CHAPTER 215

DEVELOPMENT OF WATER LEVEL CHANGES IN THE GERMAN BIGHT, AN ANALYSIS BASED ON SINGLE VALUE TIME SERIES

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Abstract

Time series of semidiurnal single values of Tidal High Water and Tidal Low Water and their occurrence times from certain tide gauges in the German Bight were evaluated. Detailed analyses were performed to detect distict periodicities and changes in the trends not only of water levels but also of the occurrence times by means of mathematical-statistical methods.

Introduction

The eustatic variations of the global sea level are strongly influenced by worldwide changes in climate. There is no longer any doubt that the "greenhouse effect" and other human activities have a definite impact on our climate. In many parts of the world changes and accelerations in sea level rise have been detected, such as the east coast of the USA, the Gulf of Mexico, and the Bay of Bengal. In the North Sea, and even in the German Bight, an enhanced rise of the sea level will also lead to far-reaching alterations. In this context not only changes in mean sea level are important, especially alterations in Tidal High Water (THW), Tidal Low Water (TLW) and Tidal Range (TR) will play a decisive role. Changes in tidal dynamics of the flat coastal regions affect erosion, endangering of storm surges, changes in ground water level, and shipping.

In the project "Water Level Changes in the German Bight", the evaluation of time series of semidiurnal THW and TLW shows rises of THW up to 6 mm/year for cer-

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tain sites on the German coastline, whereas the TLW decreases (Jensen et.al.,1988). This leads to the assumption, that during the last three decades a change in the tidal dynamics of the German North Sea coast may have taken place (Führböter, 1986, Siefert, 1984).

The Data

In order to achieve satisfactory results in determination of long term (secular) changes in water level and tidal dynamics, the analysis must be based not only on comparatively prolonged series of observations or records, but also on data which are highly accurate.

The database of the present examination consists of more then 500000 single values of semidiurnal THW and TLW. The data were recorded at 12 sites in the German Bight (Fig.1).

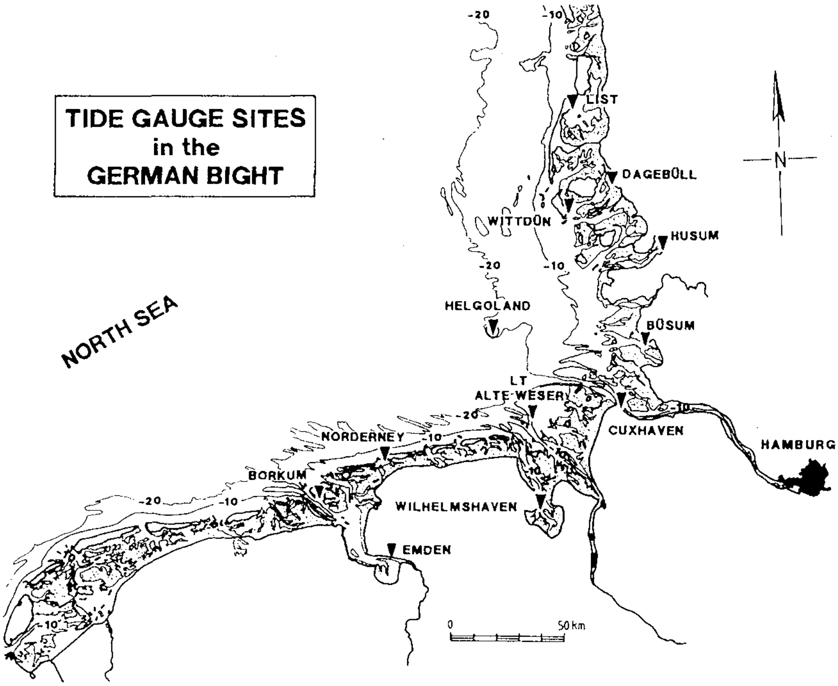

Fig. 1: Tide gauge sites in the German Bight.

The tide gauges are located in the south eastern part of the North Sea. The sites are on islands (Borkum, Norderney, LT Alte Weser, Helgoland, Wittdün/Amrum, and List/Sylt), in tidal estuaries (Emden, Wilhelmshaven, and Cuxhaven), and in small harbours (Büsum, Husum, and Dagebüll). The area includes most of the wadden sea. Big parts of the coastal region are below the sea level. The whole coastline is protected with dykes. The oldest continuous tide gauge recordings considered here had been performed in 1843 at Cuxhaven.

The time series of the tide gauges had to be as long as possible and should not much be influenced by antropgenic or morphologic factors. The data had been carefully checked and adjusted to a unique reference level. Changes in the location and vertical alterations of the tide gauges also had been taken into account. Gaps in the older parts of the time series had to be closed with the aid of linear regression and double-sum-analysis.

Linear Trends

The linear trends are determined with the aid of least square methods, as $H(t) = H_O + S_T * t$. S_T denotes the average rise or fall of THW, TLW, TR, or Mean Sea Level (MSL) within the time period examined. The trends can be expressed either in mm/year or, as some authors do, formally extrapolated to a century and expressed in cm/100 years as secular trends (Führböter and Jensen, 1985).

In the German Bight a rise of the THW of 20 - 30 cm per century, i.e. 2-3 mm/year, has been observed since the beginning of regular water level observations in the middle of the last century (Rhode, 1977). Pirazzoli (1989) anticipated a rise of MSL in the North Sea of 1 - 1.5 mm/year. Woodworth (1987) estimated a global eustatic rise of 1 - 2 mm/year based on U.K. tide gauge data. In the current project, linear regressions show an increase of THW up to 6 mm/year at some tide gauges on the German North Sea coast. The TLW remains constant or decreases with maximum rates of 4 mm/year at certain tide gauges.

Table 1 shows spatial averaged trends of THW, TLW, TR, and MSL and their standard deviations over different time periods of the last 100, 50, 25, and 19 years (≈ period of the nodal tide). The mean trends are obtained by computing linear trends for each tide gauge seperately and then taking spatial mean values.

TIME SERIES	LINEAR TRENDS $S_T \pm \sigma$ [mm/YEAR] MEAN VALUES GERMAN BIGHT			
	Tidal Low Water	Tidal High Water	Tidal Range	Mean Sea Level
1890-1989 (100 Years)	0.0±0.7	2.5±1.0	2.6±1.0	1.2±0.6
1940-1989 (50 Years)	-0.7±0.6	3.3±0.8	3.9±0.8	1.2±0.6
1965-1989 (25 Years)	-0.2±0.6	4.0±0.6	4.2±0.5	2.1±0.6
1971-1989 (19 Years≈ nodal tide)	4.0±0.6	6.7±0.7	2.6±0.5	5.3±0.6

Table 1: Mean trends over different time periods
(S_T: regession coefficient,
σ : standard deviation)

The increase of the trends in THW can clearly be seen, the trends of TLW are much smaller, at some tide gauges TLW even is decreasing. Due to this development the trends of TR increase faster and those of MSL rise much slower than the trends of THW. Conspicious alterations have taken place in the last decades. Compared with the longer trends, the trends from 1971 to 1989 reveal the first time an increase of TLW. So the rise of TR becomes smaller and therefore the MSL increases much faster during this period of time.

The alterations of the trends of THW and TLW at the tide gauge Cuxhaven from 1890 to 1987 are shown in Fig.2. The trends are computed within 25-year time-windows and the value is expressed in cm/100 years. The trend is plotted at the end of the 25-year period. Negative values indicate decreasing water levels within the 25-year period. The differences to the 25-year trends in table 1 arise from the different time periods. In table 1 only data until 1987 are considered.

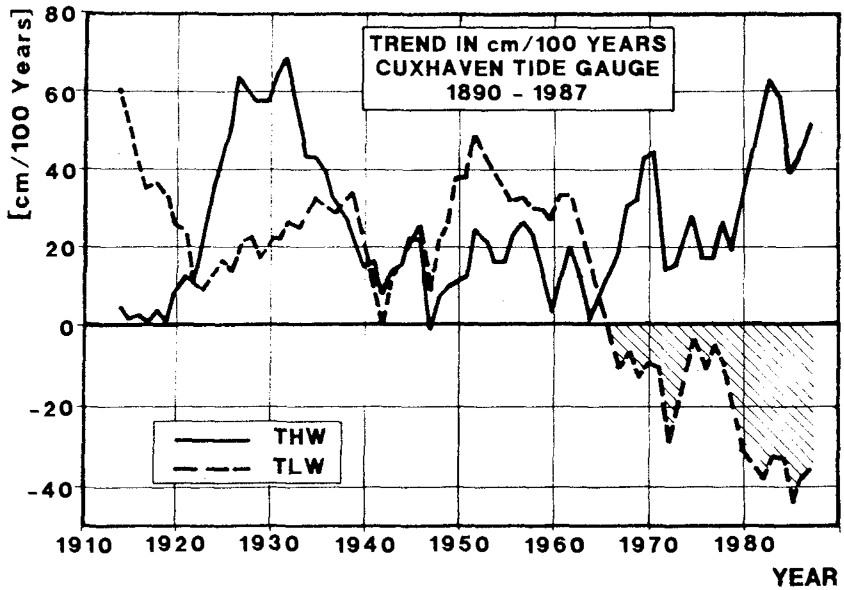

Fig. 2: Alterations of the trends of THW and TLW at the tide gauge Cuxhaven from 1890 to 1987, computed with 25-year time-windows.

The trends reveal strong temporal variations. In the middle of this century (the trend within the time period from 1941 to 1965 is plotted in 1965) the trend of THW clearly is rising and the trend of TLW is decreasing (negative values since 1965). Hence an increased rise of TR took place. The rise of the TR is of great importance for the tidal dynamics. Enhancement of tidal energy will lead to increased current velocities and sediment transports. This has great impact on the morphological structure of the coastal regions.

Frequency Analysis - Fast Fourier Transform

The corrected time series of tide gauge observations were transformed from periodic functions of time into the frequency domain using the Fast Fourier Transform.

Fig. 3 shows as a result of the FFT the frequency distribution of THW at the tide gauge Cuxhaven. The amplitudes of the frequencies for 1, 14, and 28 days as well as for 1 year are clearly seen. Furthermore some longperiodic oscillations of 4.2, 6.2, 7.8, 13.3, and 18.6 years can be recognized.

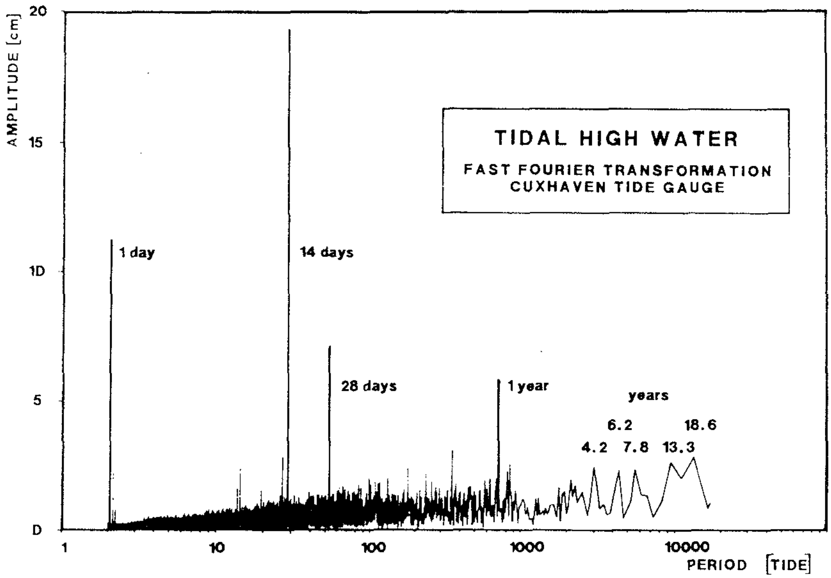

Fig. 3: Frequency distribution of THW at tide gauge Cuxhaven for the years 1894 to 1986.

The periods up to 1 year and the 18.6 year period obviously are of astronomical origin. The origin of higher amplitudes in periods between 3 and 13.3 years are at present not clear. Meteorological or hydrological cycles may play a role (eg. a supposed 6 to 7 year metrorological cycle).

Fig. 4 shows the frequency distribution of the TR at the same tide gauge. Here the 18.6 year period (nodal tide) with an amplitude of 4 cm, this is a range of 8 cm, can clearly be seen. At other gauge sites the range of this partial tide amounts up to 12 cm.

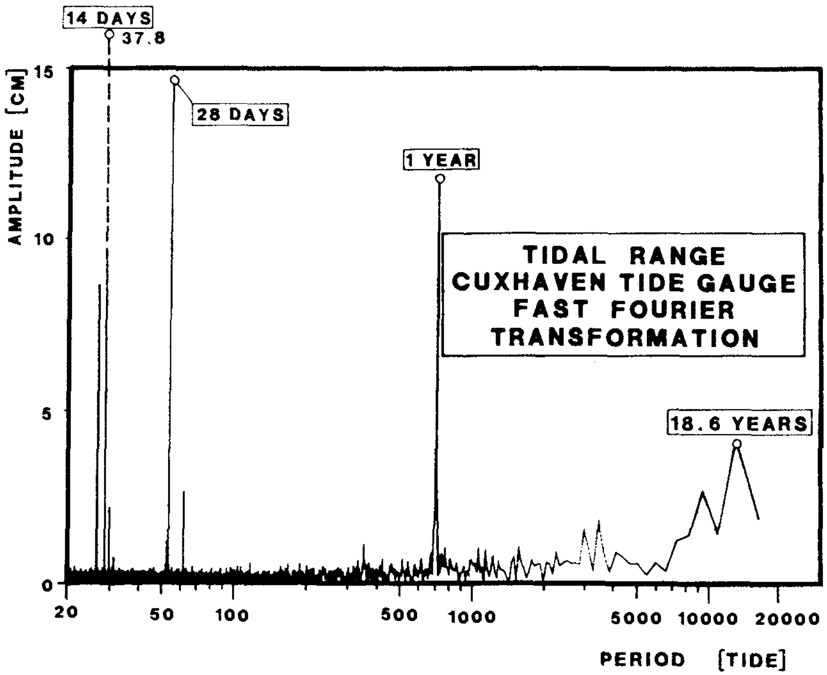

Fig. 4: Frequency distribution of the TR at tide gauge Cuxhaven.

Filtering

With the "Inverse Fast Fourier Transform", a retransformation of the frequency spectrum can be performed. By omitting distinct frequencies one gets digitally filtered time series.

A retransformation of THW and TLW at tide gauge Cuxhaven was performed with a low-pass-filter, all periods shorter than 2.7 years have been omitted. So long periodic oscillations can be recognized and analyzed. Fig. 5 shows an increase of the amplitudes of long periodic oscillations in the last decades.

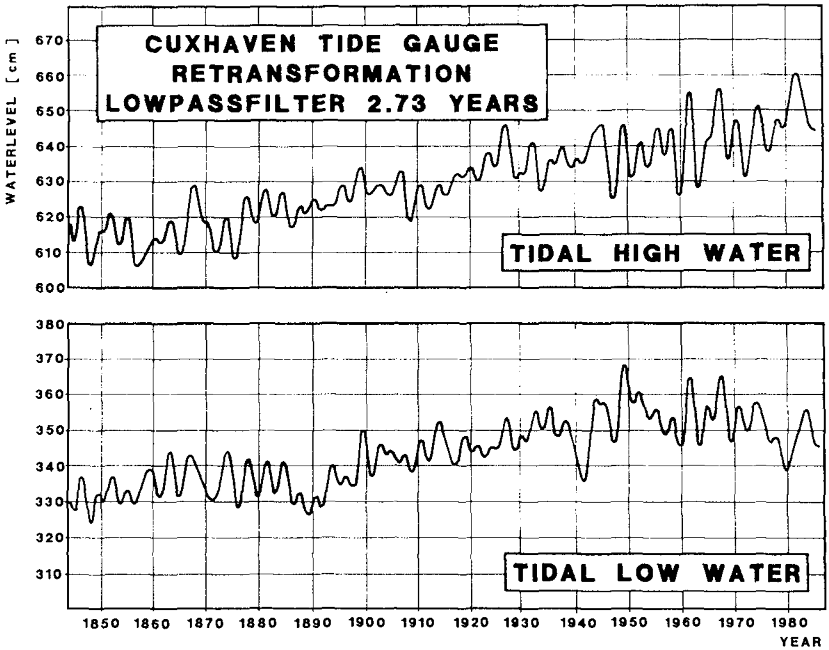

Fig. 5: Retransformation of THW and TLW at tide gauge Cuxhaven (from 1843 to 1986).

In another application of the inverse FFT, first distinct periods of TR time series have been filtered out and then the other components were superposed.

Fig. 6 shows the oscillations of the TR with periods of 13.3, 18.6, and greater 23.3 years. The upper curve is the sum of these oscillations with periods greater then 13.3 years. The curves for 13.3, 18.6, and greater 23 years all have a maximum appoximately at the same time, so the curve of the sum of these components has an extraordinarily maximum at the beginning of the eighties. The 13.3 year cycle cannot yet be explained.

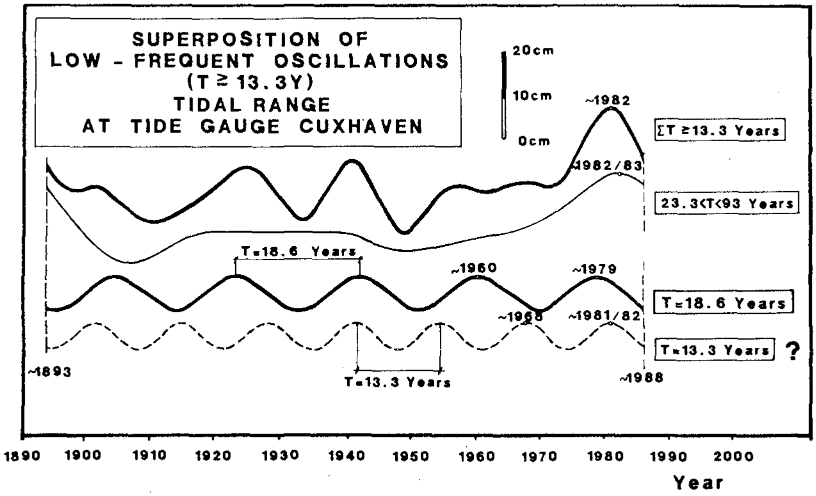

Fig. 6: Superposition of periods > 13.3 years

Nodal Tide

The nodal tide arises from the relative movement of moon and earth to each other. The lunar and the earth's orbit are inclined with an angle of 5°9'. The point of intersection of the lunar orbit and the ecliptic changes its position within a period of 18.6 years. Due to this, the declination of the moon varies between 18.5° and 28.5° around the equator.

From a viewpoint on the earth this effect is depicted in Fig. 7. At the minimum declination, the tide generating force of the nodal tide has a maximum. The last minimum declination was in 1979.

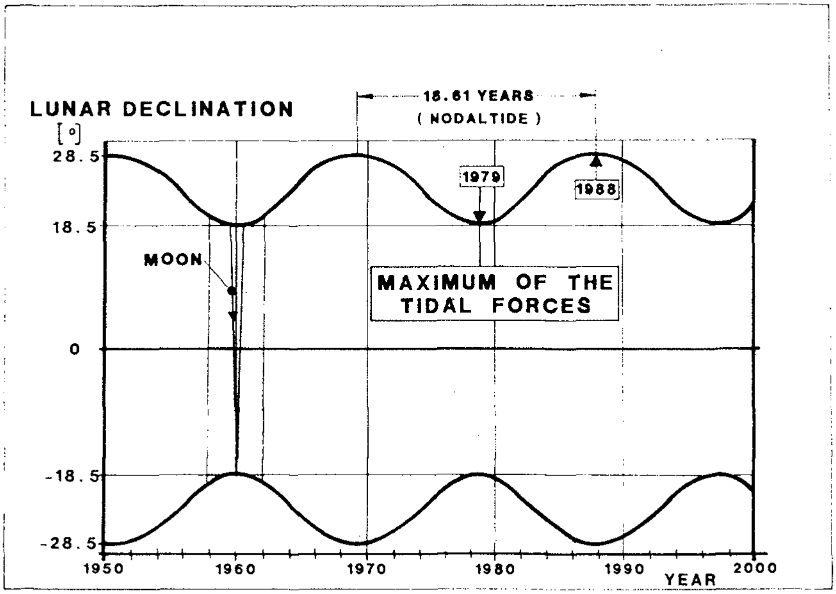

Fig. 7: Declination of the moon

The nodal tide effect is mainly detectable in the TR. In the time series of THW and TLW this signal is considerably weaker. At the tide gauges in the German Bight the contribution of the nodal tide on the TR is about 7 cm. Other investigations reveal the TR at the dutch tide gauge at Vlissingen a portion of ≈12 cm and at certain english tide gauges more then 16 cm (Woodworth et al., 1990).

Occurrence times of THW and TLW

The previous investigations considered only the variations of water levels and TR. Water level changes, however, also cause temporal changes in the tidal dynamics. The investigations of tidal dynamics include the time series of the occurrence times of semidiurnal THW and TLW.

The tidal regime of the North Sea is dominated by the semidiurnal M2-tide. The tidal wave from the Atlantic Ocean enters the North Sea through the entrance to the north and through the English Channel. First the tide propagates counterclockwise along the english coastline southward and turns east near the dutch coast. In the German Bight the tide turns northward and leaves the North Sea along the norwegian coastline. Therefore the time of occurence of THW and TLW at the North Sea coastline takes place in a definite sequence. Temporal alterations of the tidal regime will change the time when THW or TLW occur at certain tide gauge sites.

The tide in the North Sea is not directly determined by the astronomical potential, it depends on the tidal wave of the Atlantic Ocean. Nevertheless there is a relation of the position of the moon and the occurence time of semidiurnal THW and TLW in the North Sea. Therefore the time of transition of the moon through the Greenwich meridian is choosen as a reference time. This reference time only depends on astronomical factors. The investigations of temporal variations are based on the time difference between occurrence of THW and TLW at several tide gauges in the German Bight and the transition of the moon through the Greenwich meridian. The data are not affected by vertical movements, eustatic effects or changes in reference levels.

Table 2 shows the averaged time differences between the occurrence of THW and TLW and the transition of the moon through the Greenwich meridian for selected tide gauges in the German Bight. The differences are averaged over a period of 34 years from 1954 to 1987. At tide gauge Norderney eg. the THW occurs in 1987 approximately 17 min earlier then in 1954 with respect to the transition of the moon through the Greenwich meridian.

GAUGE SITE	MEAN TIME DIFFERENCE		ALTERATION WITHIN 34 YEARS $T_T \pm \sigma$	
	Δt(THW) [min]	Δt(TLW) [min]	T_T(THW) [min/34a]	T_T(TLW) [min/34a]
NORDERNEY	613	253	-17±1.2	-21±0.7
HELGOLAND	637	297	- 7±1.2	- 3±0.7
WILHELMSHAVEN	711	334	-25±1.2	-26±0.7
CUXHAVEN	716	378	- 9±1.2	-12±0.7
HUSUM	764	406	-15±1.3	- 8±0.8
LIST	802	425	- 6±1.4	- 8±0.6

Table 2: Mean time difference between the occurrence of THW and TLW and reference time

The development of the time difference at tide gauge Wilhelmshaven from 1936 to 1987 is depicted in Fig. 8 . Generally the time differences reveal a negative trend. Since the beginning of the sixties an enhanced reduction of the time differences can be detected. Presumable this is due to construction works in the Jade Waterway.

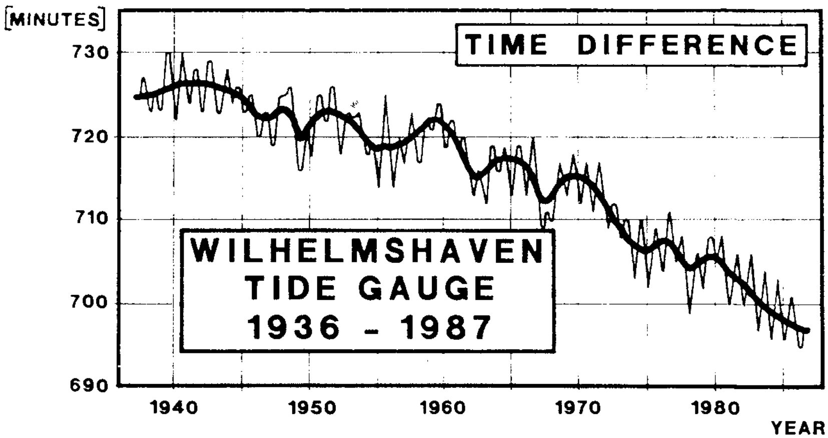

Fig. 8: Development of mean time difference between the occurrence of THW at tide gauge Wilhelmshaven and reference time.

At all tide gauges considered here, the time differences of occurrence of THW and TLW and reference time has been reduced in the last decades. So it can be resumed, that also changes in tidal dynamics have taken place in the German Bight.

Conclusions

These evaluations reveal, that there is no uniform trend in the tidal regime of the German Bight. The secular rise strongly depends on the location of the tidal gauge and on the period of time considered. One obtains different results depending upon whether the MSL (predominantly used parameter) or THW and TLW are computed. Based on the historical development of MSL in the German Bight, no extraordinary rise can be detected when taking time periods of more then 25 years into account. Only computations of trends over shorter periods reveal an enhanced increase of the MSL in the German Bight. As mentioned above, more interesting developments have occurred with respect to the extreme values of the tidal regime . The rise of THW compared with constant or decreasing TLW leads to an enhanced increase of the TR. The rise of the TR is of great importance for the tidal dynamics. Enhancement of tidal energy will lead to increased current velocities and sediment transports. This has great impact on the morphological structure of the coastal regions and is of high importance for coastal engineering purposes.

The evaluations of occurrence times lead to the assumption, that the propagation velocity of the tidal wave has increased in the last decades.

More insight into the development of tidal phenomena in the German Bight may also be gained when taking meteorological time series into account.

Acknowledgement

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