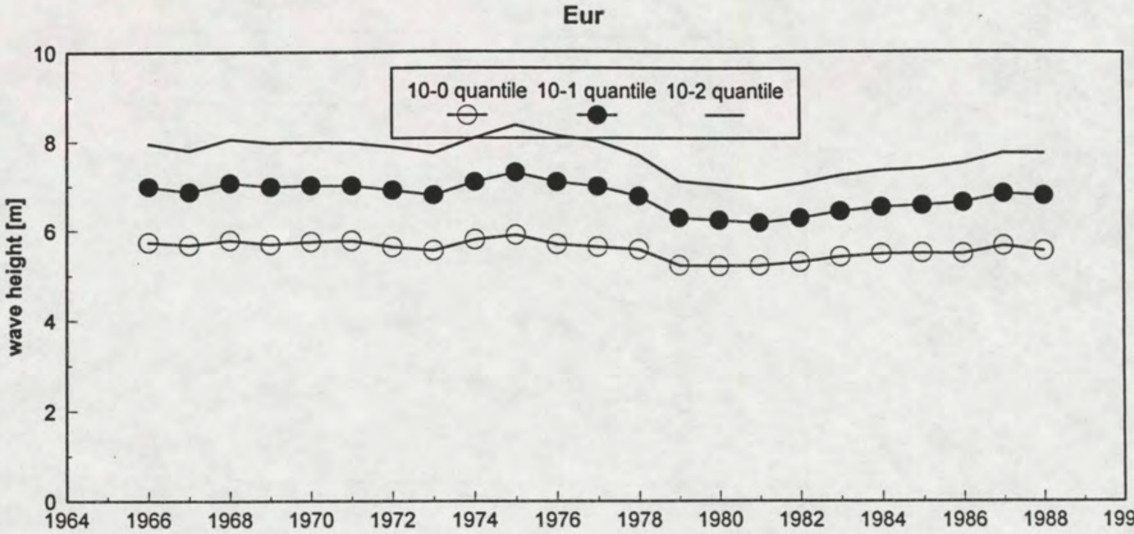

Son
wave height [m]
0
1
2
3
4
5
6
7
8
9
10
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990

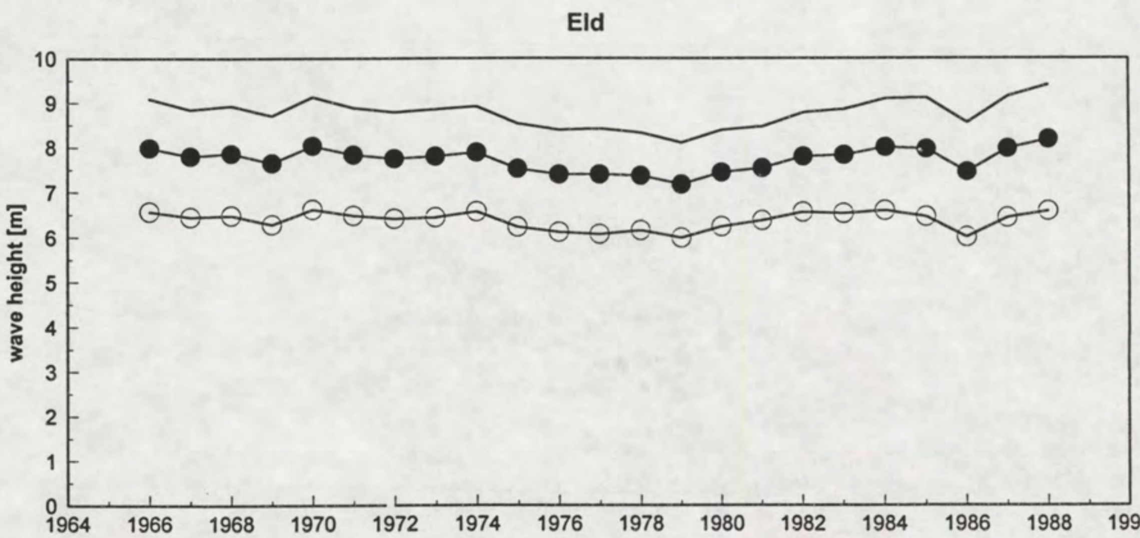

Terschelling
wind speed [m/s]
0
5
10
15
20
25
30
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990

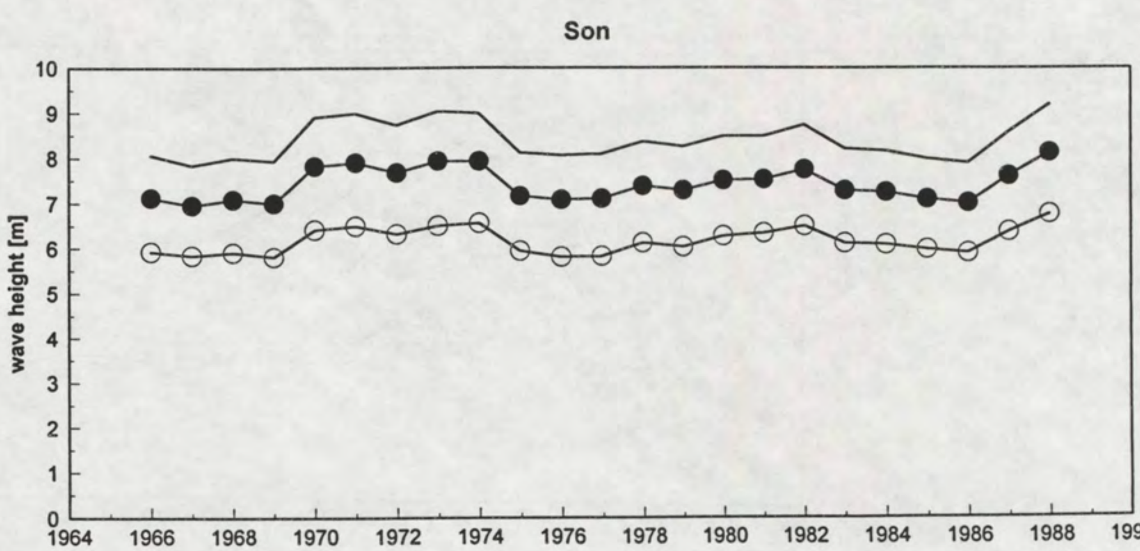

Vlissingen
10-0 quantile
10-1 quantile
10-2 quantile
high-water set-up [m]
0
1
2
3
4
5
6
7
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990

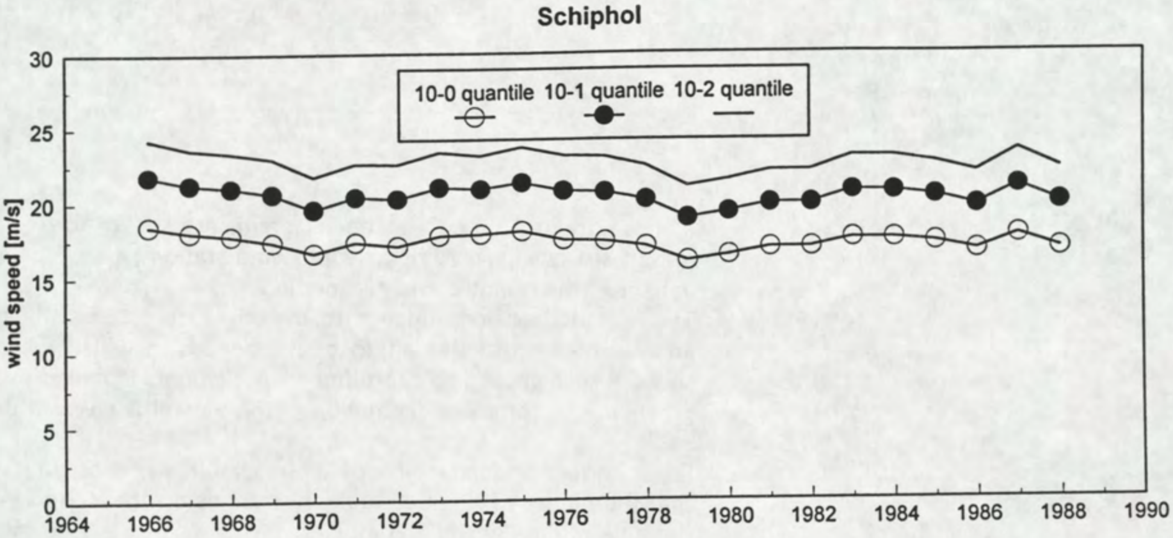

Hoek van Holland
high-water set-up [m]
0
1
2
3
4
5
6
7
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990

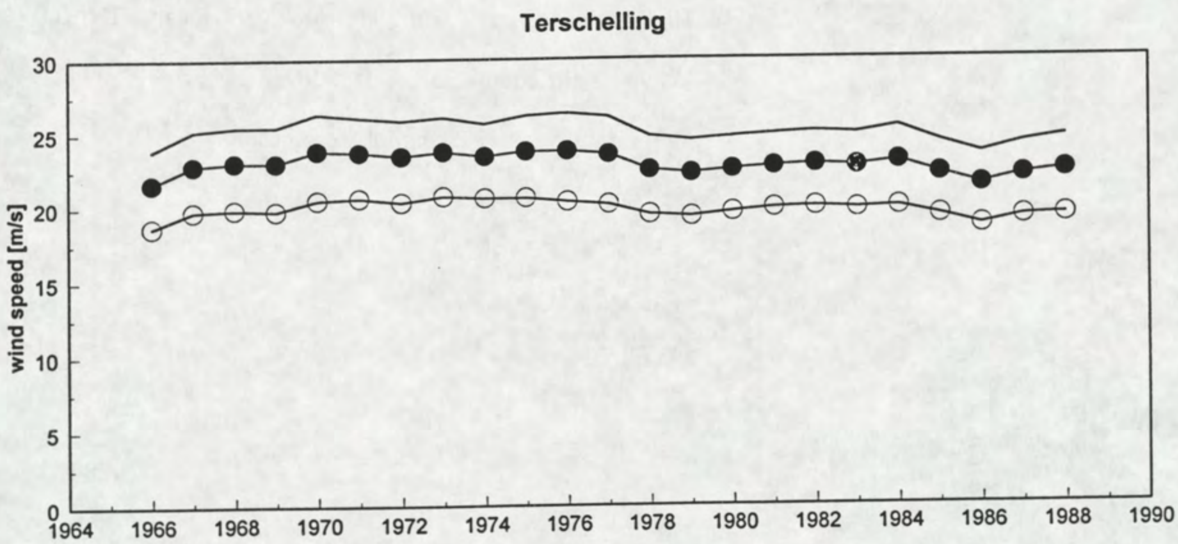

Delfzijl
high-water set-up [m]
0
1
2
3
4
5
6
7
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990


Eur
10-0 quantile 10-1 quantile 10-2 quantile
wave height [m]
0
2
4
6
8
10
1964 1966 1968 1970 1972 1974 1976 1978 1980 1982 1984 1986 1988 1990


Eld
wave height [m]
0 1 2 3 4 5 6 7 8 9 10
1964 1966 1968 1970 1972 1974 1976 1978 1980 1982 1984 1986 1988 1990


Son
wave height [m]
0 1 2 3 4 5 6 7 8 9 10
1964 1966 1968 1970 1972 1974 1976 1978 1980 1982 1984 1986 1988 1990


Schiphol
10-0 quantile
10-1 quantile
10-2 quantile
wind speed [m/s]
30
25
20
15
10
5
0
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990


Terschelling
wind speed [m/s]
30
25
20
15
10
5
0
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990

Annex C, part 2

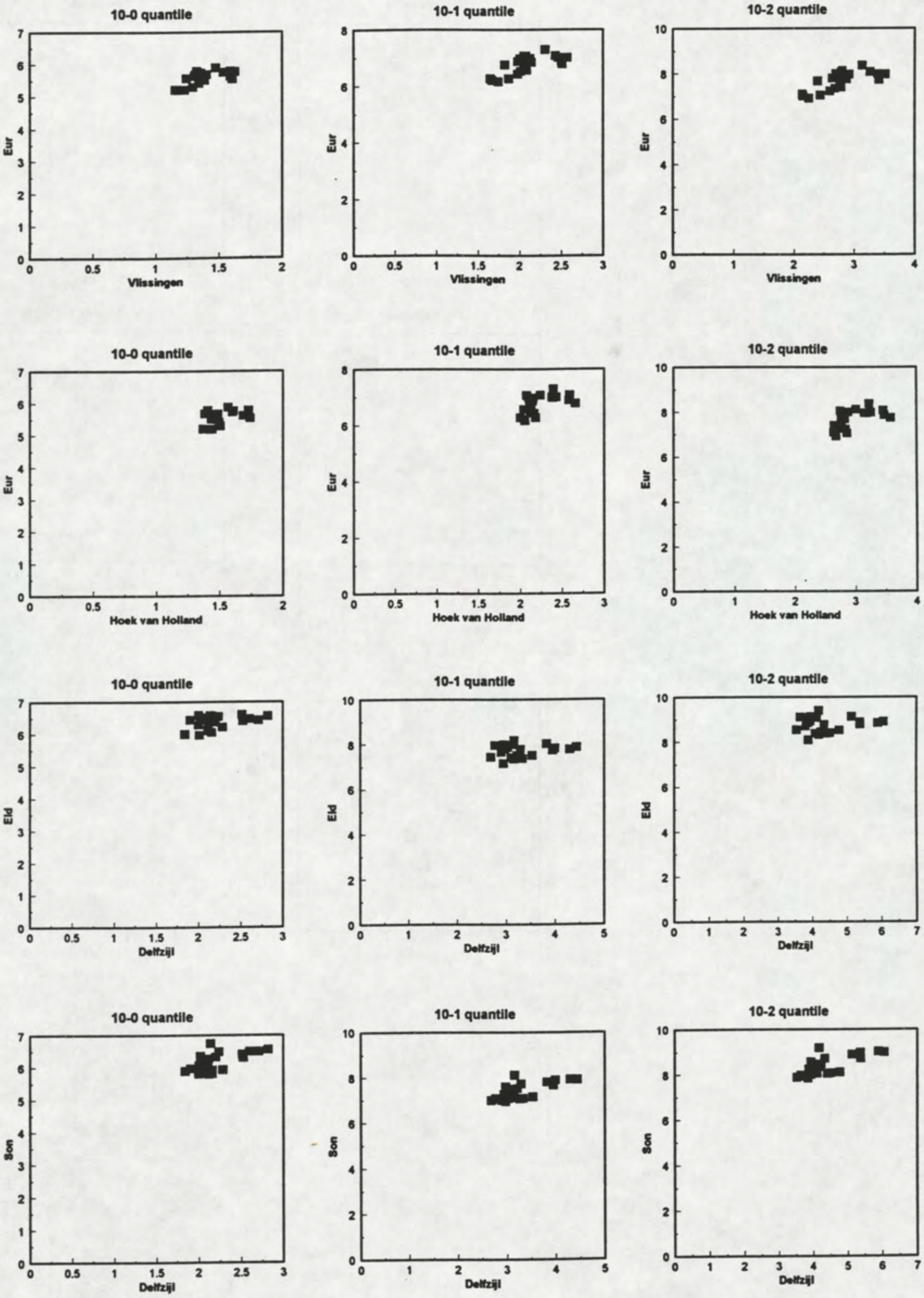
In this part of Annex C, scatter diagrams are shown for various combinations of sea-level, wave height and wind stations, based on the result of a variant of the quantile analysis method.
This variant has been applied to investigate the sensitivity of the quantile analysis method to the length of the periods in which the complete datasets are split up and to the number of elements involved in the Weibull fit procedure. A complete description of this variant is given at page 17.

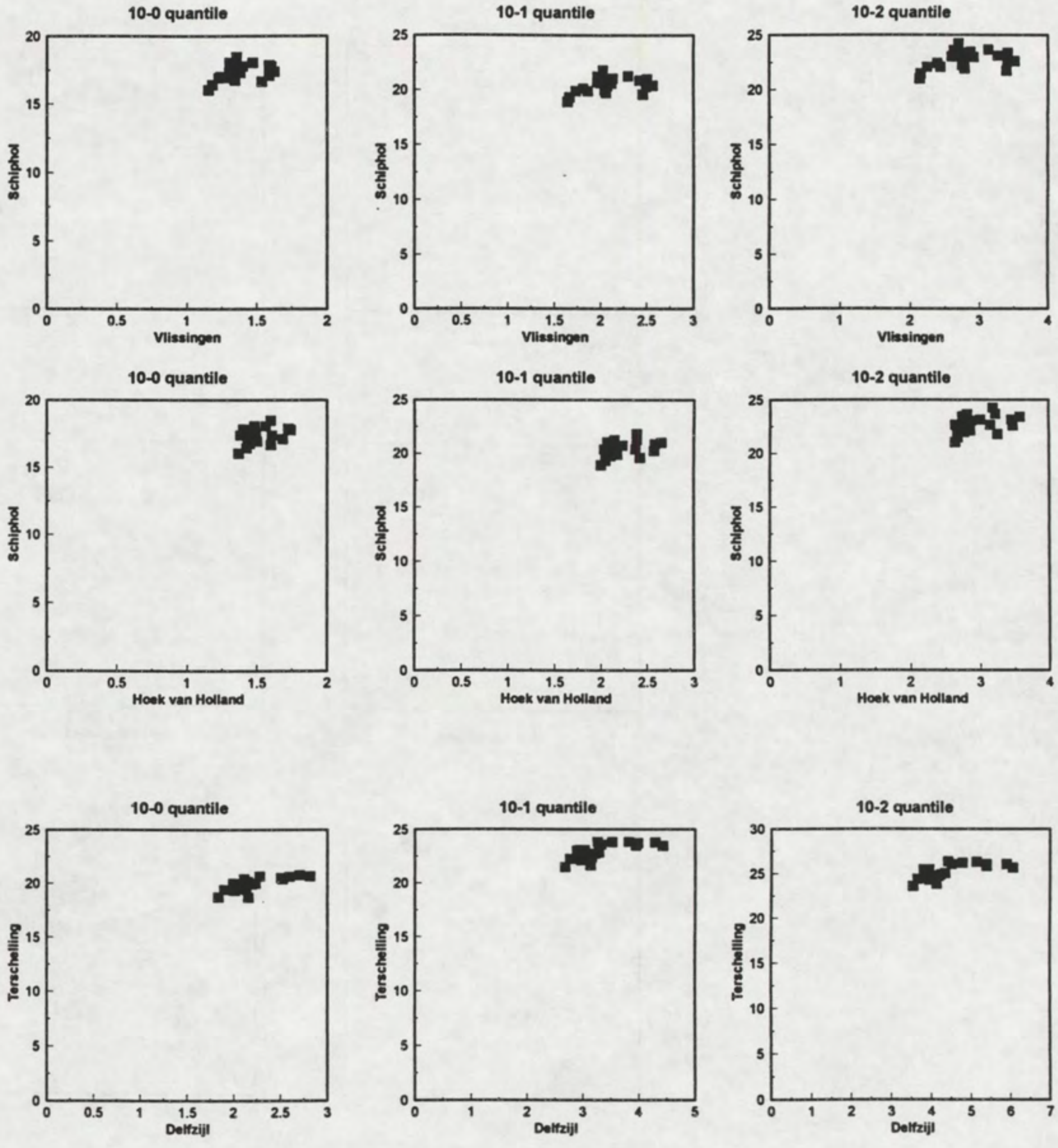
For a correct understanding of these scatter diagrams, one must be aware that the names of the measurement stations on the x- and y-axis also imply the type of data which is compared:

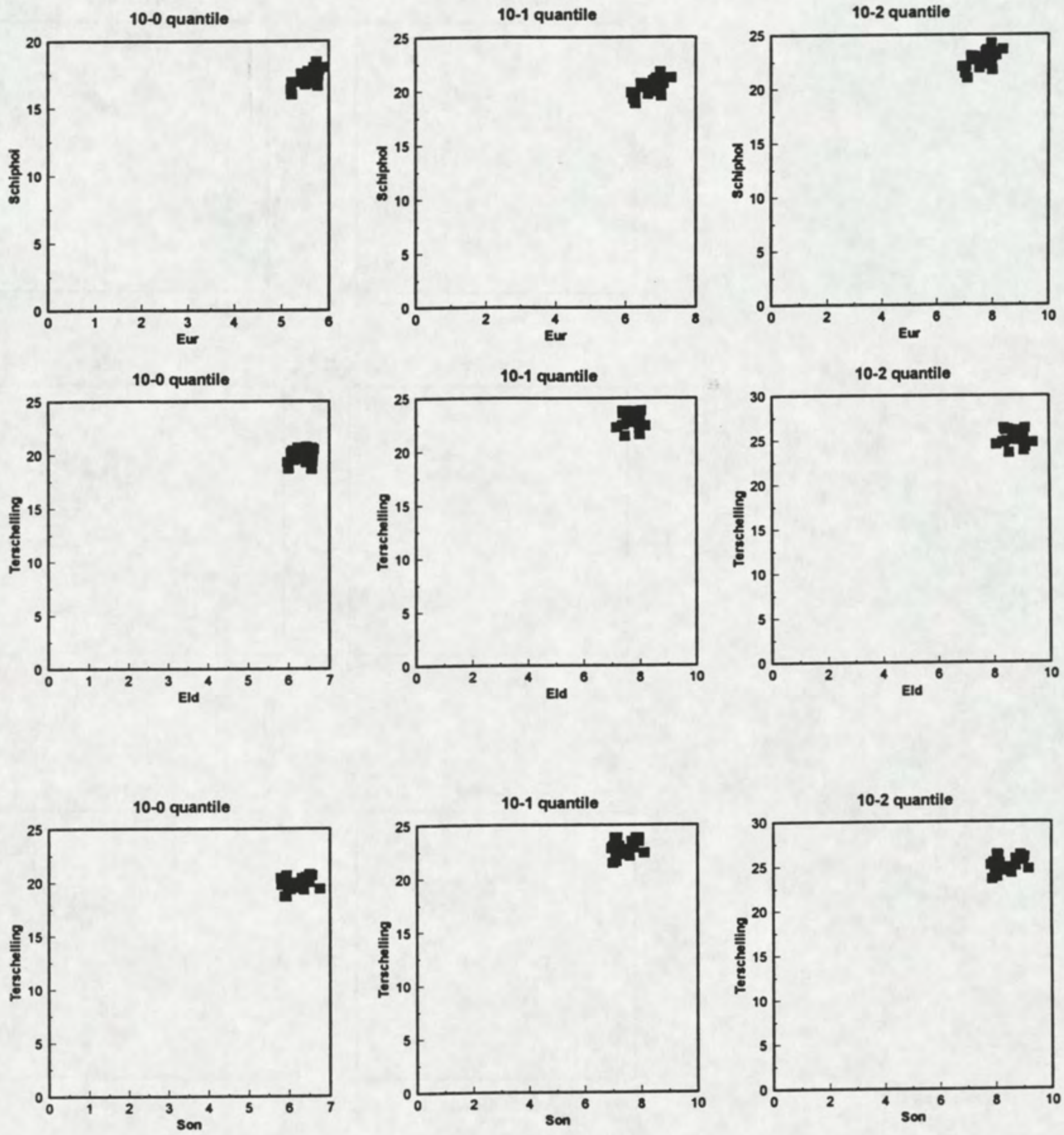
High-water set-up: Vlissingen, Hoek van Holland, Delfzijl

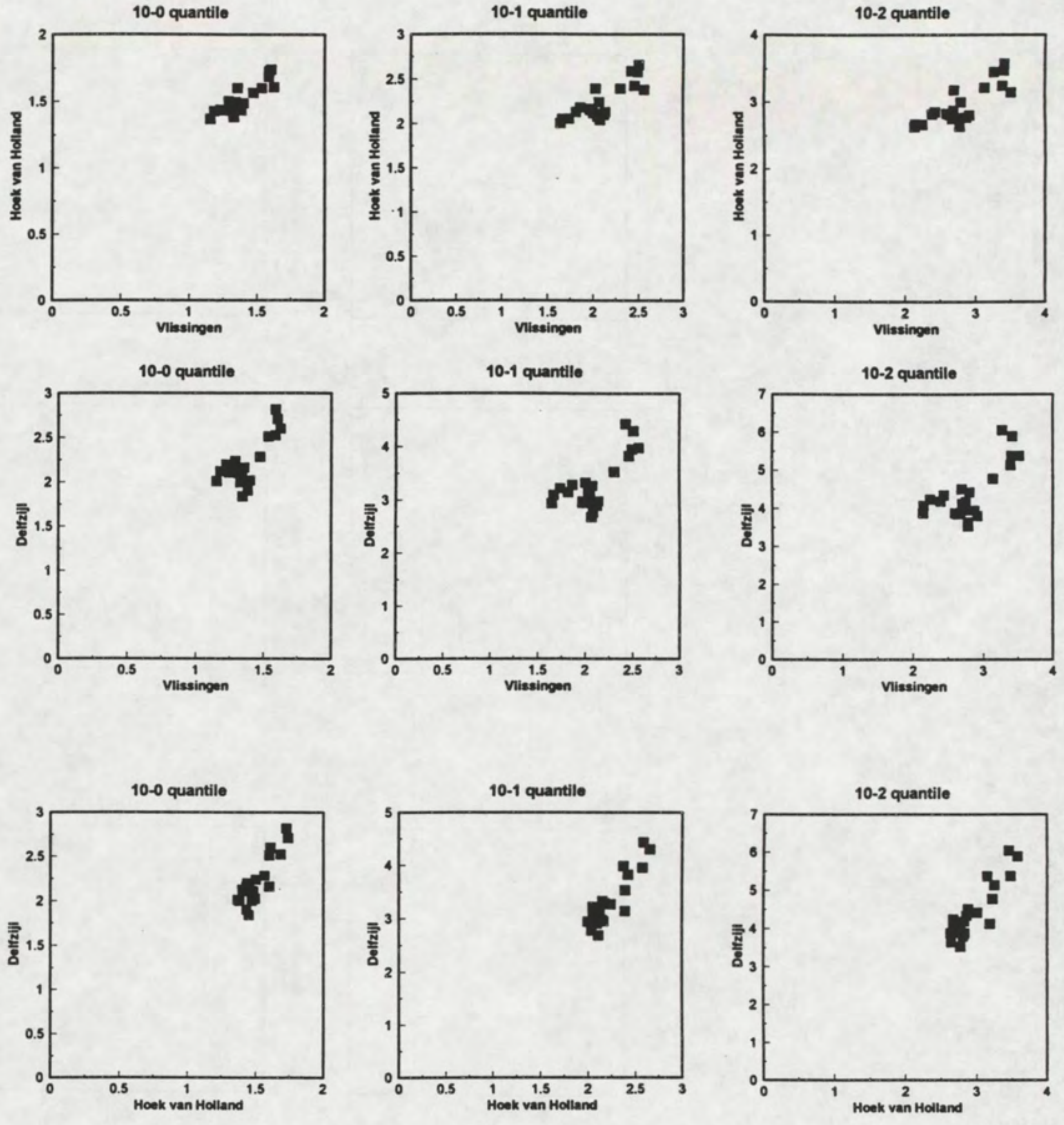
Wave height data: EUR, ELD, SON

Wind data: Schiphol, Terschelling

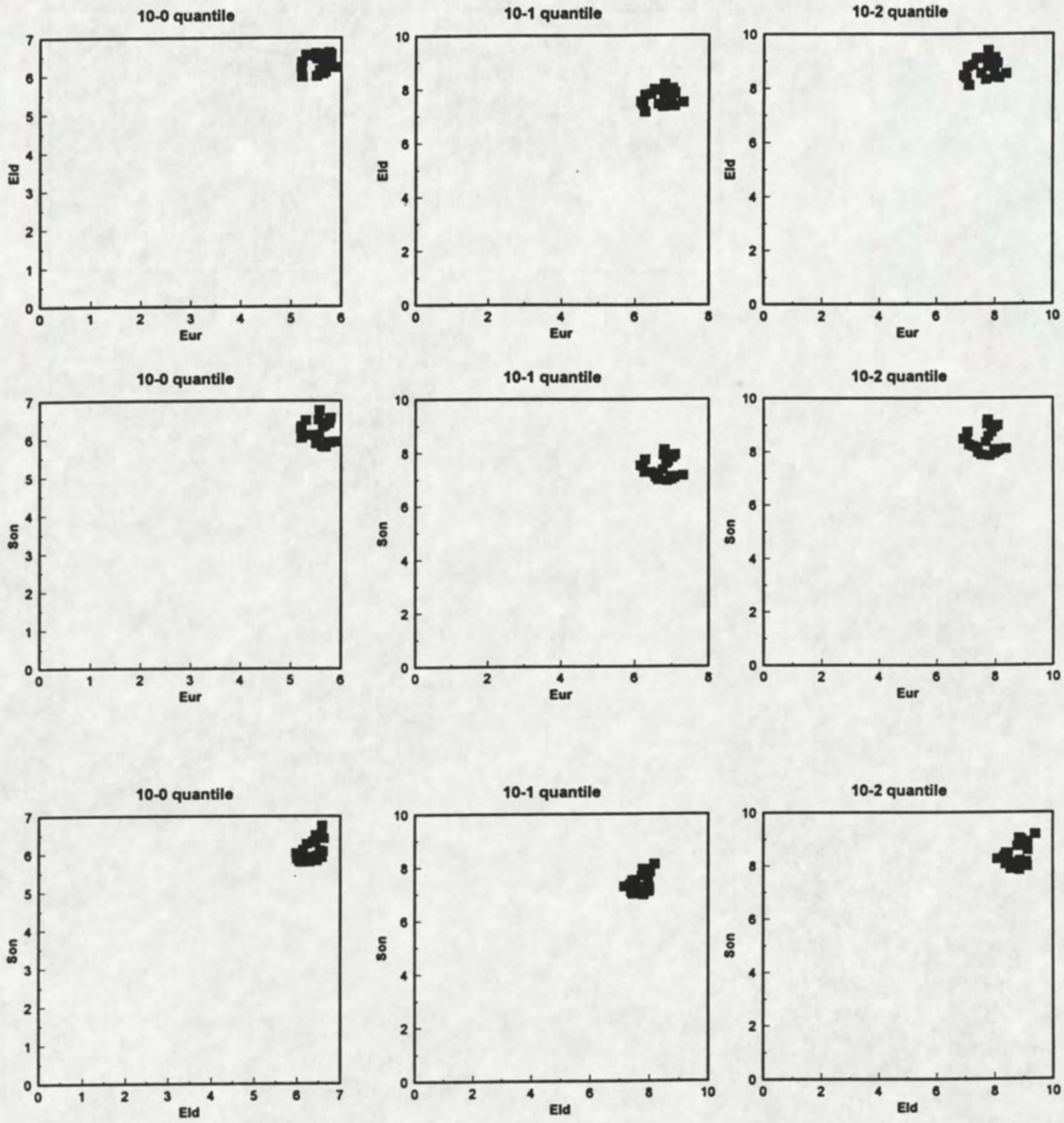

10-0 quantile
10-1 quantile
10-2 quantile
Eur
Vlissingen
Hoek van Holland
Eld
Son
Delfzijl

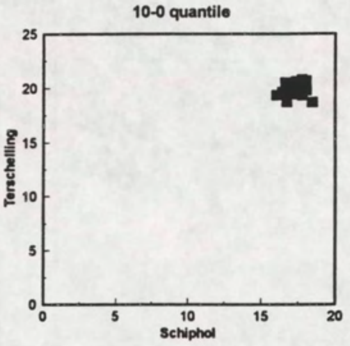

10-0 quantile
Schiphol
Vlissingen
10-1 quantile
Schiphol
Vlissingen
10-2 quantile
Schiphol
Vlissingen
10-0 quantile
Schiphol
Hoek van Holland
10-1 quantile
Schiphol
Hoek van Holland
10-2 quantile
Schiphol
Hoek van Holland
10-0 quantile
Terschelling
Delfzijl
10-1 quantile
Terschelling
Delfzijl
10-2 quantile
Terschelling
Delfzijl

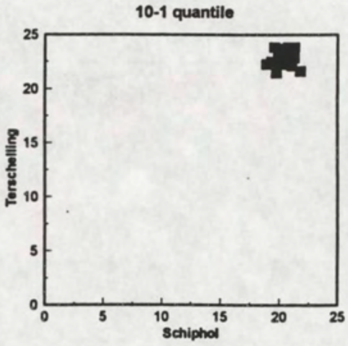

10-0 quantile
Schiphol
Eur
10-1 quantile
Schiphol
Eur
10-2 quantile
Schiphol
Eur
10-0 quantile
Terschelling
Eld
10-1 quantile
Terschelling
Eld
10-2 quantile
Terschelling
Eld
10-0 quantile
Terschelling
Son
10-1 quantile
Terschelling
Son
10-2 quantile
Terschelling
Son

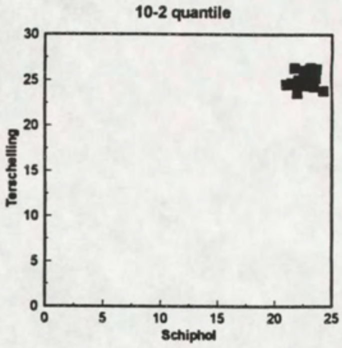


10-0 quantile
Hoek van Holland
Vlissingen
10-1 quantile
Hoek van Holland
Vlissingen
10-2 quantile
Hoek van Holland
Vlissingen
10-0 quantile
Delfzijl
Vlissingen
10-1 quantile
Delfzijl
Vlissingen
10-2 quantile
Delfzijl
Vlissingen
10-0 quantile
Delfzijl
Hoek van Holland
10-1 quantile
Delfzijl
Hoek van Holland
10-2 quantile
Delfzijl
Hoek van Holland


10-0 quantile
10-1 quantile
10-2 quantile
Eld
Eur
10-0 quantile
10-1 quantile
10-2 quantile
Son
Eur
10-0 quantile
10-1 quantile
10-2 quantile
Son
Eld


10-0 quantile
Terschelling
Schiphol


10-1 quantile
Terschelling
Schiphol


10-2 quantile
Terschelling
Schiphol

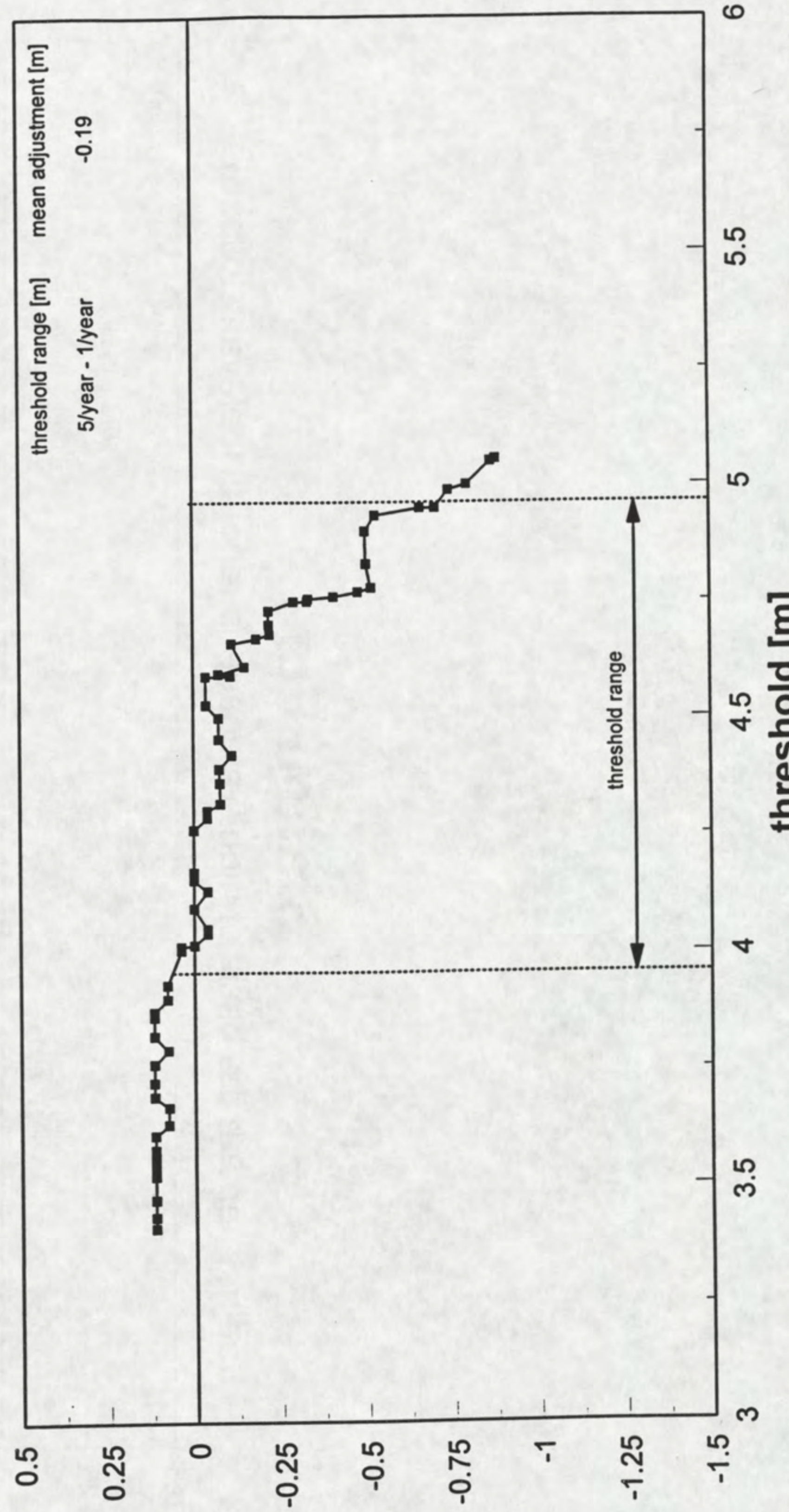
Annex D

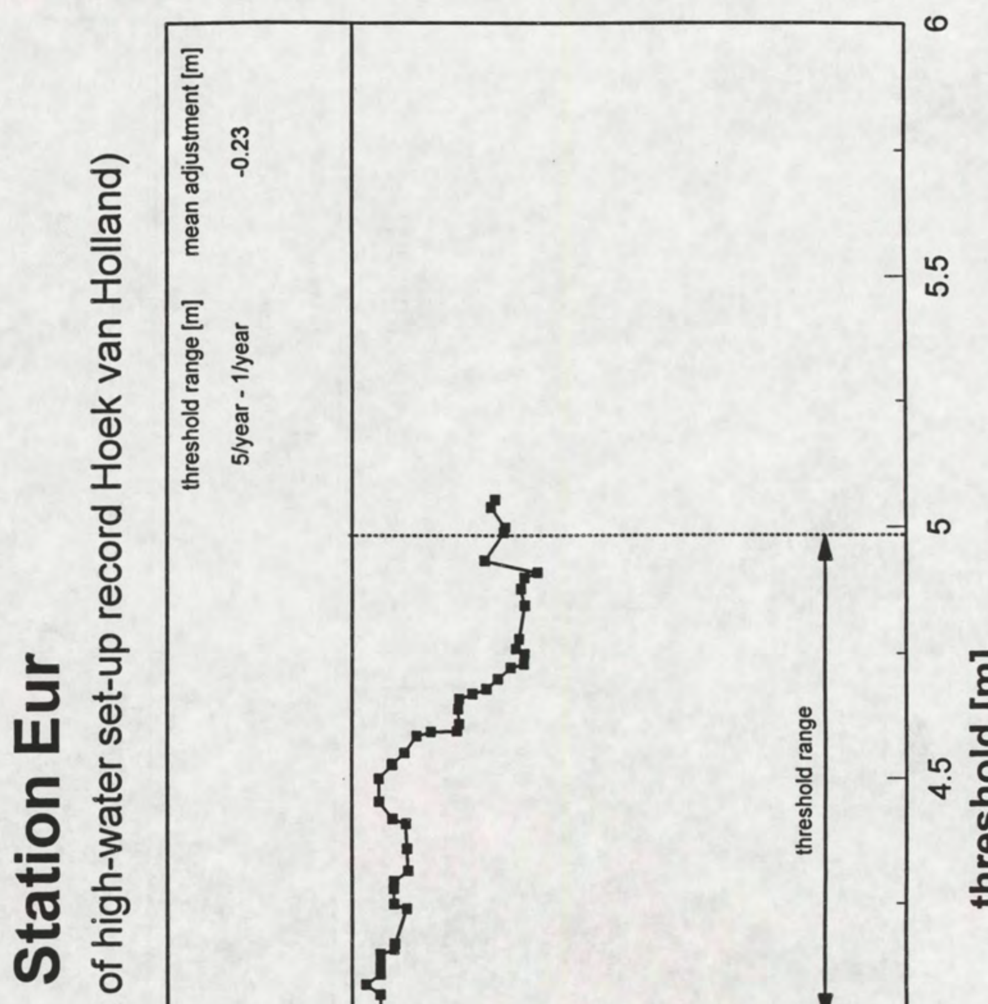
In this Annex, the result of the downscaling method is shown. It should be noticed that:

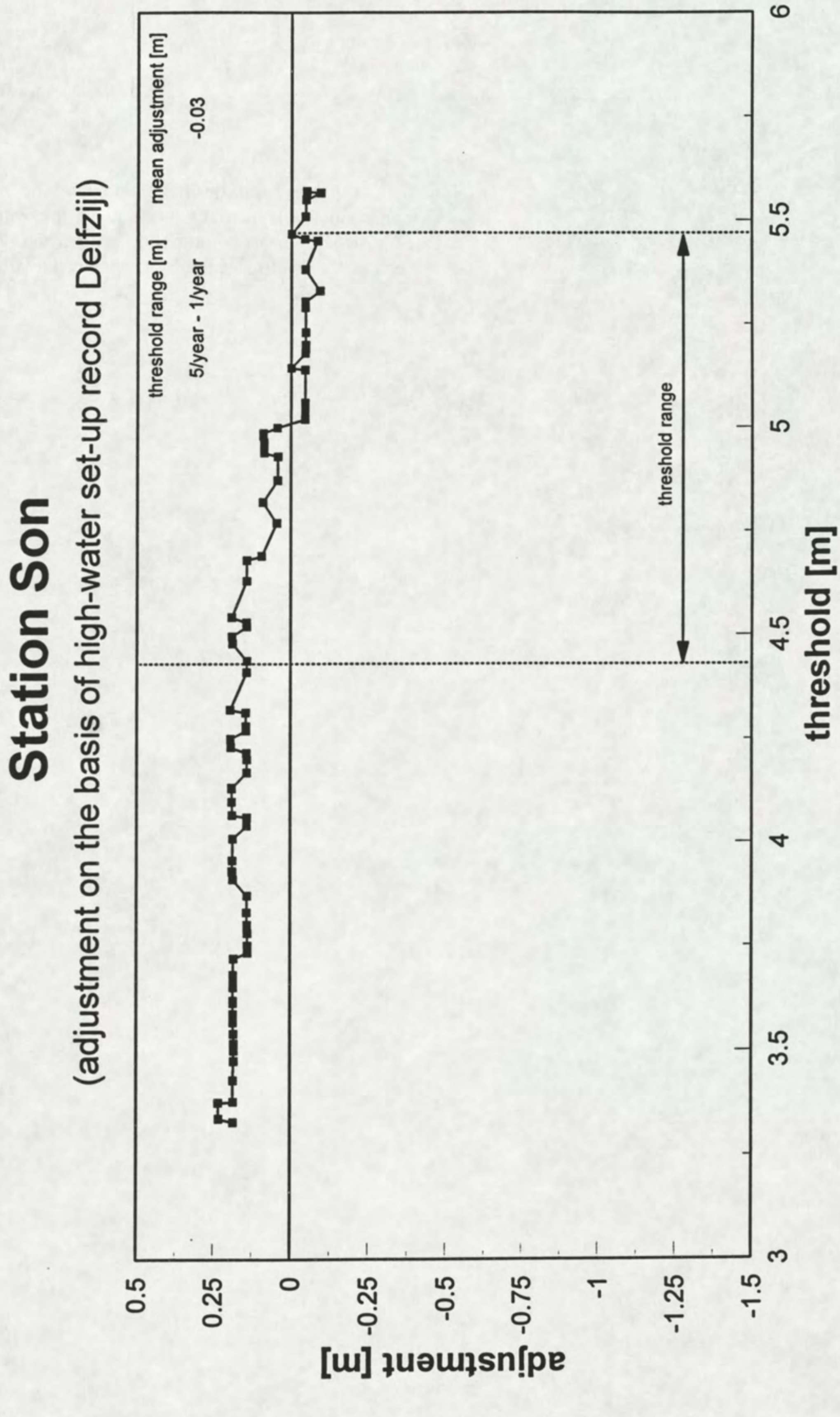
- a negative adjustment means that the short period was relatively smooth compared to the 'artificial' long period.
- a positive adjustment means that the short period was relatively rough compared to the 'artificial' long period.

Station Eur

(adjustment the basis of high-water set-up record Vlissingen)



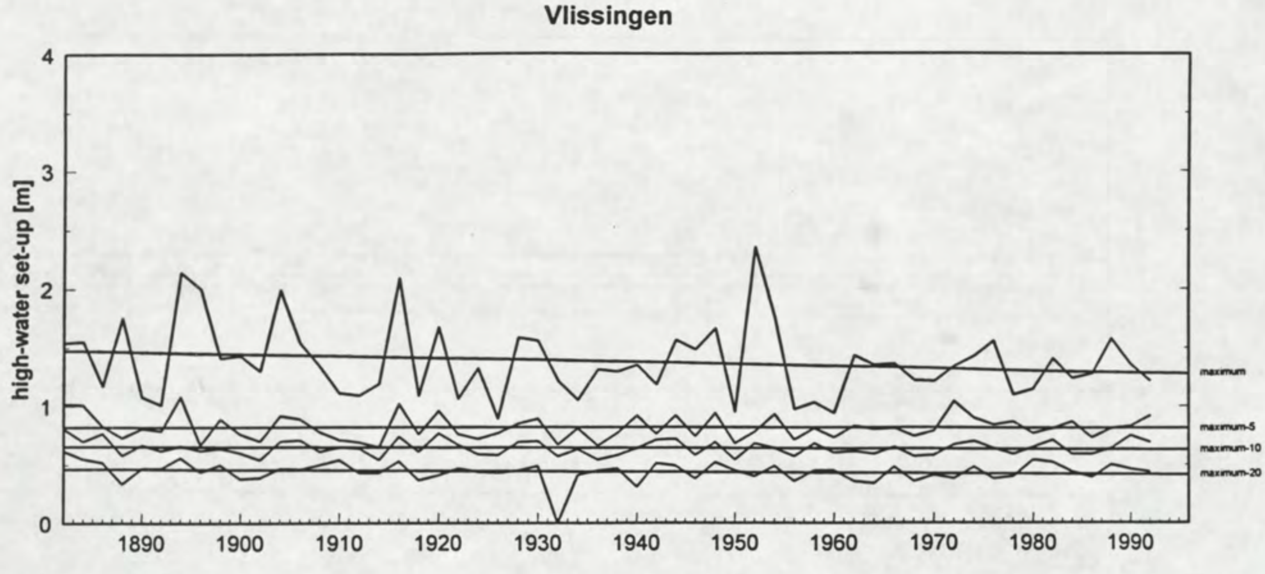

Station Eur
(adjustment on the basis of high-water set-up record Hoek van Holland)
threshold range [m]
5/year - 1/year
mean adjustment [m]
-0.23
threshold range
threshold [m]
adjustment [m]
0.5
0.25
0
-0.25
-0.5
-0.75
-1
-1.25
-1.5
3
3.5
4
4.5
5
5.5
6

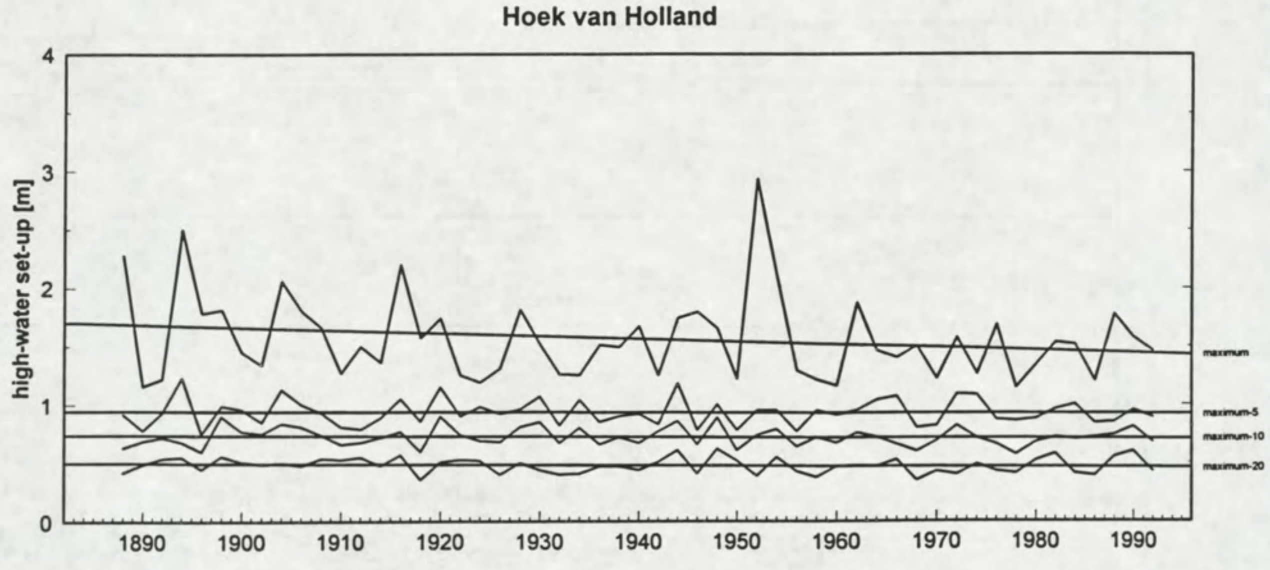

Station Son
(adjustment on the basis of high-water set-up record Delfzijl)
threshold range [m]
5/year - 1/year
mean adjustment [m]
-0.03
threshold range
adjustment [m]
0.5
0.25
0
-0.25
-0.5
-0.75
-1
-1.25
-1.5
threshold [m]
3
3.5
4
4.5
5
5.5
6

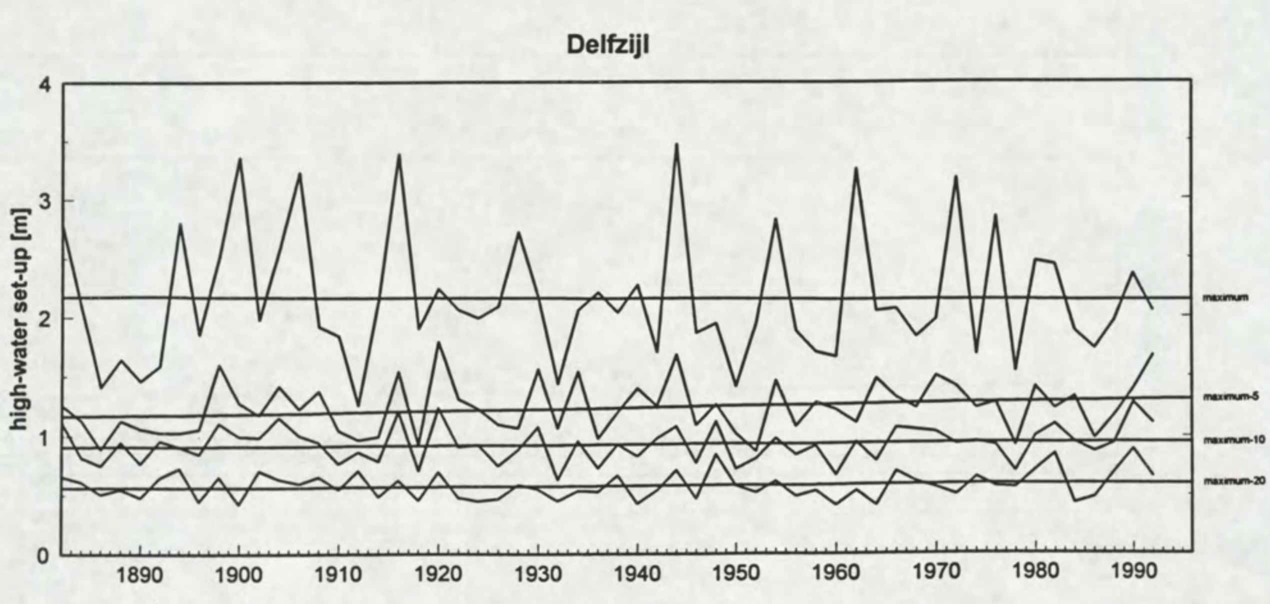
Annex E

In this Annex, the result of applying the maxima analysis method to the complete sea-level data-sets and to the wind data-sets of Terschelling and Mike is shown, in combination with trend lines which have been calculated for each individual curve by means of linear regression.

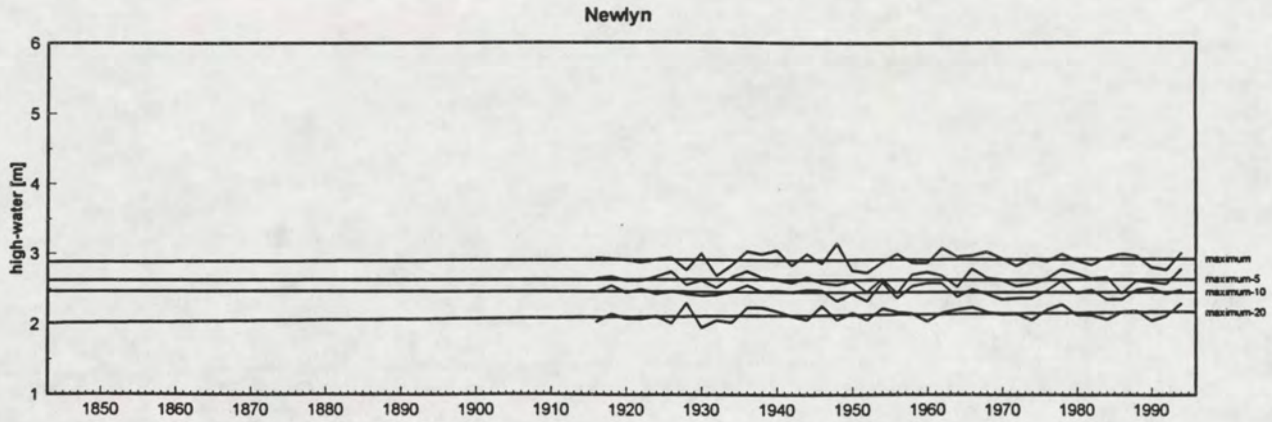
High-water set-up data

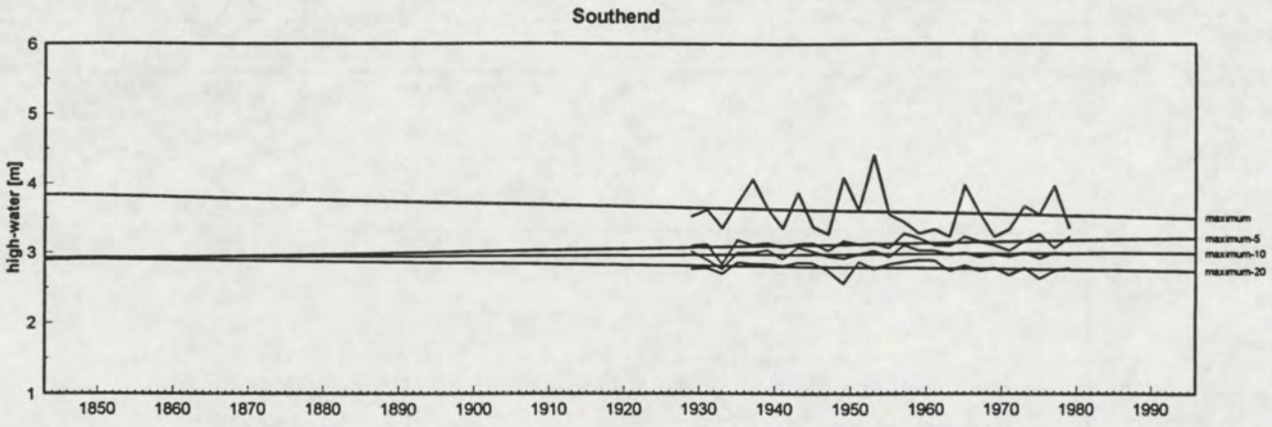


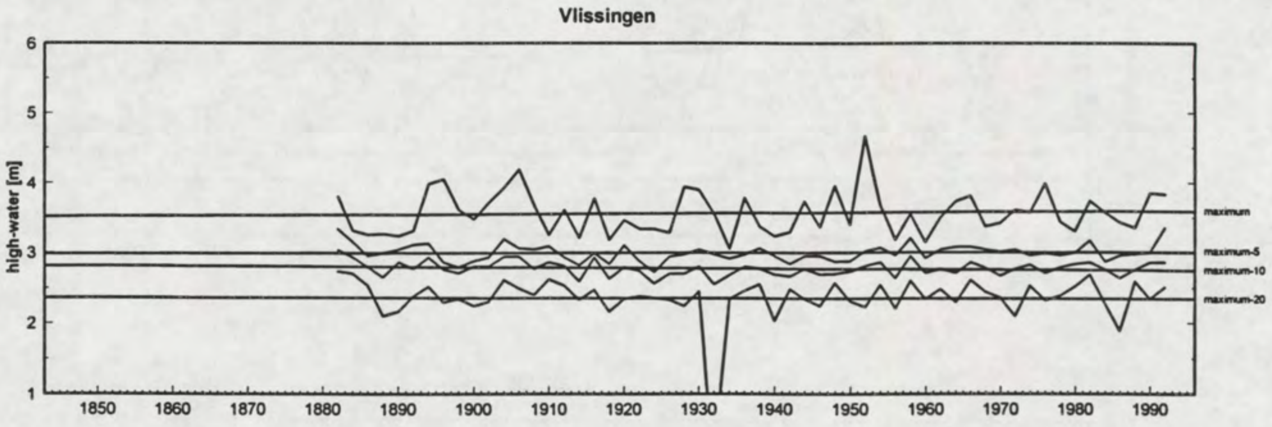


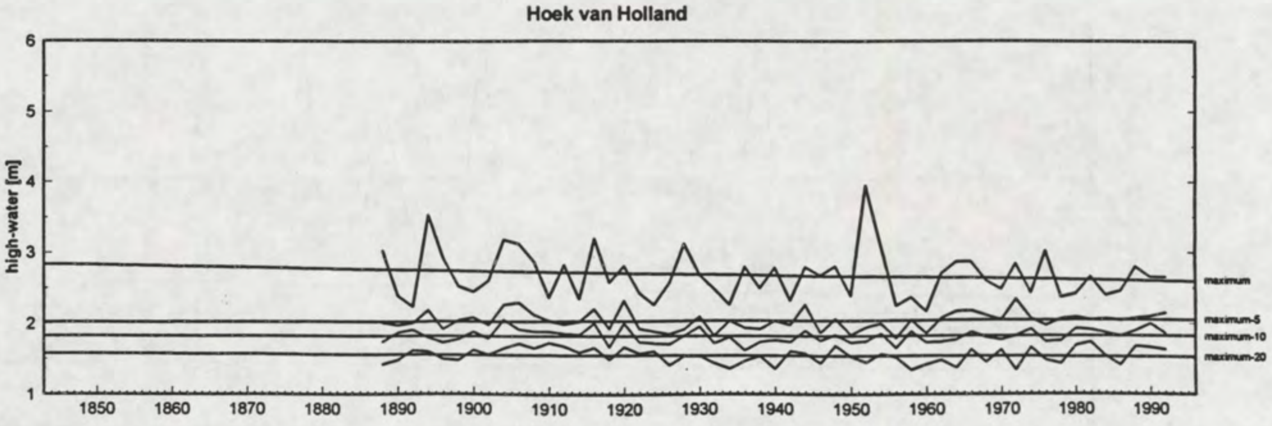


High-water data

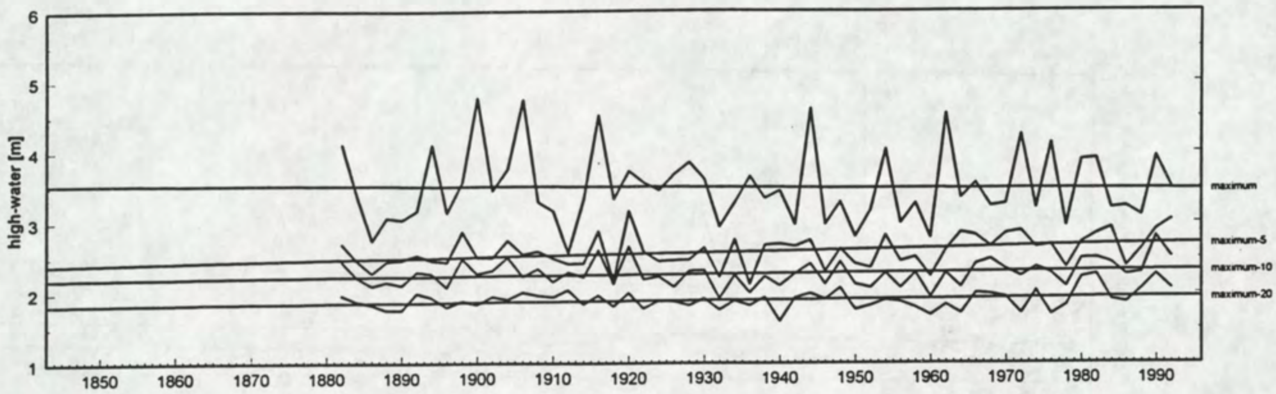




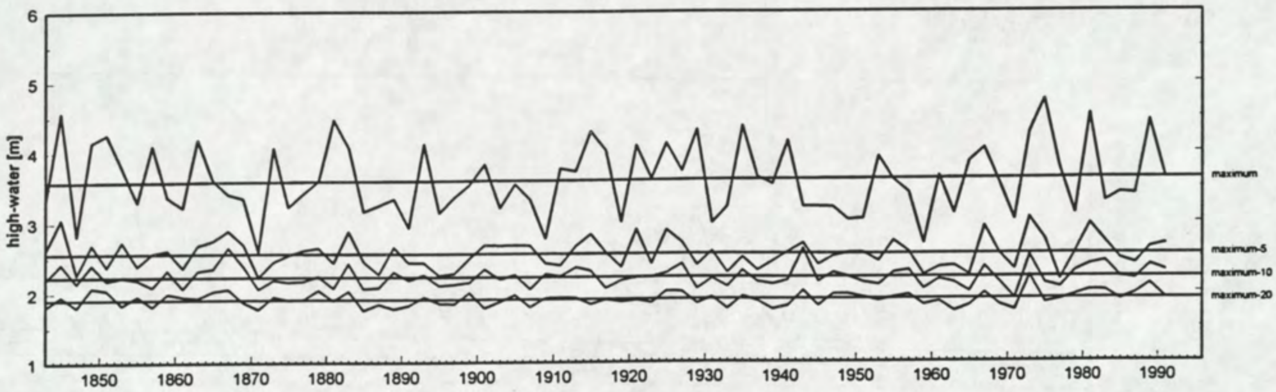




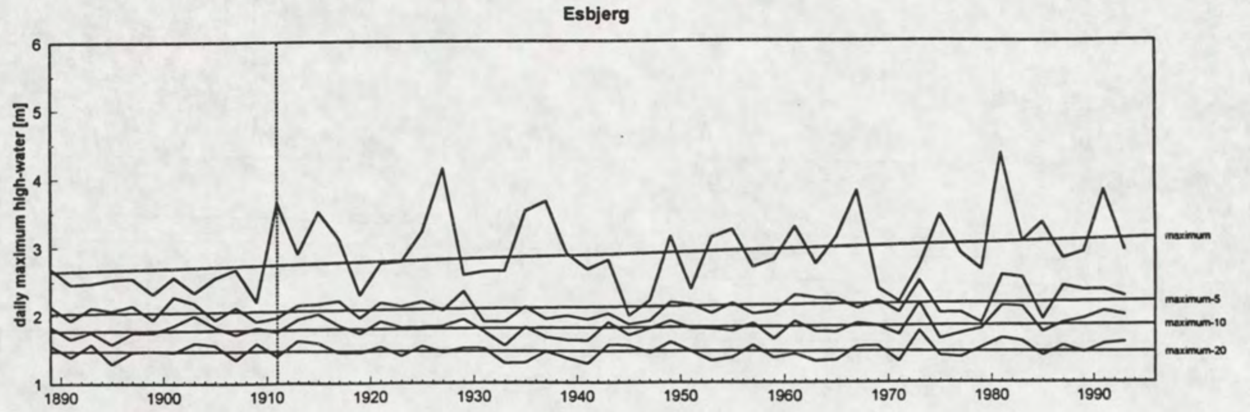
Delfzijl

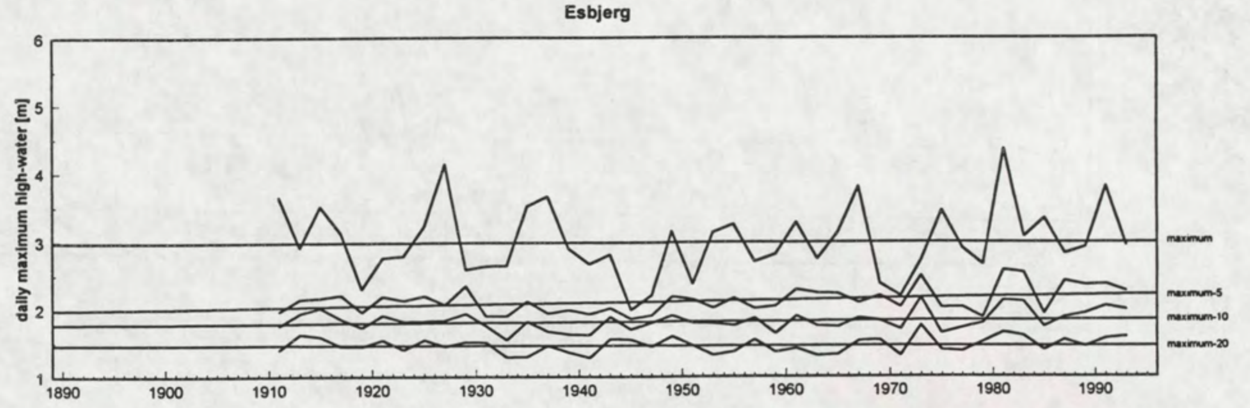


Cuxhaven

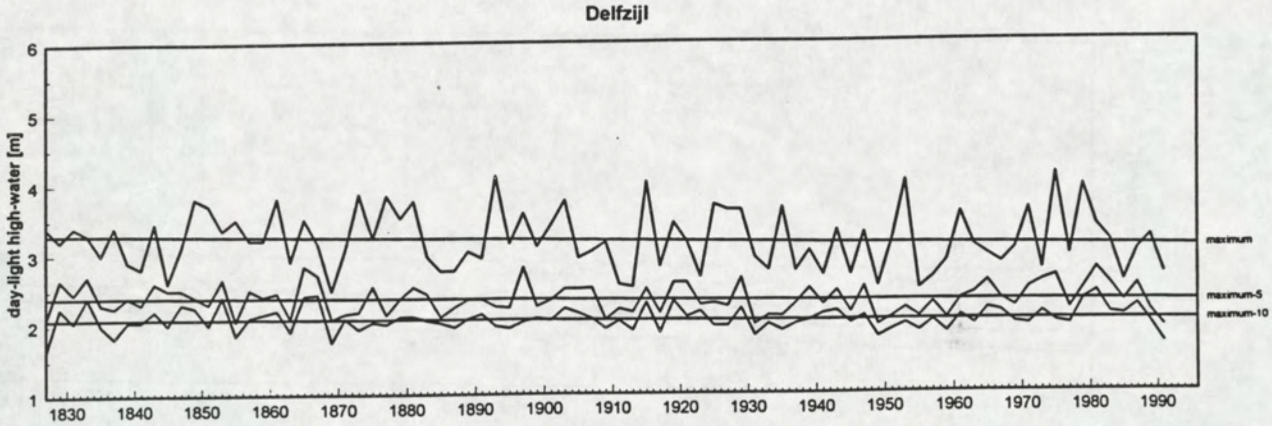


Daily maximum high-water data



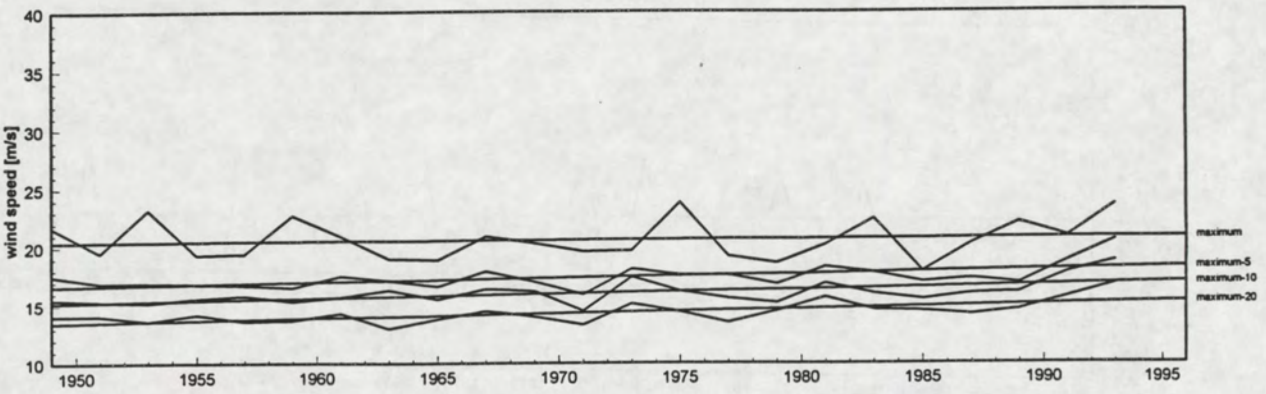


Day-light high-water data

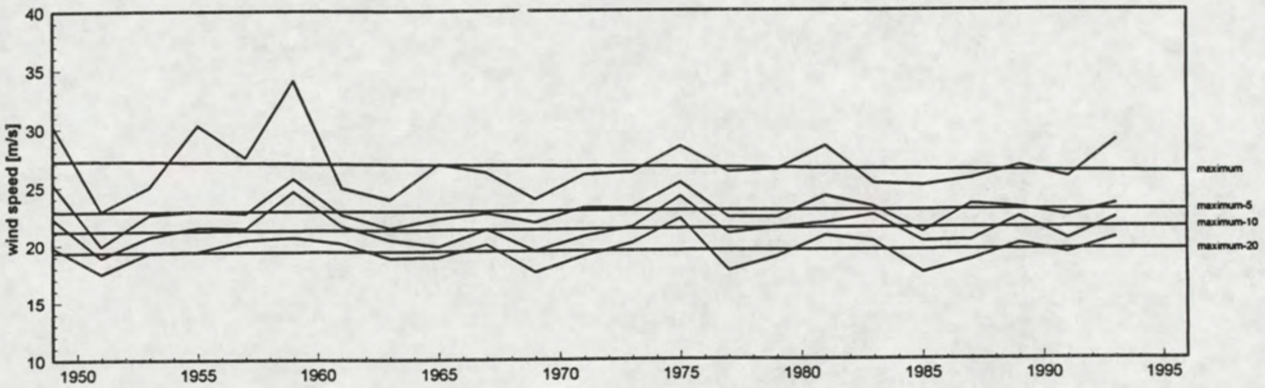


Wind data

Terschelling



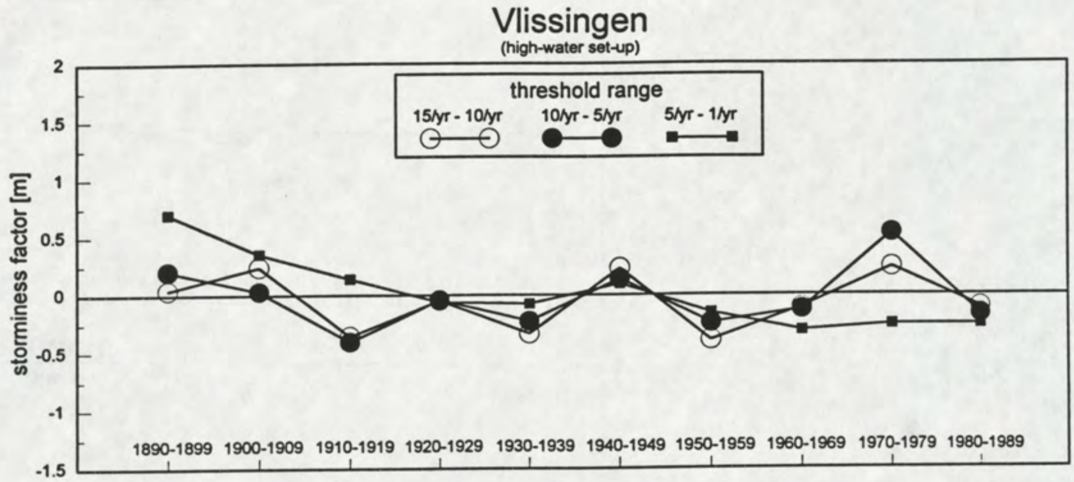
Mike

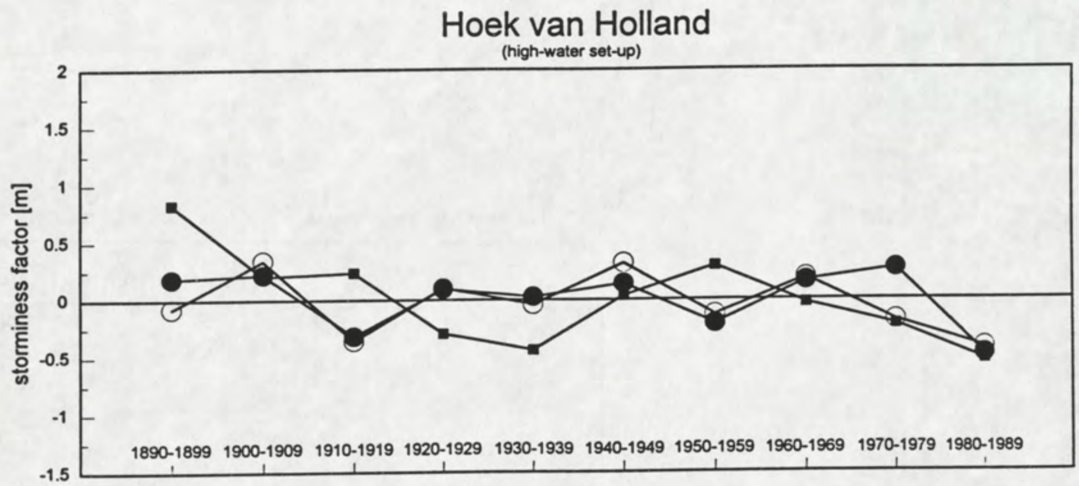


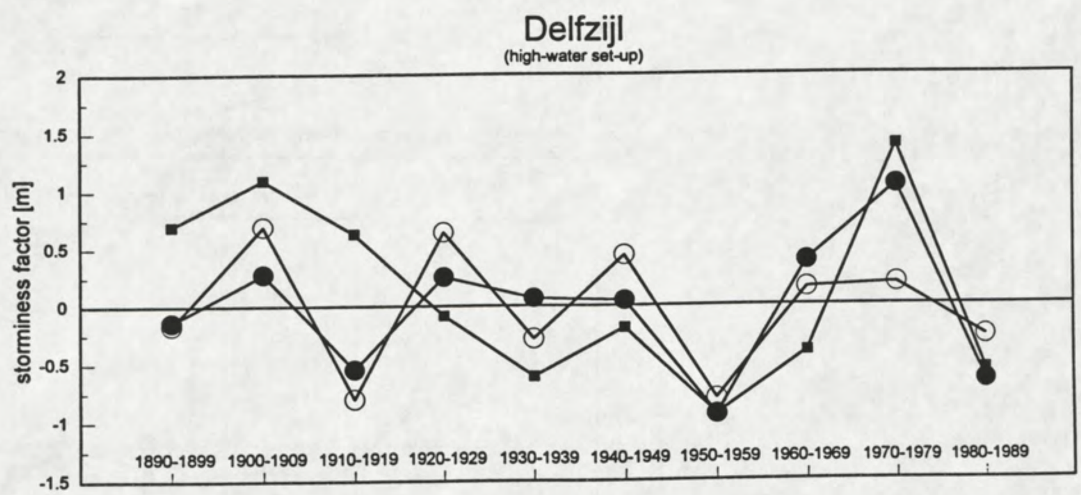
Annex F, part 1

In this Annex, the result of applying the quantile analysis method to the complete sea-level data-sets and to the wind data-sets of Terschelling and Mike is shown.

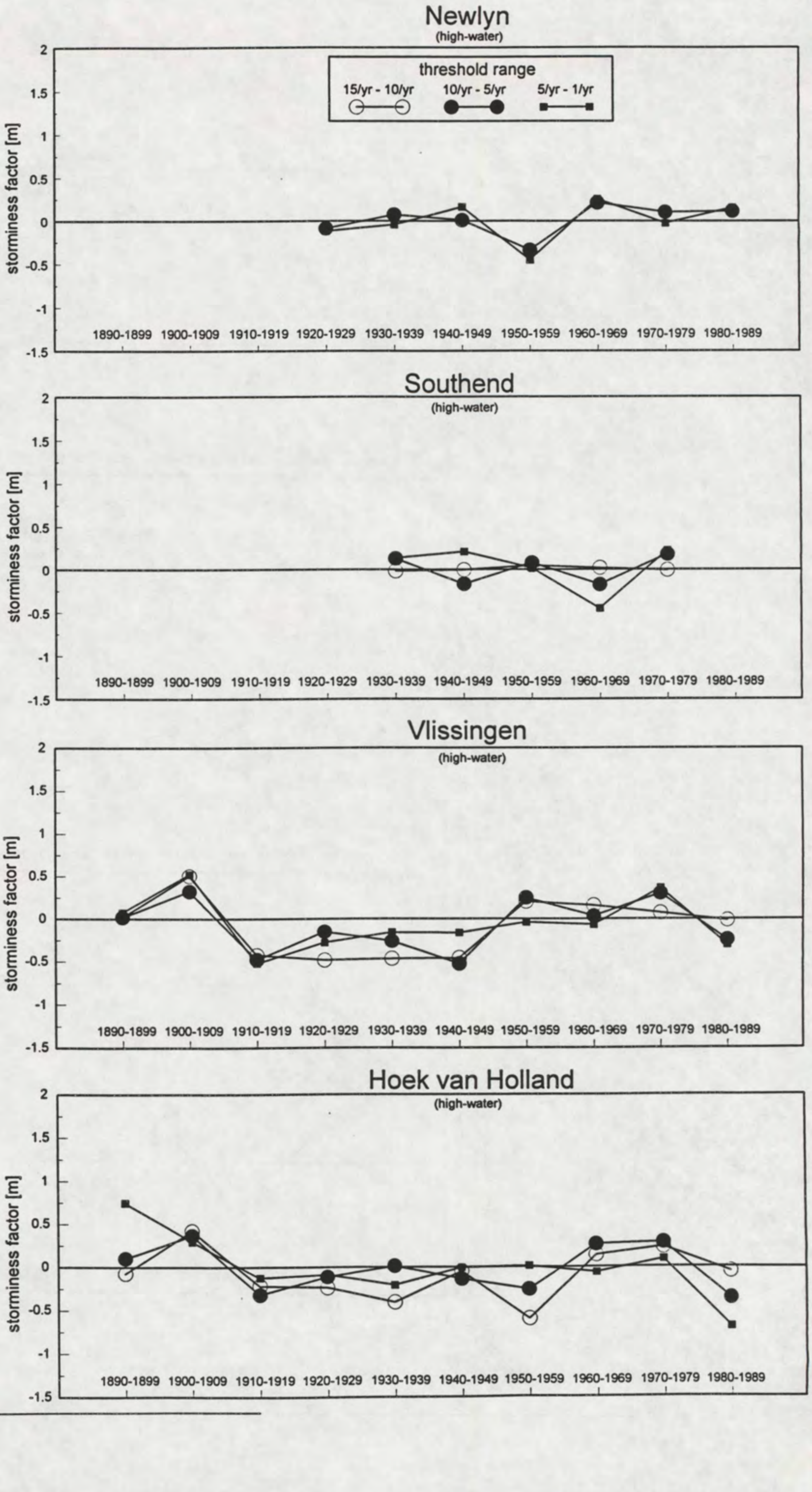
High-water set-up data

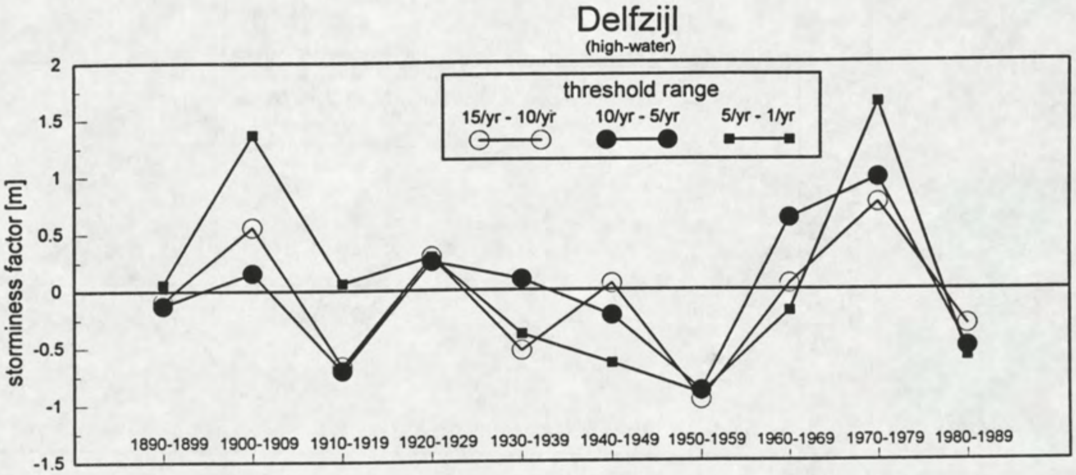


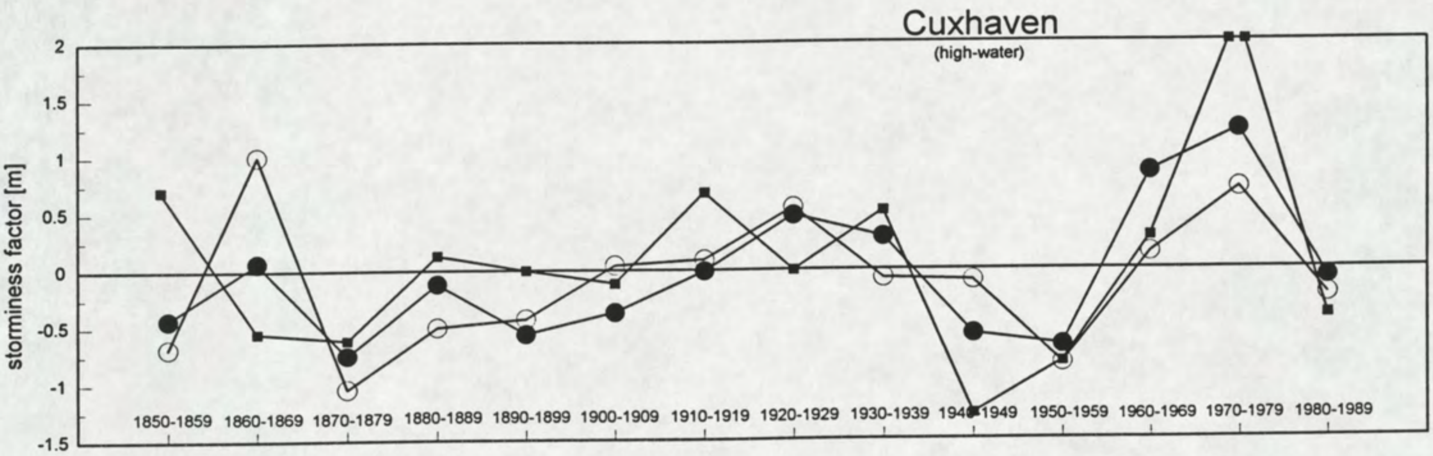




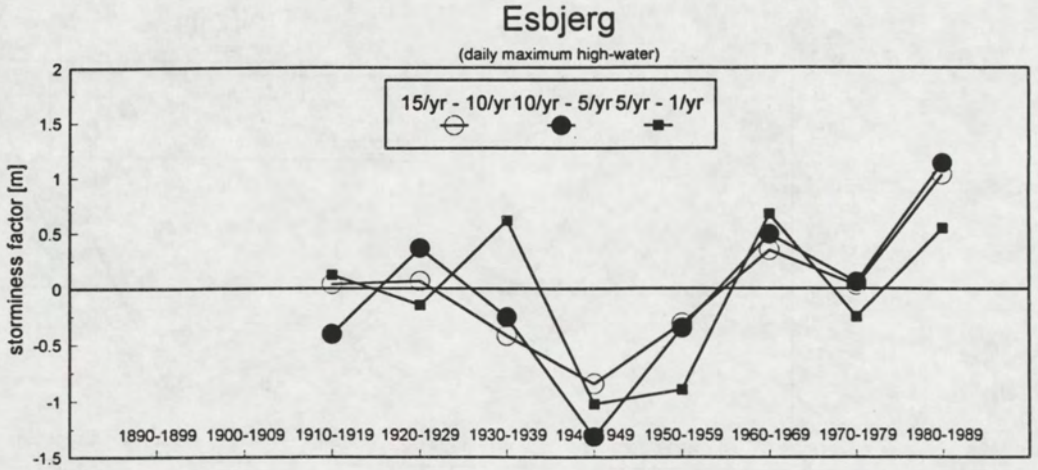
High-water data



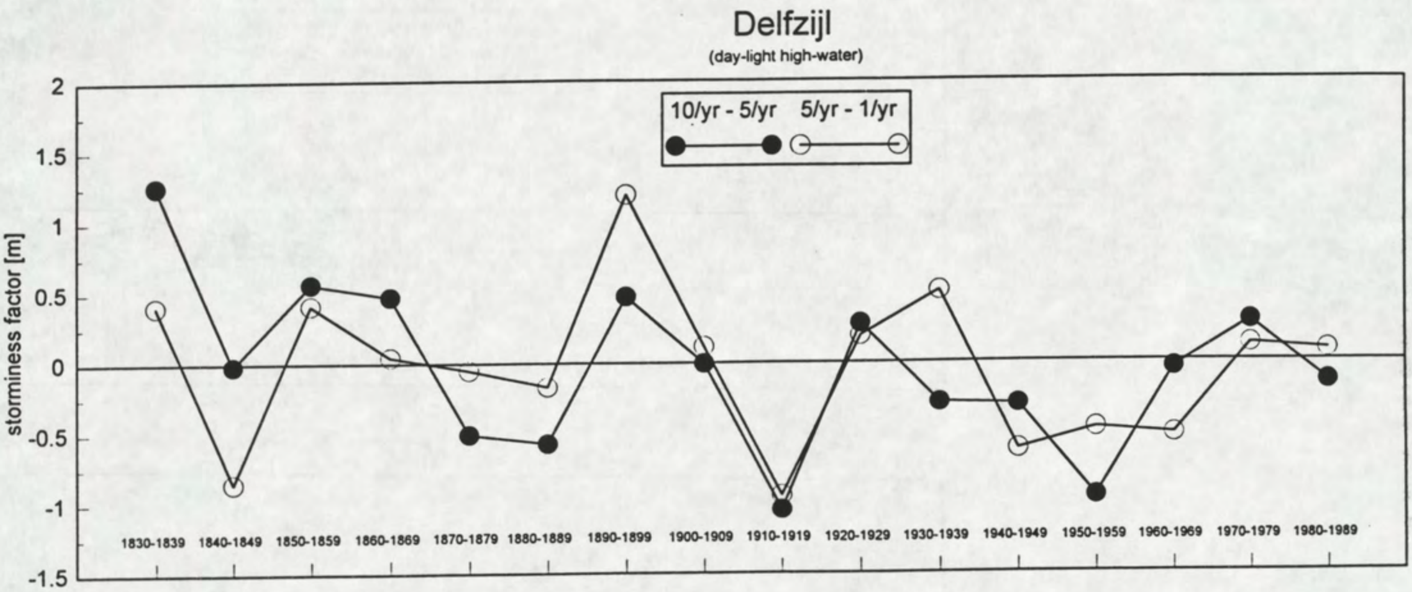

Delfzijl
(high-water)
threshold range
15/yr - 10/yr
10/yr - 5/yr
5/yr - 1/yr
storminess factor [m]
2
1.5
1
0.5
0
-0.5
-1
-1.5
1890-1899
1900-1909
1910-1919
1920-1929
1930-1939
1940-1949
1950-1959
1960-1969
1970-1979
1980-1989


Cuxhaven
(high-water)
storminess factor [m]
2
1.5
1
0.5
0
-0.5
-1
-1.5
1850-1859
1860-1869
1870-1879
1880-1889
1890-1899
1900-1909
1910-1919
1920-1929
1930-1939
1940-1949
1950-1959
1960-1969
1970-1979
1980-1989

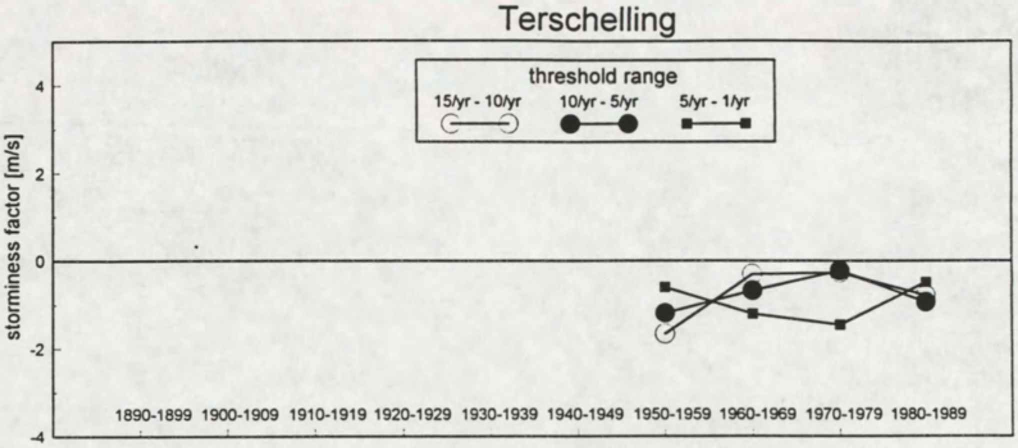
Daily maximum high-water data

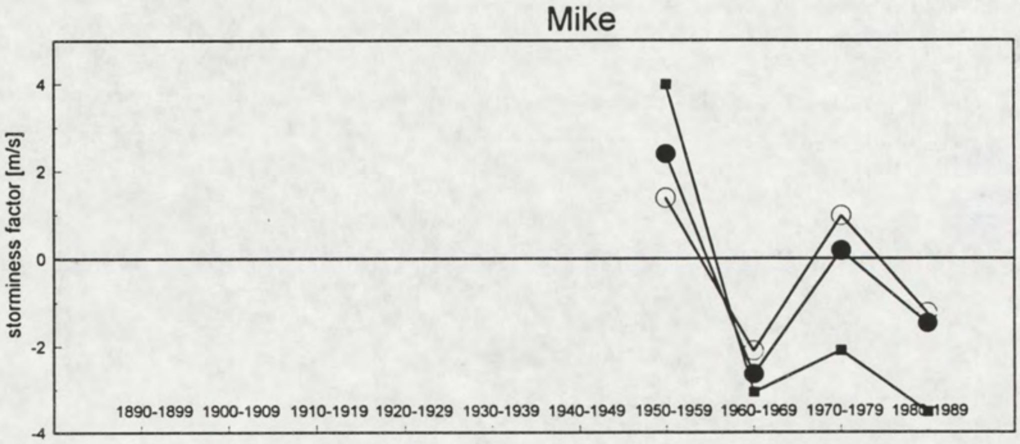


Day-light high-water data



Wind data

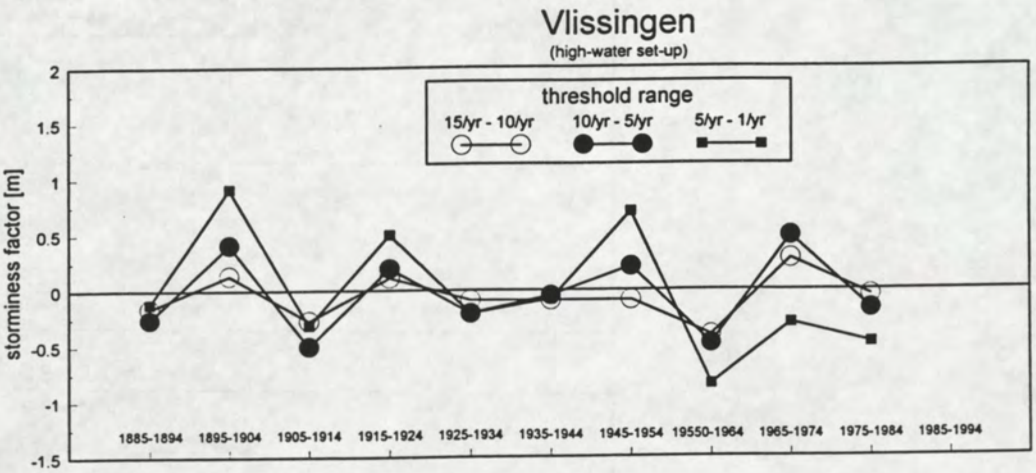

Terschelling
threshold range
15/yr - 10/yr
10/yr - 5/yr
5/yr - 1/yr
storminess factor [m/s]
4
2
0
-2
-4
1890-1899
1900-1909
1910-1919
1920-1929
1930-1939
1940-1949
1950-1959
1960-1969
1970-1979
1980-1989

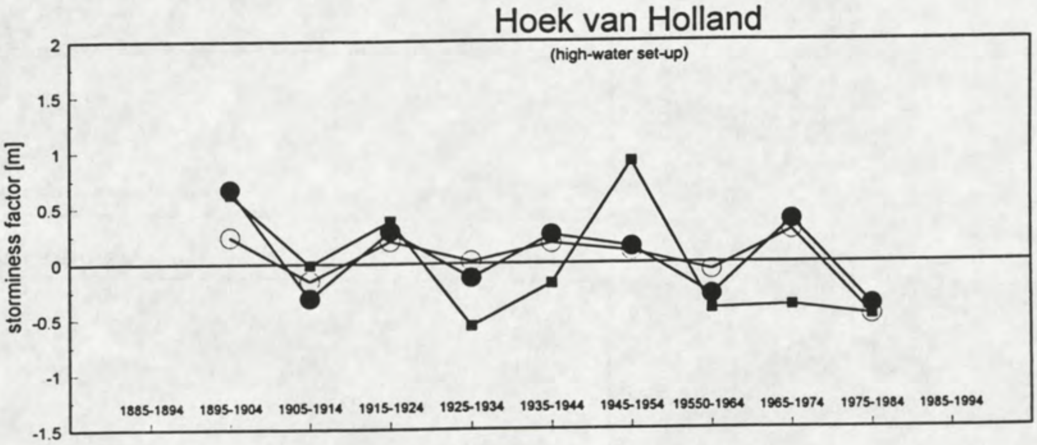

Mike
storminess factor [m/s]
4
2
0
-2
-4
1890-1899
1900-1909
1910-1919
1920-1929
1930-1939
1940-1949
1950-1959
1960-1969
1970-1979
1980-1989

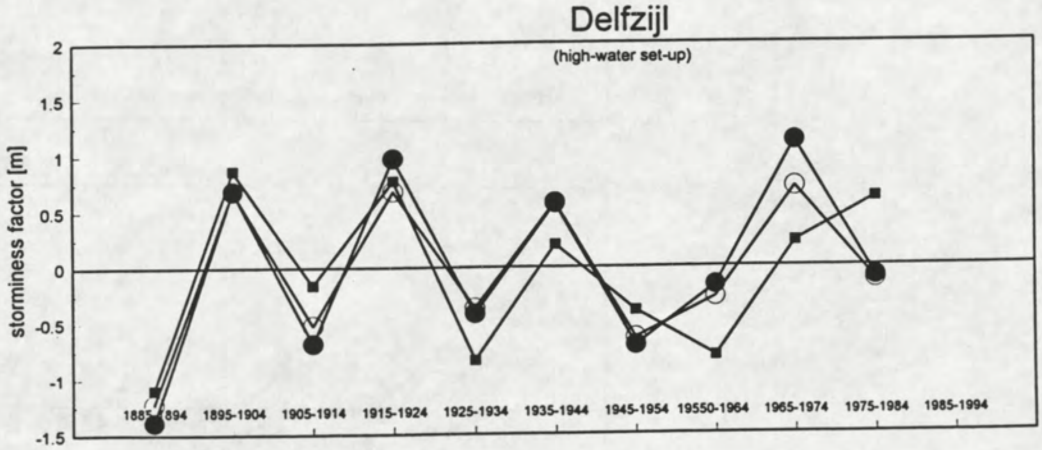
Annex F, part 2

In this Annex, the result of applying the time-shift variant of the quantile analysis method to the complete sea-level data-sets and to the wind data-sets of Terschelling and Mike is shown.

High-water set-up data



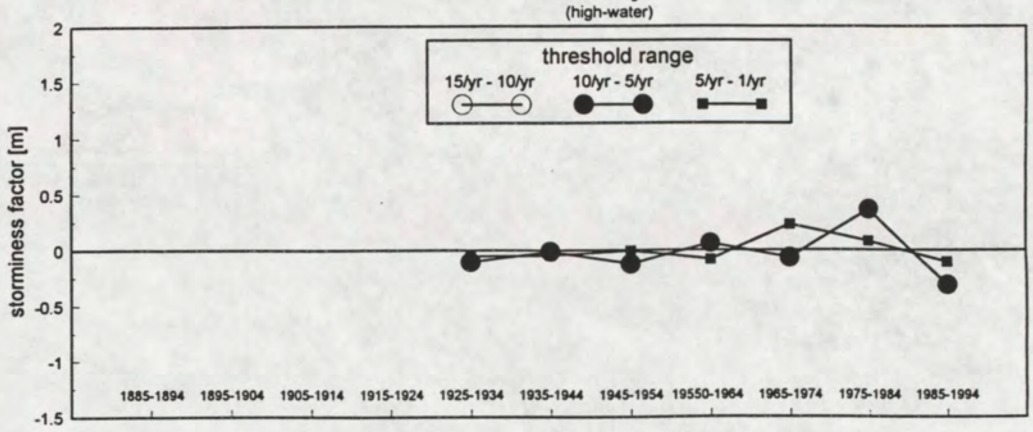




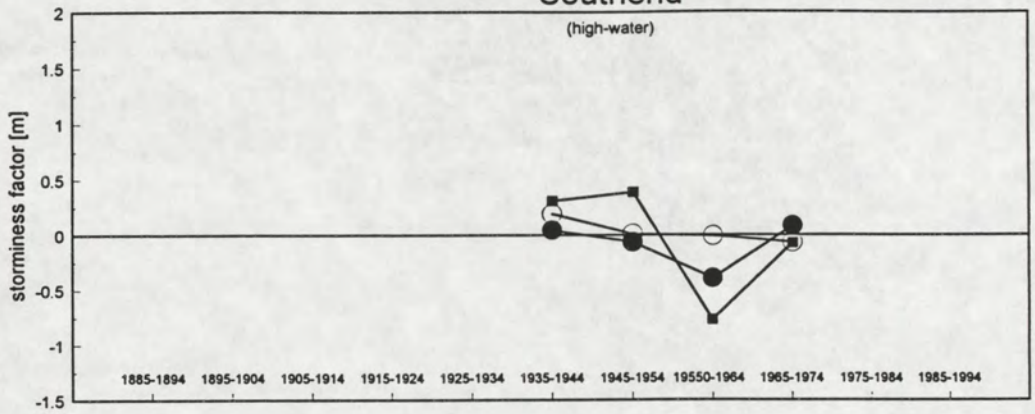
High-water data

Newlyn

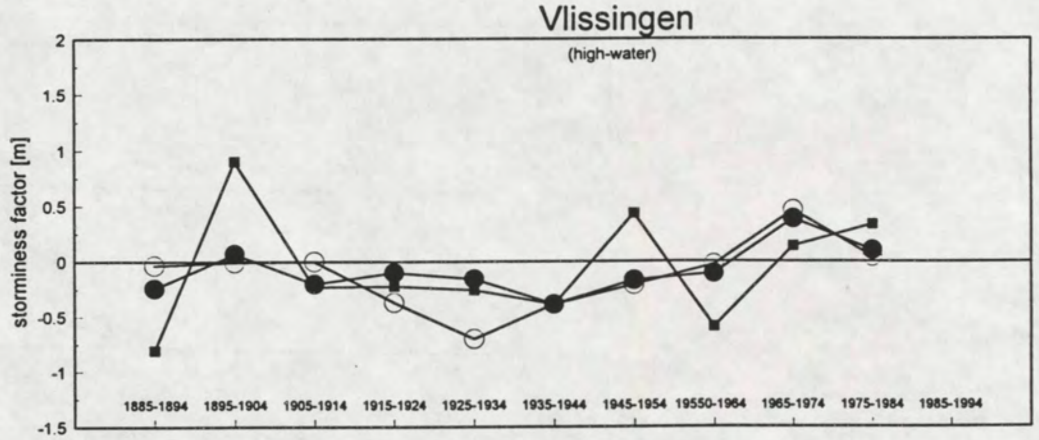
(high-water)



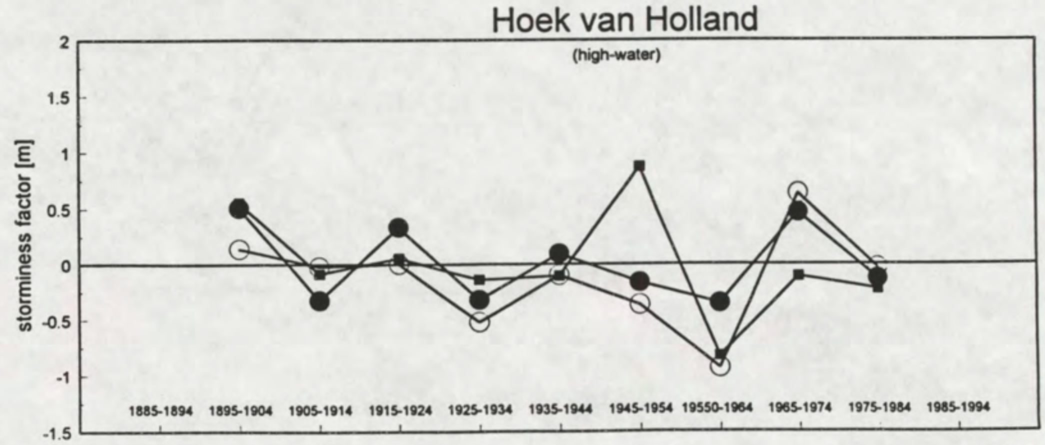
Southend

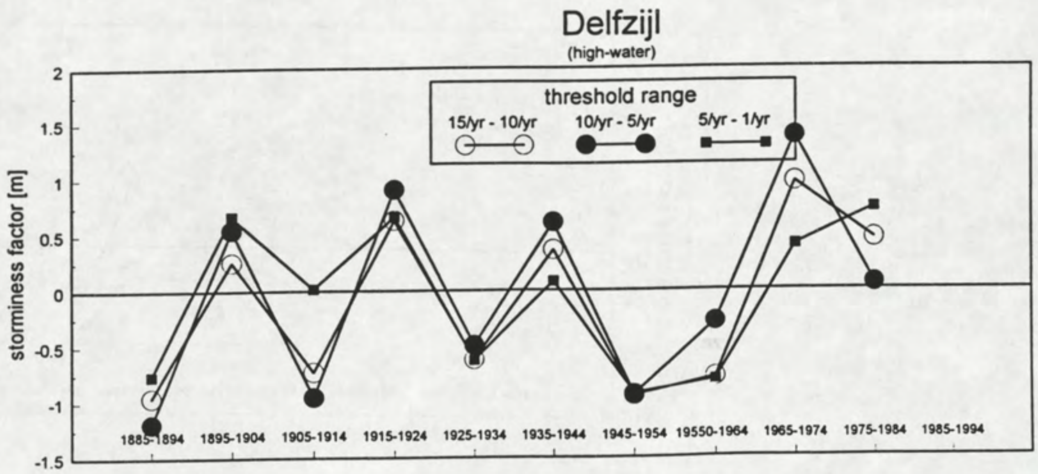


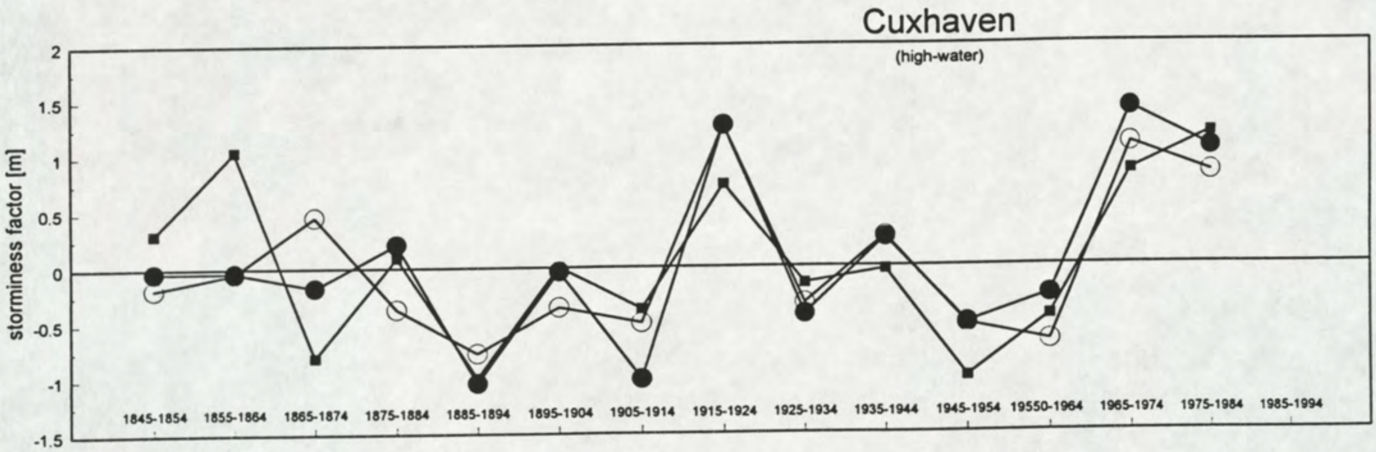
Vlissingen



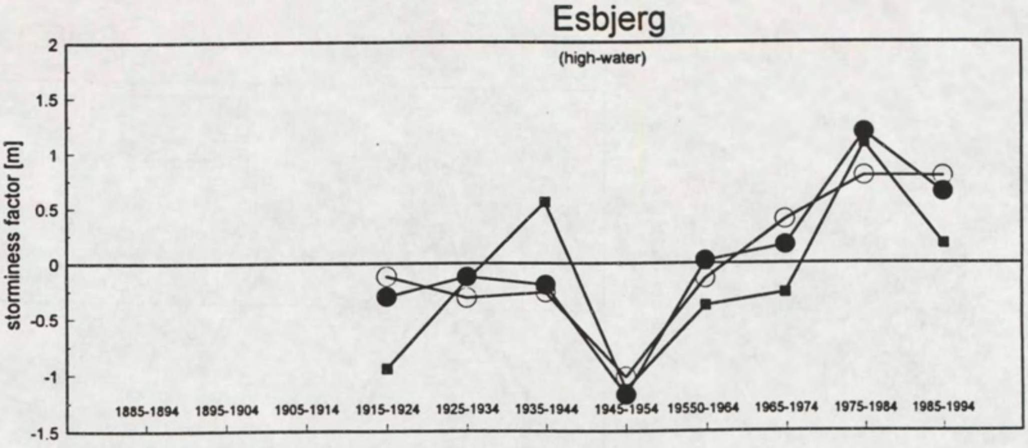
Hoek van Holland



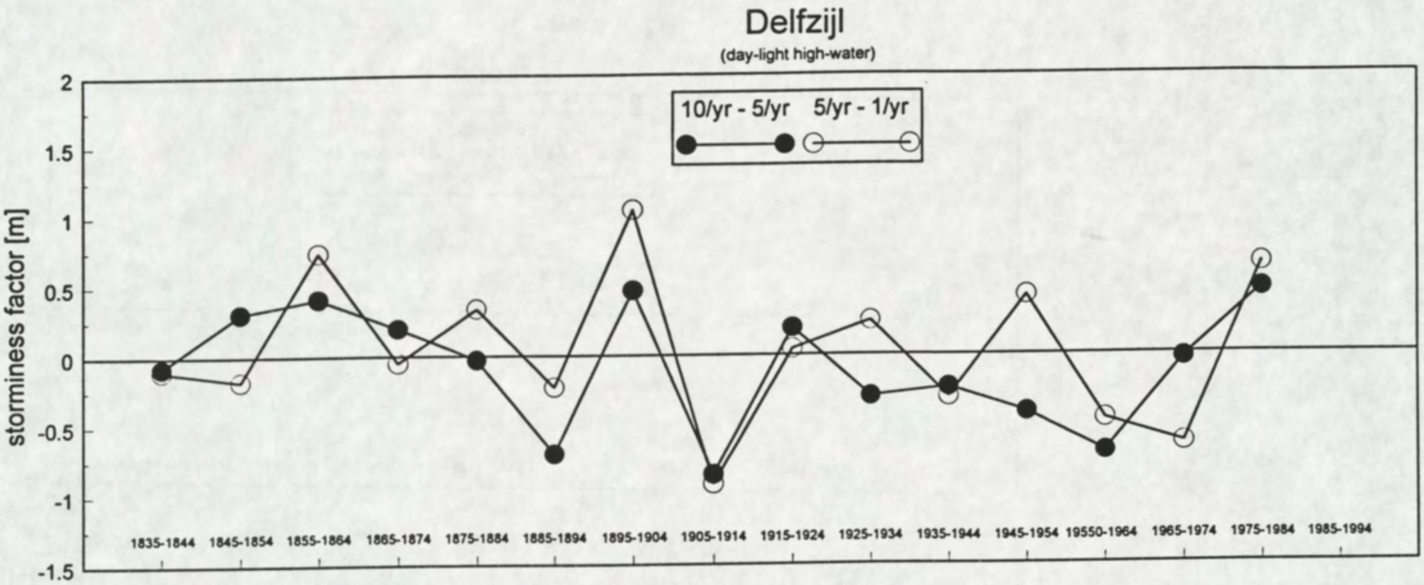

Delfzijl
(high-water)
threshold range
15/yr - 10/yr
10/yr - 5/yr
5/yr - 1/yr
storminess factor [m]
2
1.5
1
0.5
0
-0.5
-1
-1.5
1885-1894
1895-1904
1905-1914
1915-1924
1925-1934
1935-1944
1945-1954
19550-1964
1965-1974
1975-1984
1985-1994


Cuxhaven
(high-water)
storminess factor [m]
2
1.5
1
0.5
0
-0.5
-1
-1.5
1845-1854
1855-1864
1865-1874
1875-1884
1885-1894
1895-1904
1905-1914
1915-1924
1925-1934
1935-1944
1945-1954
19550-1964
1965-1974
1975-1984
1985-1994

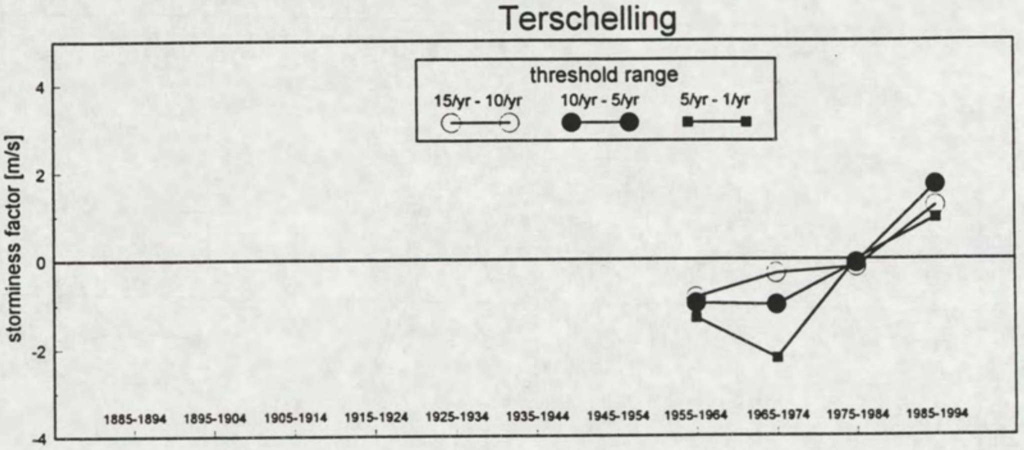
Daily maximum hig-water data

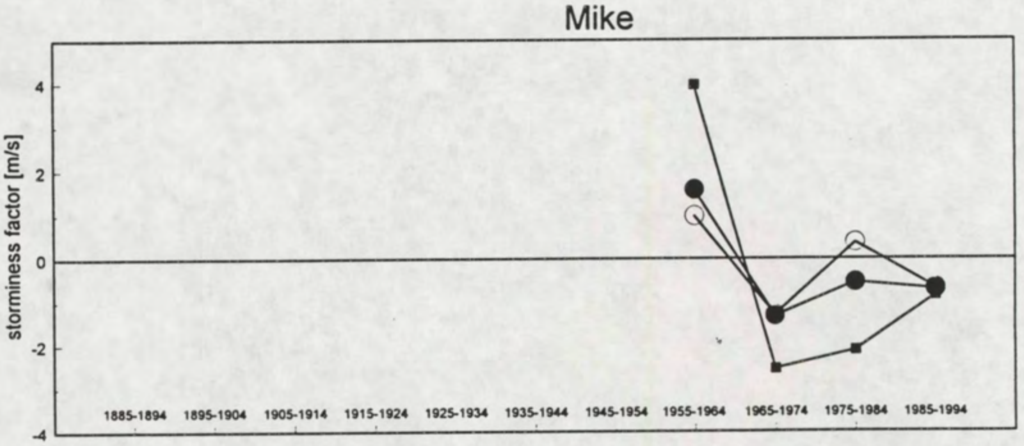


Day-light high-water data



Wind data

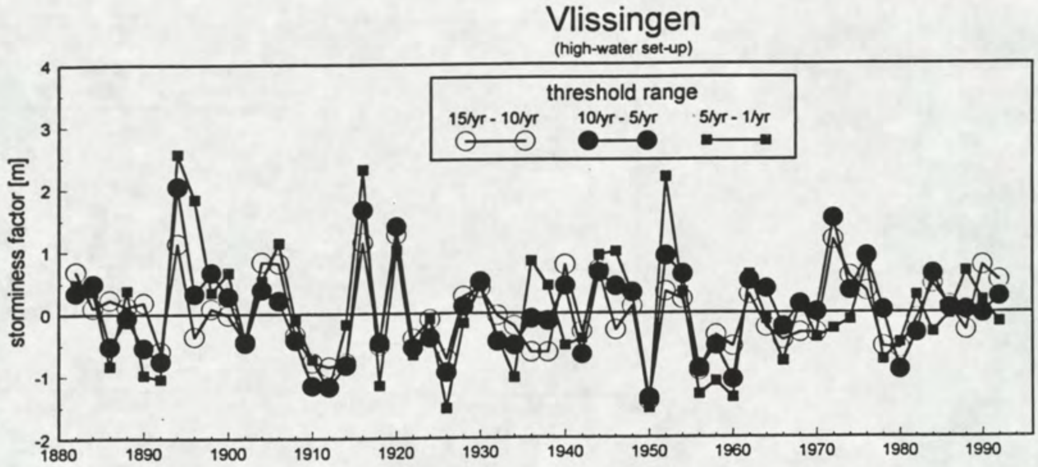

Terschelling
threshold range
15/yr - 10/yr
10/yr - 5/yr
5/yr - 1/yr
storminess factor [m/s]
1885-1894
1895-1904
1905-1914
1915-1924
1925-1934
1935-1944
1945-1954
1955-1964
1965-1974
1975-1984
1985-1994

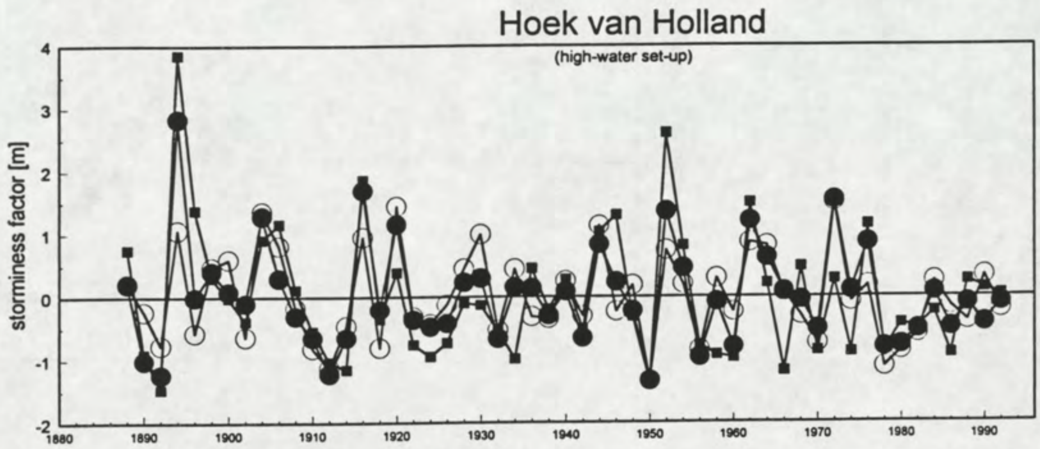

Mike
storminess factor [m/s]
1885-1894
1895-1904
1905-1914
1915-1924
1925-1934
1935-1944
1945-1954
1955-1964
1965-1974
1975-1984
1985-1994

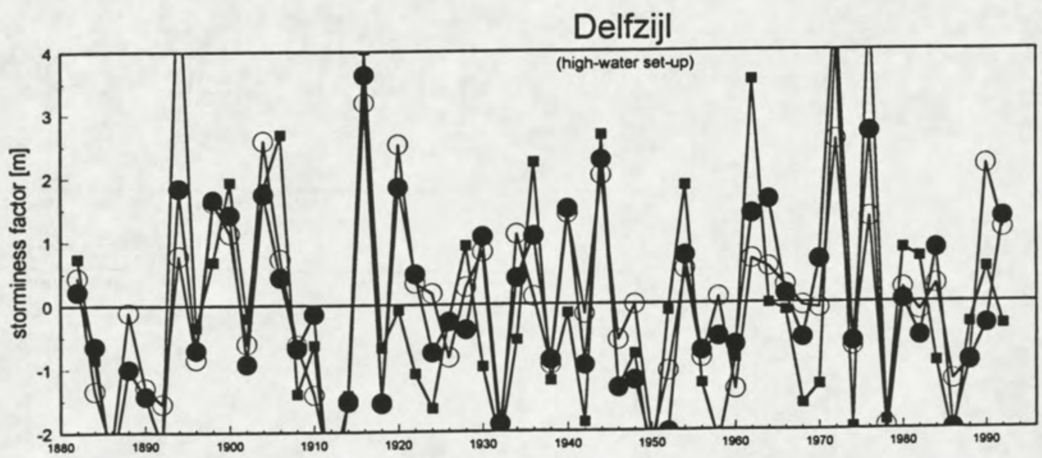
Annex F, part 3

In this Annex, the result of applying the 2-yearly variant of the quantile analysis method to the complete sea-level data-sets and to the wind data-sets of Terschelling and Mike is shown.

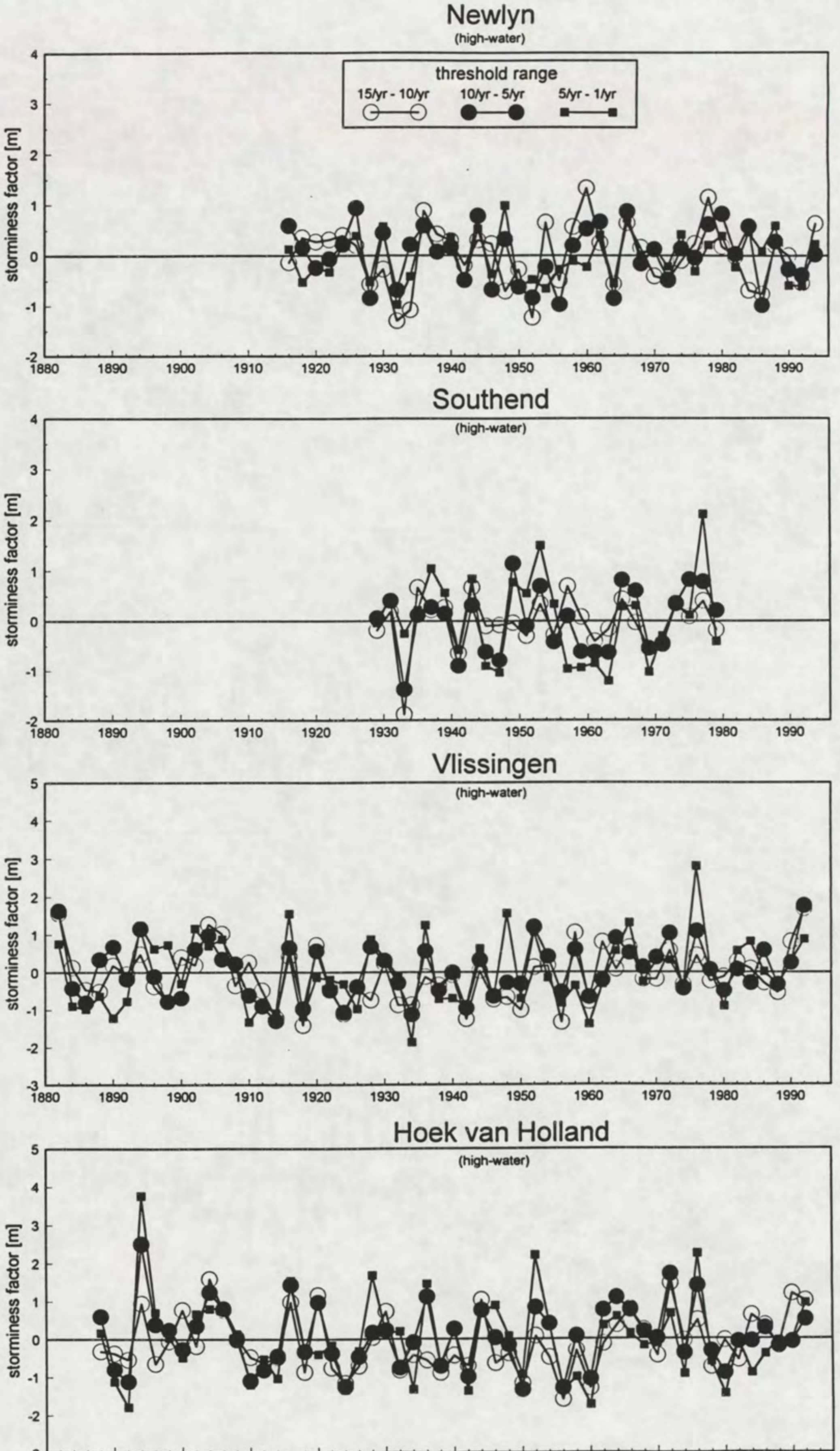
High-water set-up data

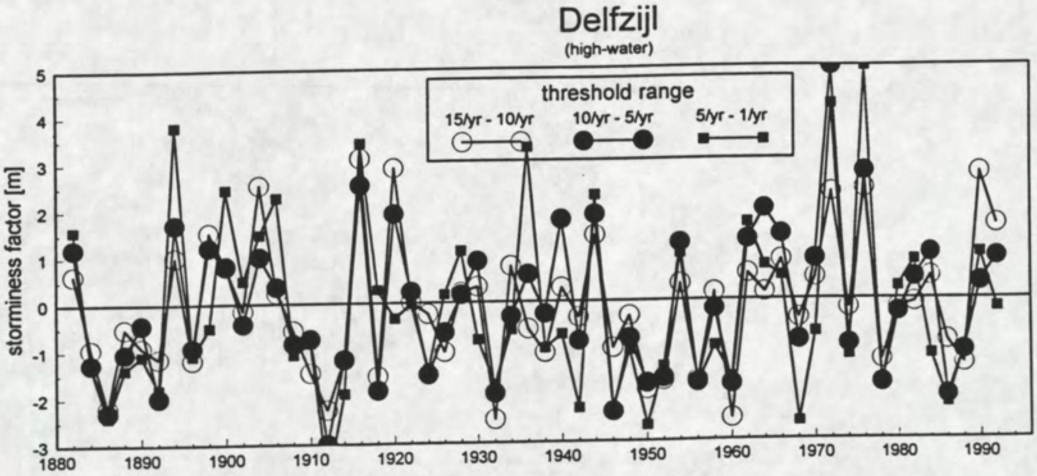


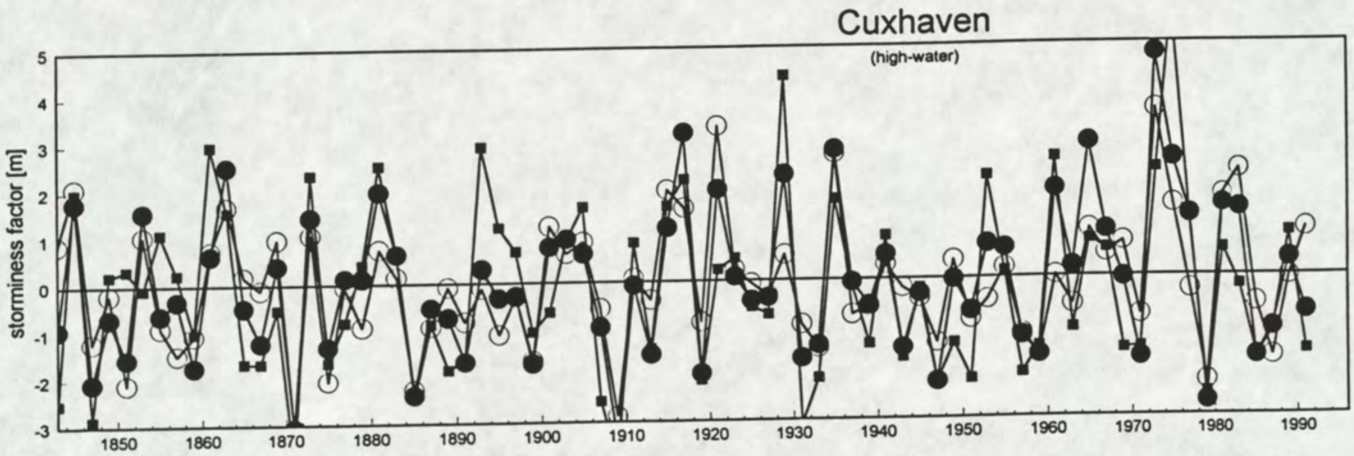




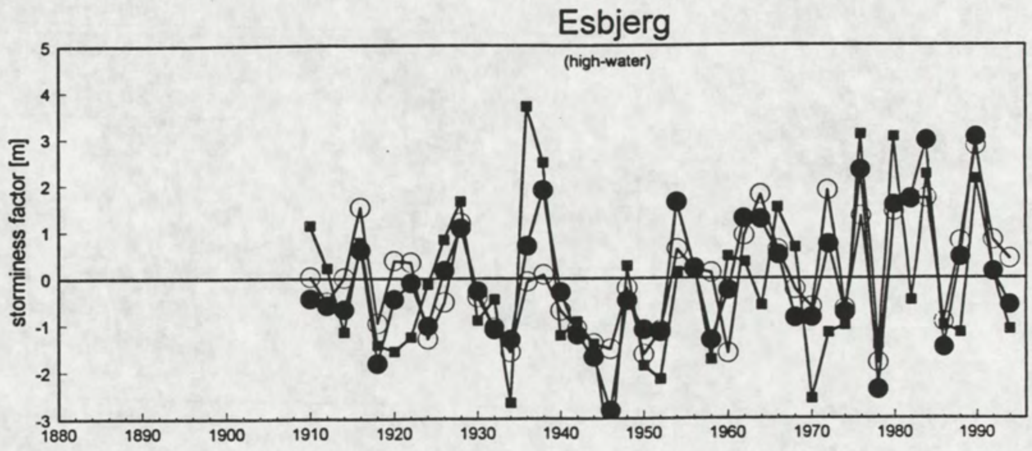
High-water data



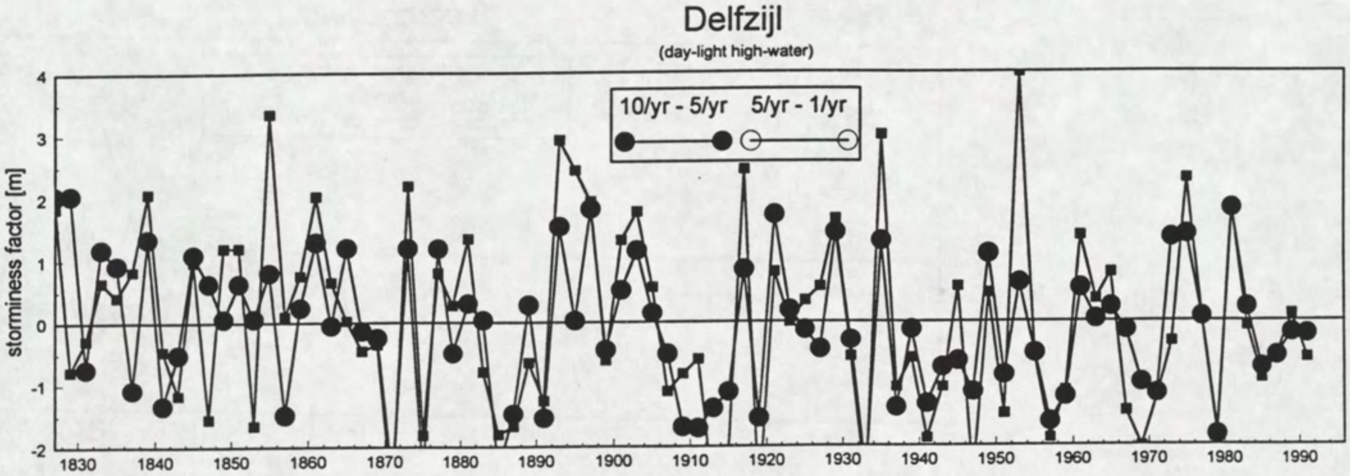

Delfzijl
(high-water)
threshold range
15/yr - 10/yr
10/yr - 5/yr
5/yr - 1/yr
storminess factor [m]
5
4
3
2
1
0
-1
-2
-3
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990


Cuxhaven
(high-water)
storminess factor [m]
5
4
3
2
1
0
-1
-2
-3
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990

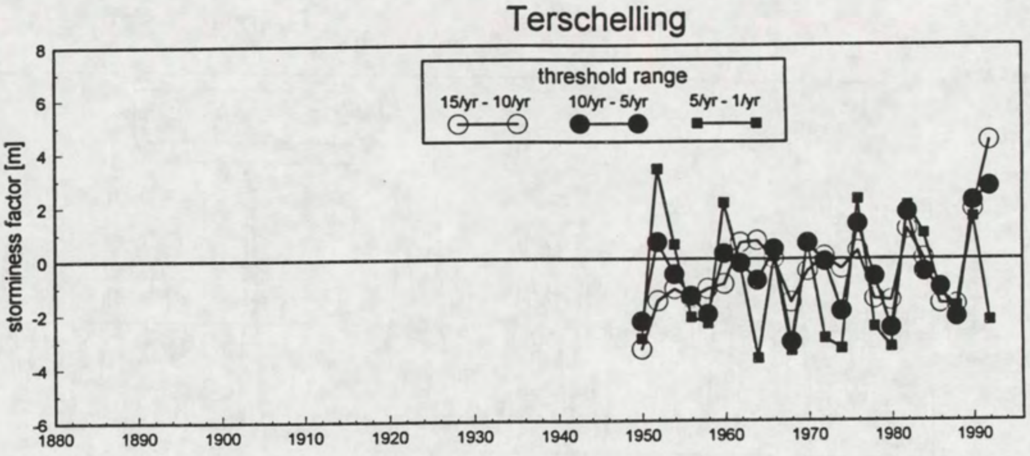
Daily maximum high-water data

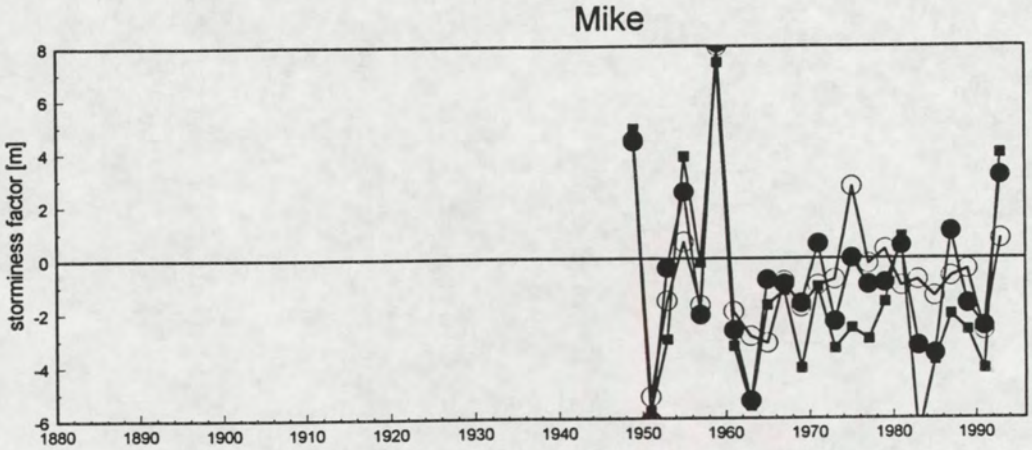


Day-light high-water data



Wind data

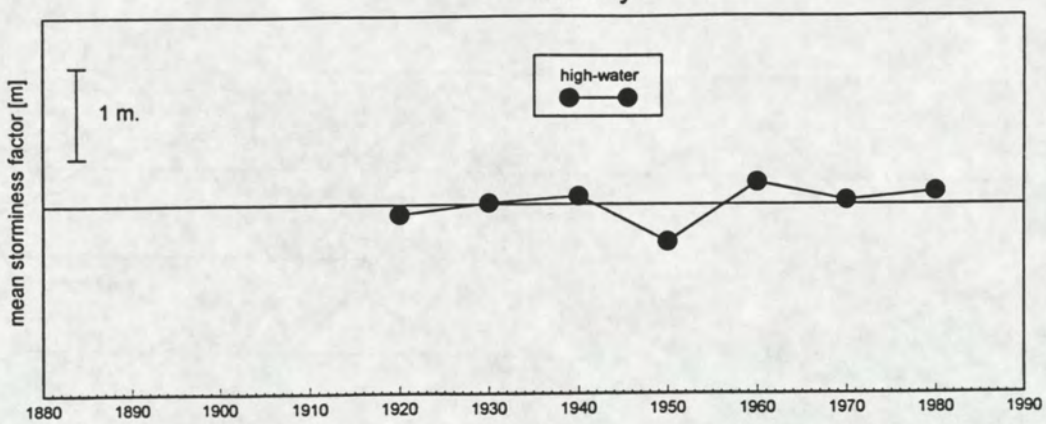

Terschelling
threshold range
15/yr - 10/yr
10/yr - 5/yr
5/yr - 1/yr
storminess factor [m]
8
6
4
2
0
-2
-4
-6
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990


Mike
storminess factor [m]
8
6
4
2
0
-2
-4
-6
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990

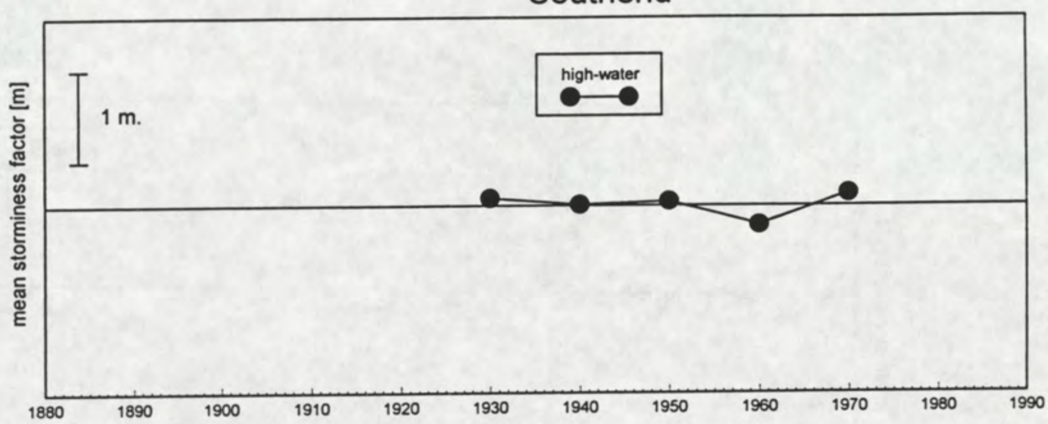
Annex F, part 4

In this Annex, the result of applying the mean variant of the quantile analysis method to the complete sea-level data-sets and to the wind data-sets of Terschelling and Mike is shown.

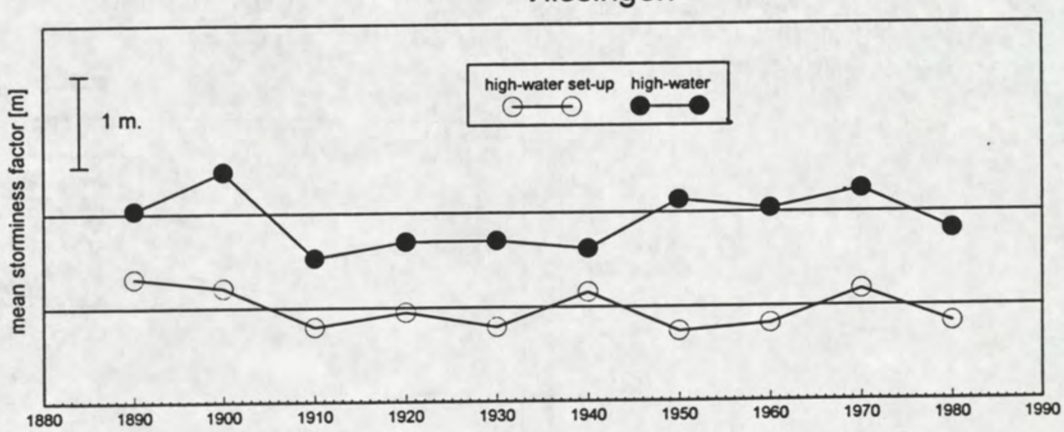
Newlyn



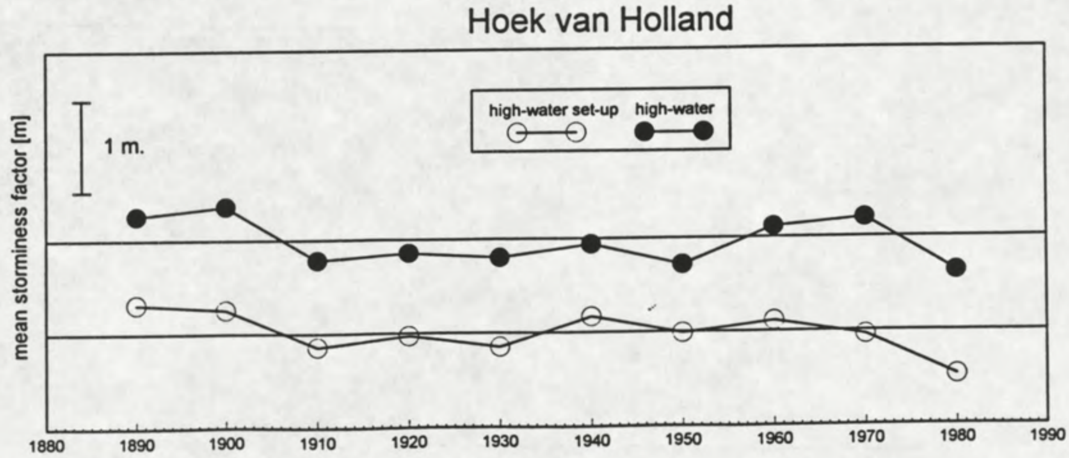
Southend



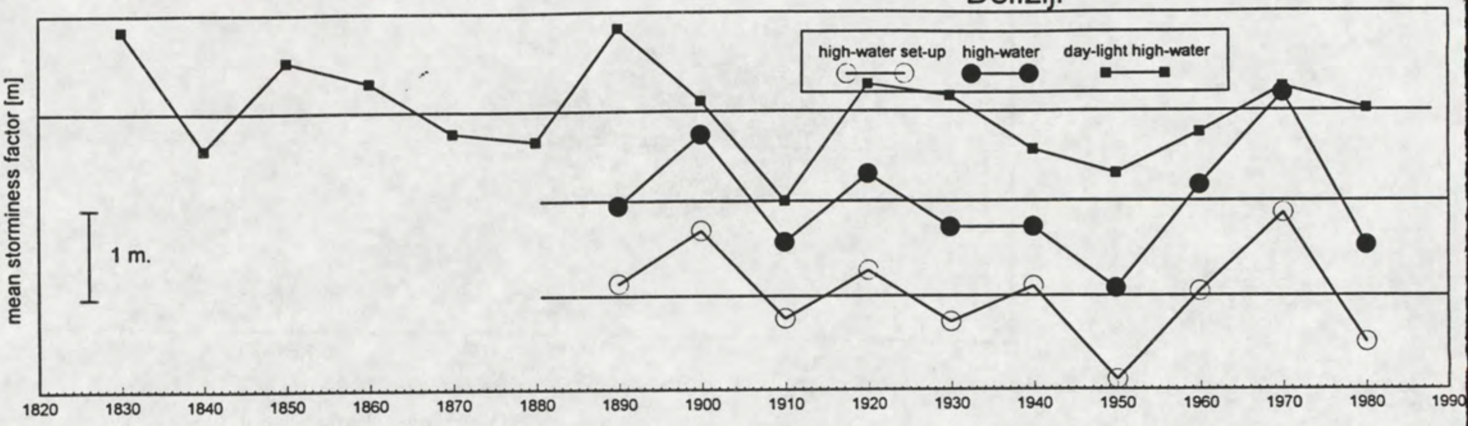
Vlissingen



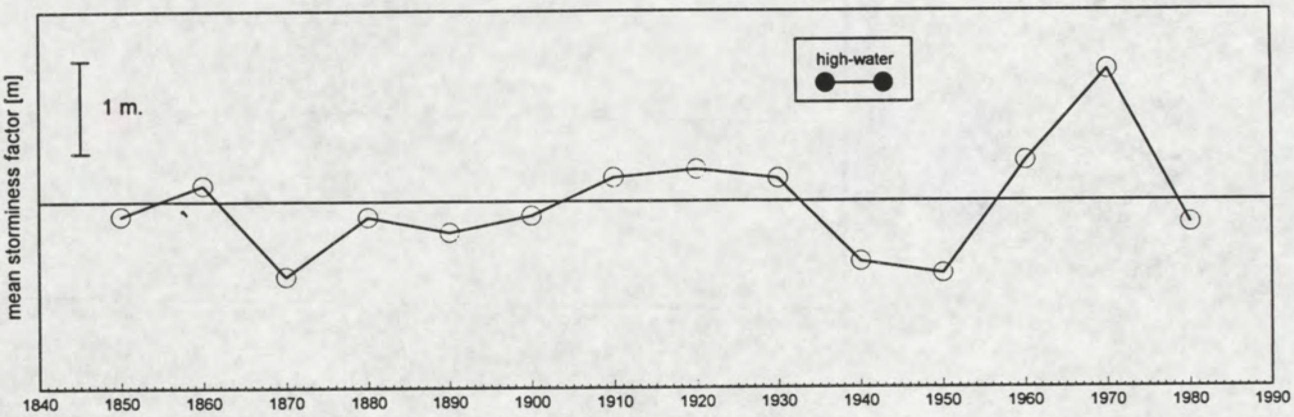
Hoek van Holland



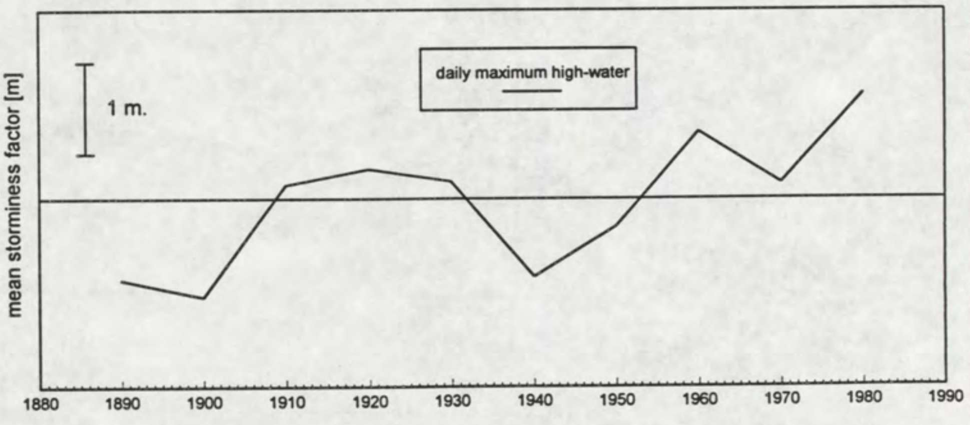
Delfzijl

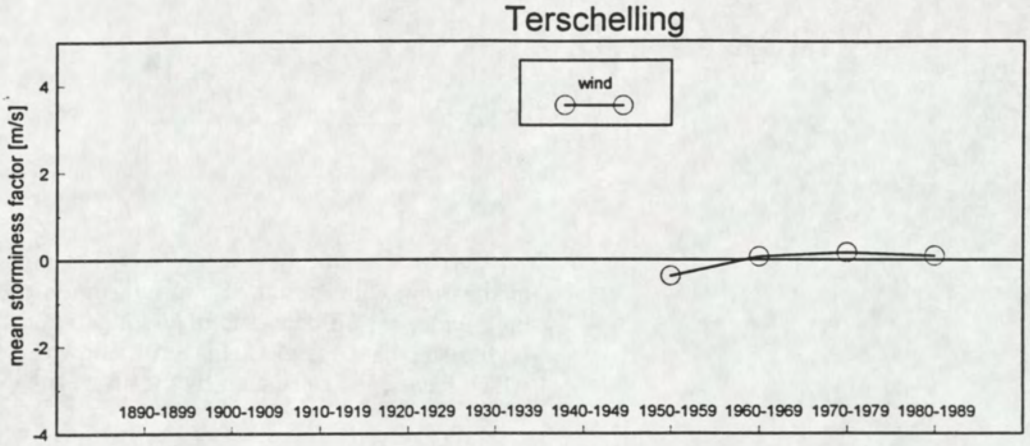


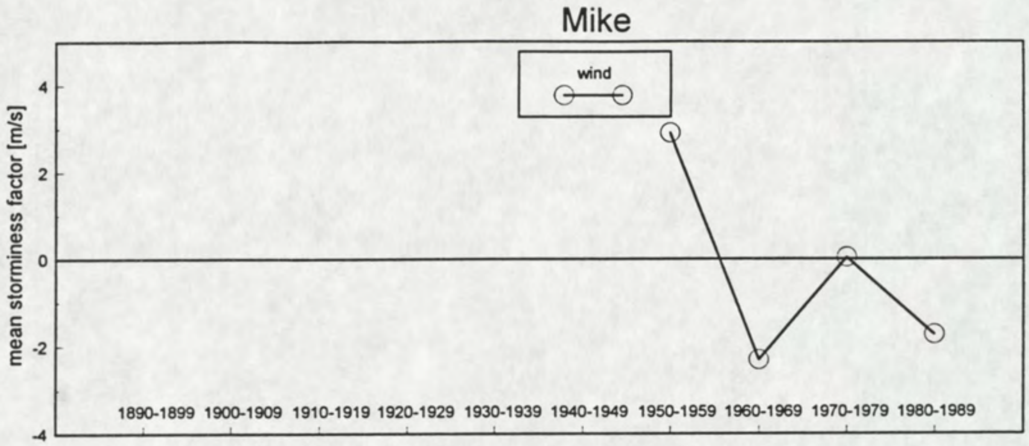
Cuxhaven



Esbjerg

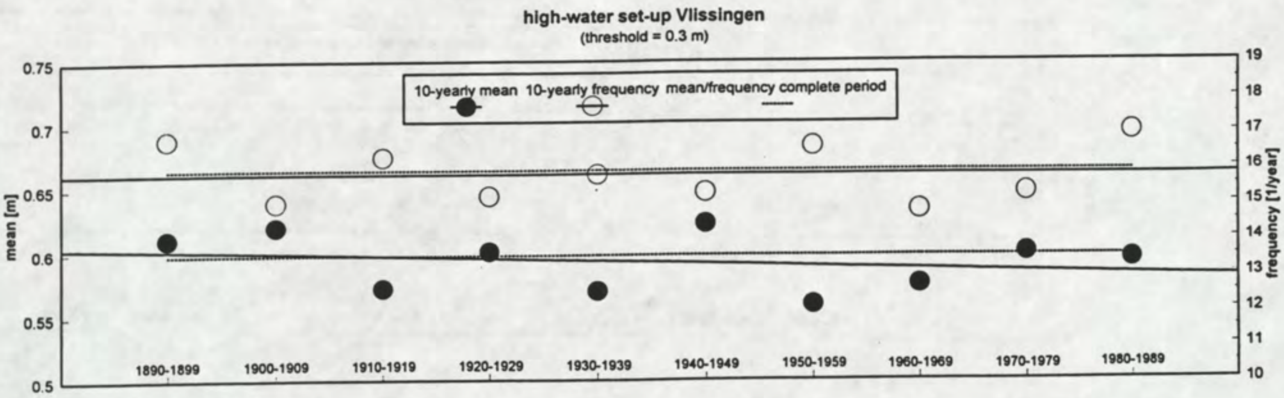


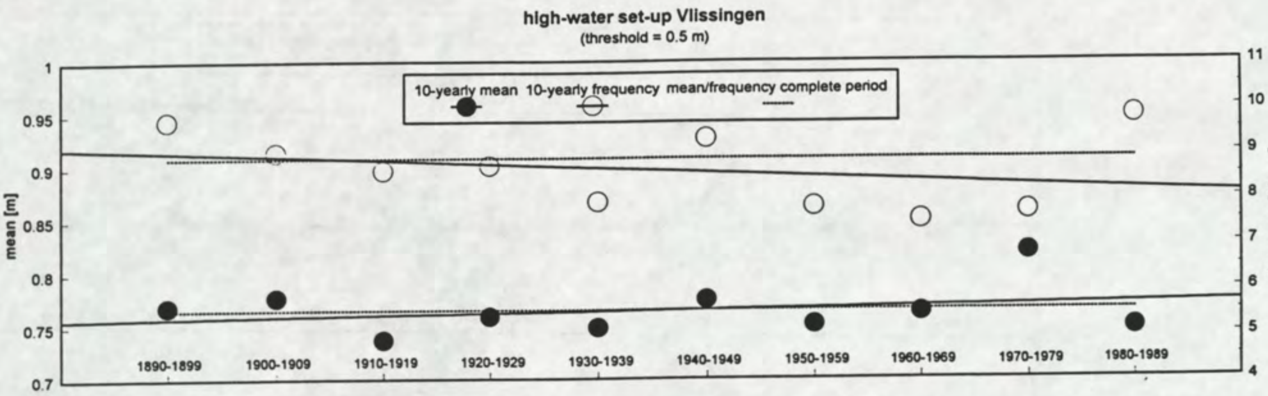

Terschelling
wind
mean storminess factor [m/s]
4
2
0
-2
-4
1890-1899 1900-1909 1910-1919 1920-1929 1930-1939 1940-1949 1950-1959 1960-1969 1970-1979 1980-1989

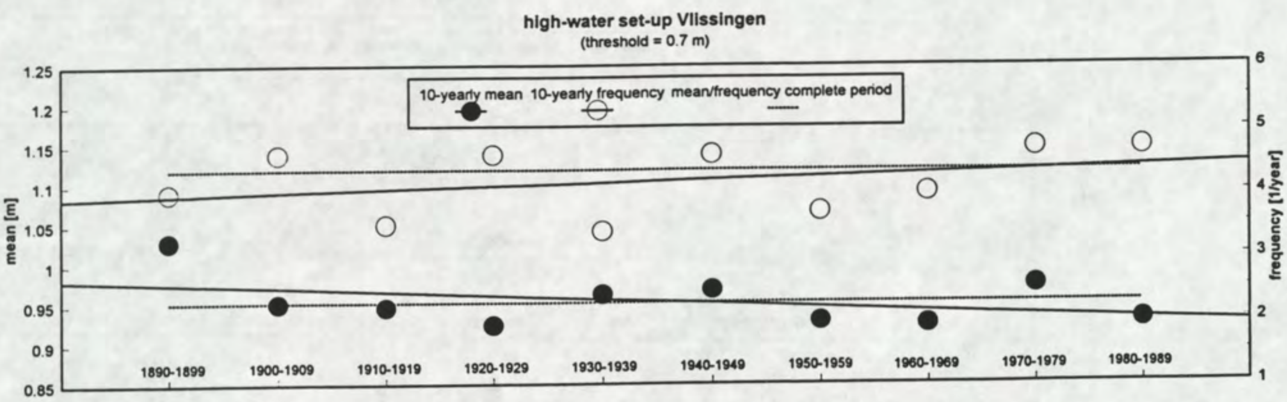

Mike
wind
mean storminess factor [m/s]
4
2
0
-2
-4
1890-1899 1900-1909 1910-1919 1920-1929 1930-1939 1940-1949 1950-1959 1960-1969 1970-1979 1980-1989

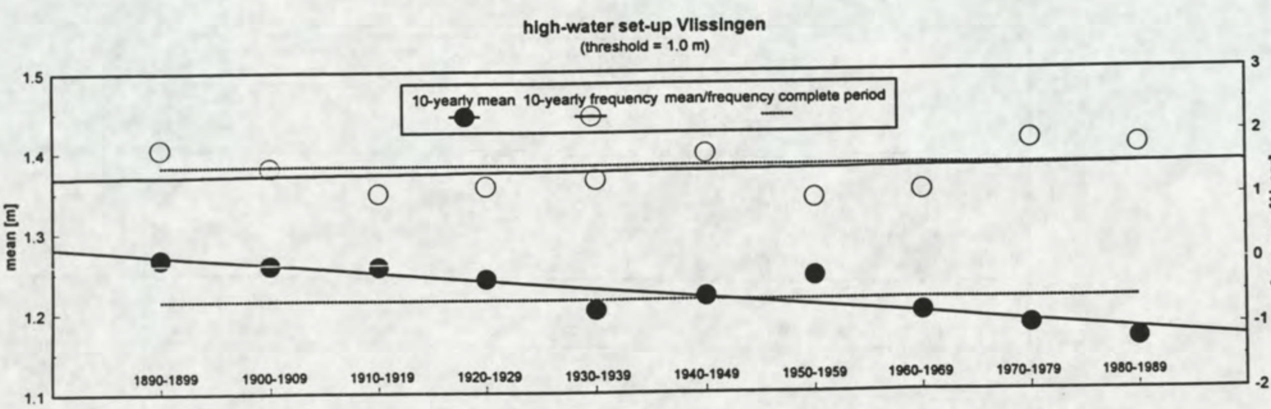
Annex G

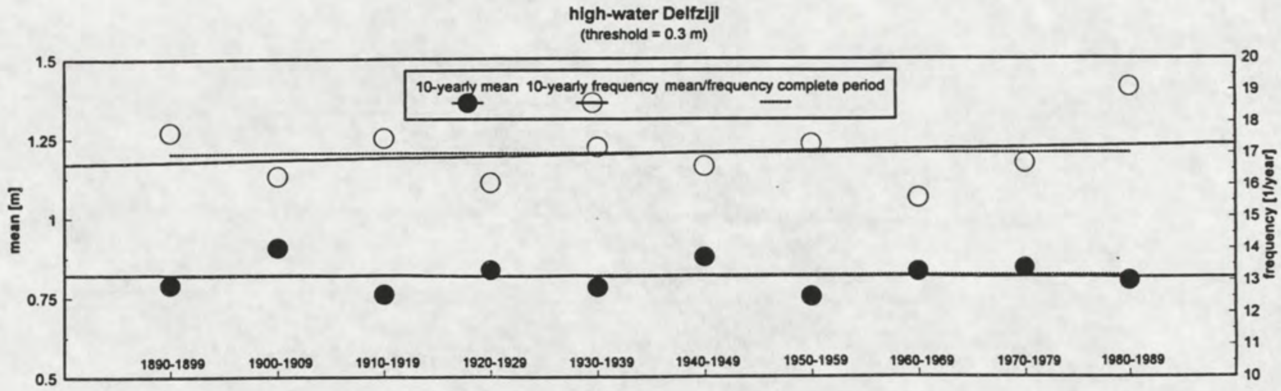
In this Annex, the result of applying the intensity/frequency method to the high-water set-up data-sets of Vlissingen and Delfzijl, and to the 'complete' high-water data-set of Cuxhaven is shown, in combination with trend lines which have been calculated by means of linear regression.

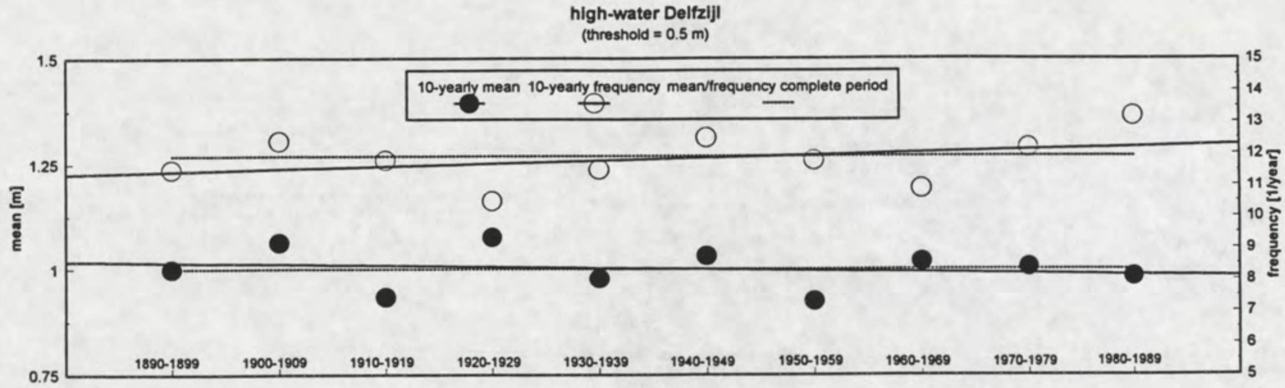

high-water set-up Vlissingen
(threshold = 0.3 m)
10-yearly mean 10-yearly frequency mean/frequency complete period
mean [m]
frequency [1/year]
1890-1899
1900-1909
1910-1919
1920-1929
1930-1939
1940-1949
1950-1959
1960-1969
1970-1979
1980-1989

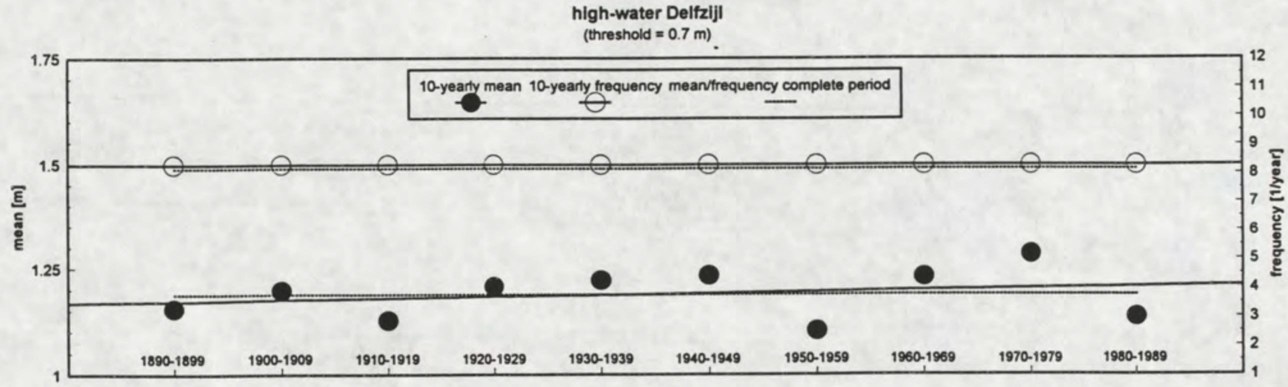

high-water set-up Vlissingen
(threshold = 0.5 m)
10-yearly mean 10-yearly frequency mean/frequency complete period
mean [m]
frequency [1/year]
1890-1899
1900-1909
1910-1919
1920-1929
1930-1939
1940-1949
1950-1959
1960-1969
1970-1979
1980-1989

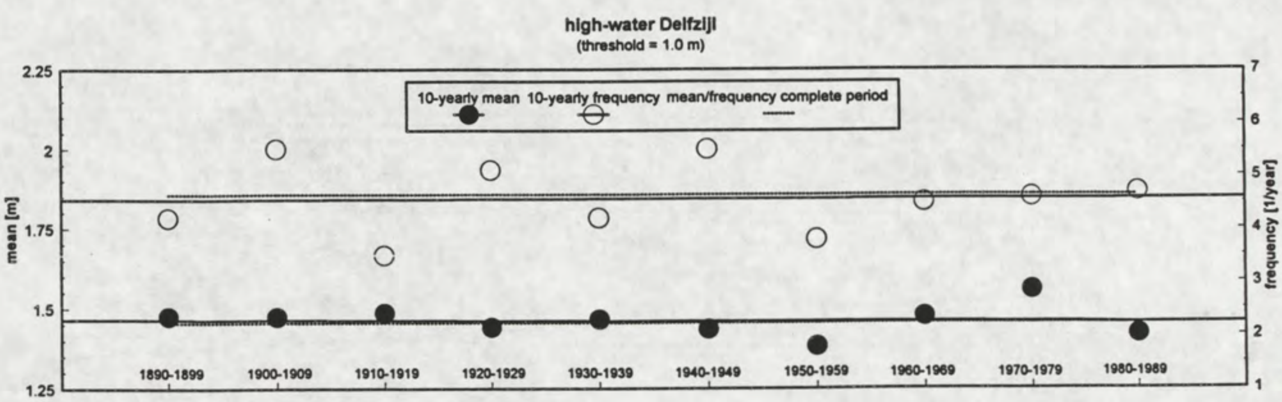

high-water set-up Vlissingen
(threshold = 0.7 m)
10-yearly mean 10-yearly frequency mean/frequency complete period
mean [m]
frequency [1/year]
1890-1899
1900-1909
1910-1919
1920-1929
1930-1939
1940-1949
1950-1959
1960-1969
1970-1979
1980-1989

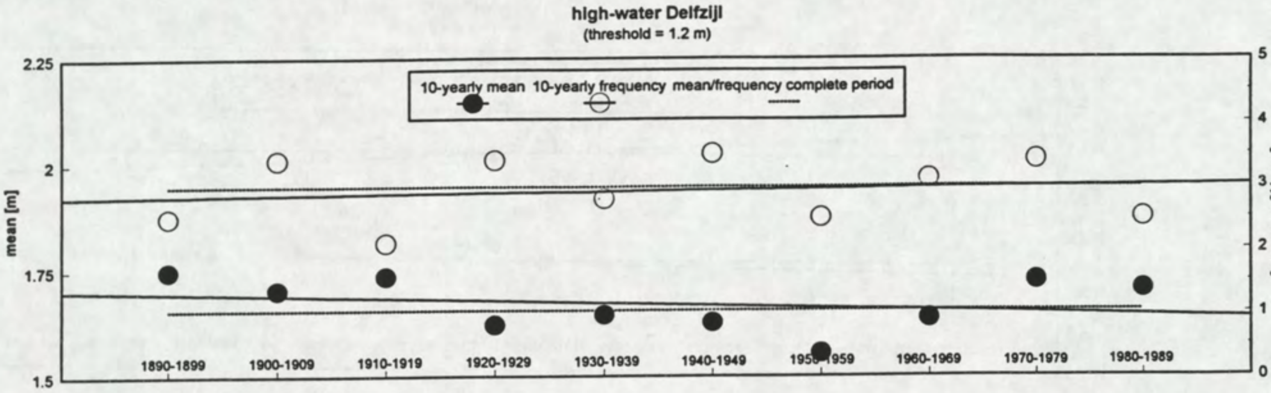

high-water set-up Vlissingen
(threshold = 1.0 m)
10-yearly mean 10-yearly frequency mean/frequency complete period
mean [m]
frequency [1/year]
1890-1899
1900-1909
1910-1919
1920-1929
1930-1939
1940-1949
1950-1959
1960-1969
1970-1979
1980-1989

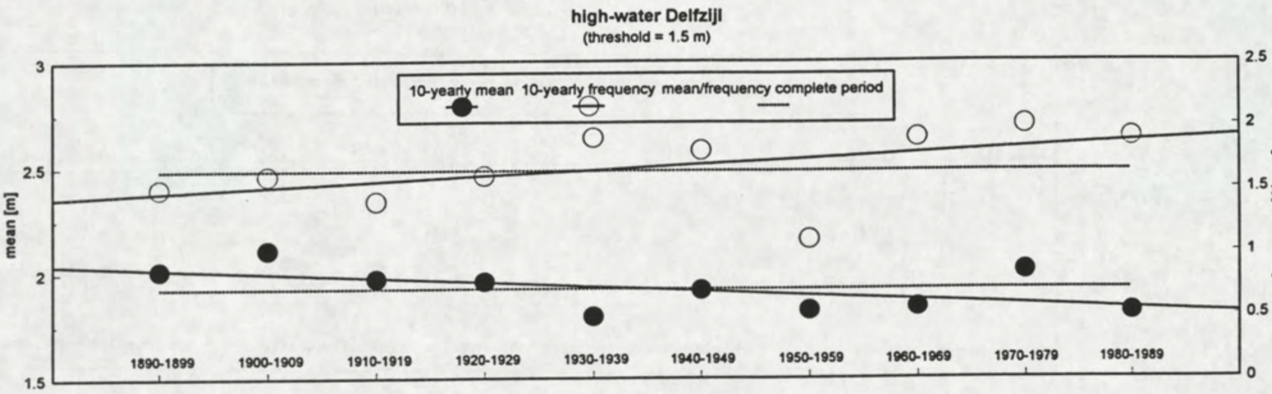

high-water Delfzijl
(threshold = 0.3 m)
10-yearly mean 10-yearly frequency mean/frequency complete period
mean [m]
frequency [1/year]
1890-1899
1900-1909
1910-1919
1920-1929
1930-1939
1940-1949
1950-1959
1960-1969
1970-1979
1980-1989

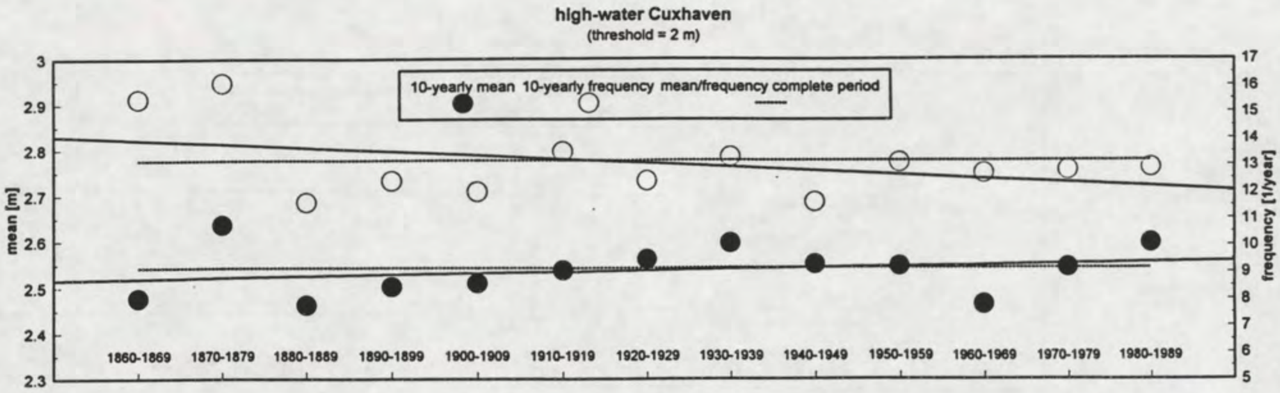

high-water Delfzijl
(threshold = 0.5 m)
10-yearly mean 10-yearly frequency mean/frequency complete period
mean [m]
frequency [1/year]
1890-1899
1900-1909
1910-1919
1920-1929
1930-1939
1940-1949
1950-1959
1960-1969
1970-1979
1980-1989

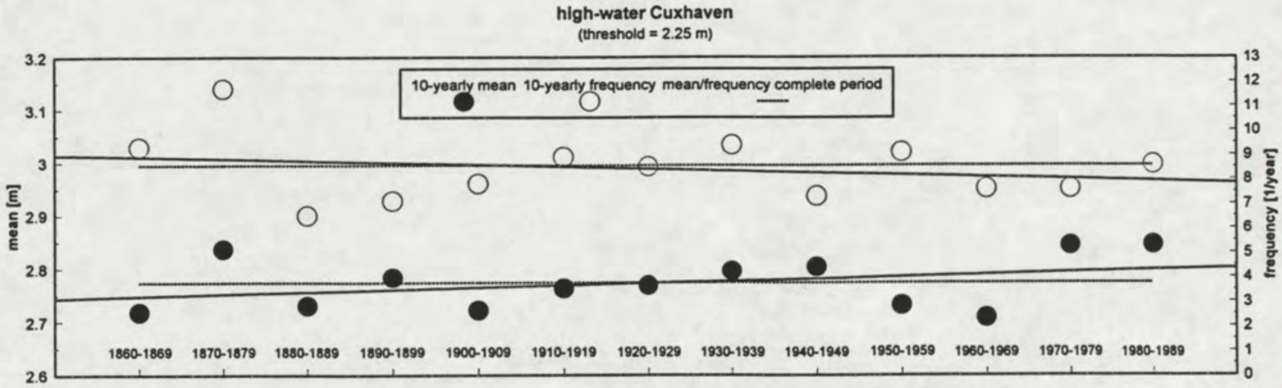

high-water Delfzijl
(threshold = 0.7 m)
10-yearly mean 10-yearly frequency mean/frequency complete period
mean [m]
frequency [1/year]
1890-1899
1900-1909
1910-1919
1920-1929
1930-1939
1940-1949
1950-1959
1960-1969
1970-1979
1980-1989

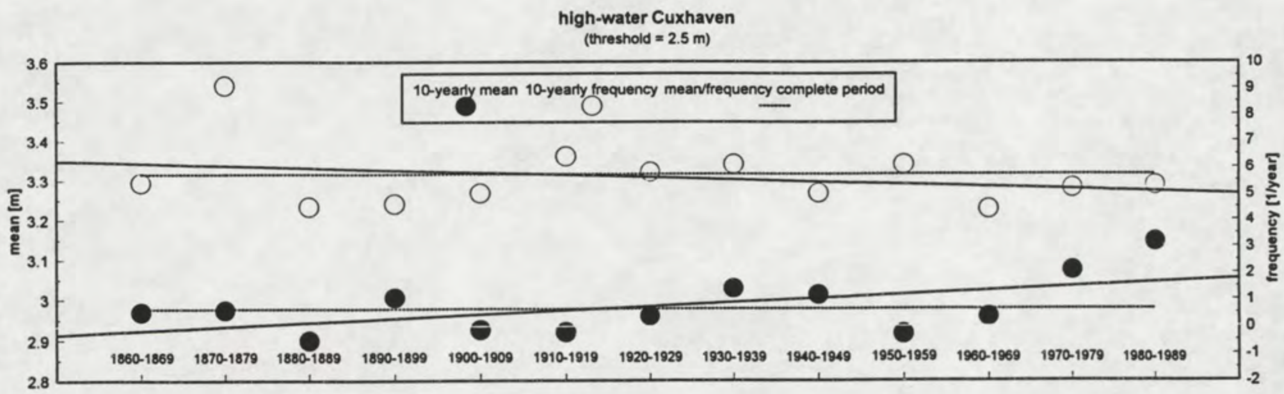

high-water Delfzijl
(threshold = 1.0 m)
10-yearly mean 10-yearly frequency mean/frequency complete period
mean [m]
frequency [1/year]
1890-1899
1900-1909
1910-1919
1920-1929
1930-1939
1940-1949
1950-1959
1960-1969
1970-1979
1980-1989

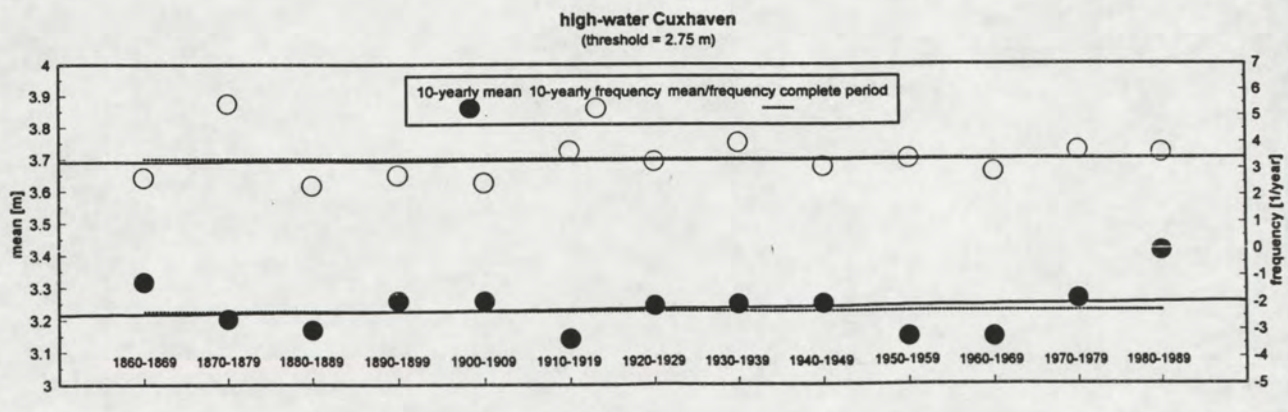

high-water Delfzijl
(threshold = 1.2 m)
10-yearly mean
10-yearly frequency
mean/frequency complete period
mean [m]
frequency [1/year]
1890-1899
1900-1909
1910-1919
1920-1929
1930-1939
1940-1949
1950-1959
1960-1969
1970-1979
1980-1989

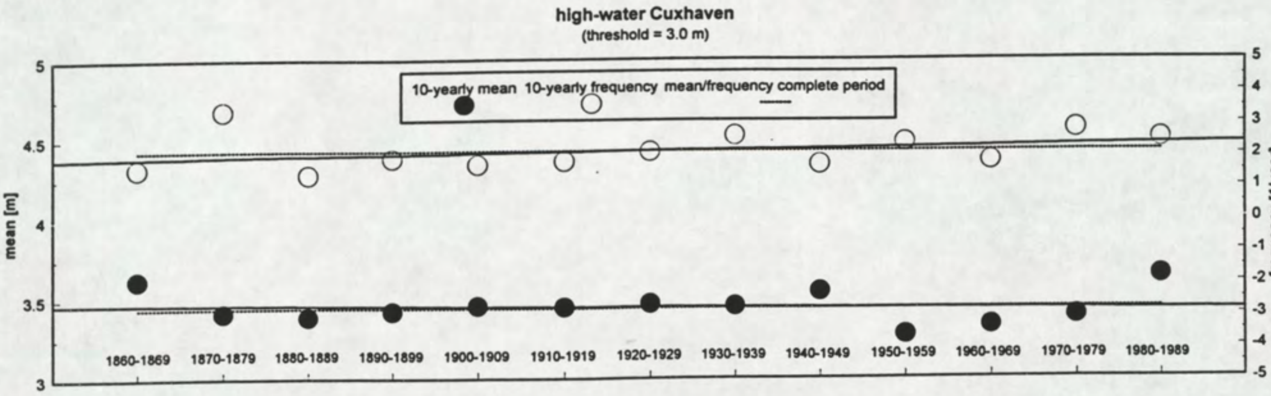

high-water Delfzijl
(threshold = 1.5 m)
10-yearly mean
10-yearly frequency
mean/frequency complete period
mean [m]
frequency [1/year]
1890-1899
1900-1909
1910-1919
1920-1929
1930-1939
1940-1949
1950-1959
1960-1969
1970-1979
1980-1989

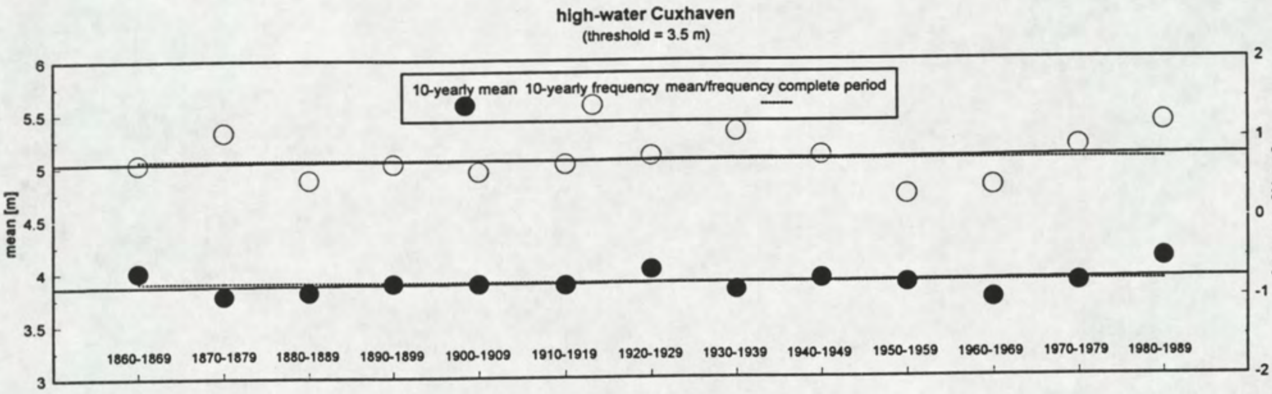

high-water Cuxhaven
(threshold = 2 m)
10-yearly mean 10-yearly frequency mean/frequency complete period
mean [m]
frequency [1/year]
1860-1869
1870-1879
1880-1889
1890-1899
1900-1909
1910-1919
1920-1929
1930-1939
1940-1949
1950-1959
1960-1969
1970-1979
1980-1989


high-water Cuxhaven
(threshold = 2.25 m)
10-yearly mean 10-yearly frequency mean/frequency complete period
mean [m]
frequency [1/year]
1860-1869
1870-1879
1880-1889
1890-1899
1900-1909
1910-1919
1920-1929
1930-1939
1940-1949
1950-1959
1960-1969
1970-1979
1980-1989


high-water Cuxhaven
(threshold = 2.5 m)
10-yearly mean 10-yearly frequency mean/frequency complete period
mean [m]
frequency [1/year]
1860-1869
1870-1879
1880-1889
1890-1899
1900-1909
1910-1919
1920-1929
1930-1939
1940-1949
1950-1959
1960-1969
1970-1979
1980-1989


high-water Cuxhaven
(threshold = 2.75 m)
10-yearly mean 10-yearly frequency mean/frequency complete period
mean [m]
frequency [1/year]
1860-1869
1870-1879
1880-1889
1890-1899
1900-1909
1910-1919
1920-1929
1930-1939
1940-1949
1950-1959
1960-1969
1970-1979
1980-1989


high-water Cuxhaven
(threshold = 3.0 m)
10-yearly mean 10-yearly frequency mean/frequency complete period
mean [m]
frequency [1/year]
1860-1869
1870-1879
1880-1889
1890-1899
1900-1909
1910-1919
1920-1929
1930-1939
1940-1949
1950-1959
1960-1969
1970-1979
1980-1989


high-water Cuxhaven
(threshold = 3.5 m)
10-yearly mean 10-yearly frequency mean/frequency complete period
mean [m]
frequency [1/year]
1860-1869
1870-1879
1880-1889
1890-1899
1900-1909
1910-1919
1920-1929
1930-1939
1940-1949
1950-1959
1960-1969
1970-1979
1980-1989