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Changes of the tidal water levels at the German North Sea coast*

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ABSTRACT: For 10 selected tide gauges at the German North Sea Coast, the time series of the mean high water (MHW) and mean low water (MLW) were analysed. Since about 1950, both levels deviate from earlier trends; MHW shows an accelerated rise, while MLW even fell after an earlier rise.

INTRODUCTION

In earlier investigations, the mean secular rise of the sea level at the German North Sea coast was found to be between 20 and 30 cm/100 years (Schütte, 1935; Lüders, 1936; Hensen, 1938; Rohde, 1977). It was interpreted formerly as a sinking of the land due to settlements and tectonic movements. Repeated geodetic surveys (Gronwald, 1960) have shown, however, that the observed rise of water levels could only be explained by changes of the water level itself as the primary cause.

It had previously been assumed that mean high water (MHW), mean sea level (MSL) and mean low water (MLW) had the same increase rate, but Liese (1978) found that the MLW was rising more slowly than the MHW. For the last decades a clear anomaly was found, showing that the rate of increase for MHW was accompanied by a decrease of MLW (Führböter, 1982; Siefert, 1982; Jensen, 1984; Führböter & Jensen, 1985; Führböter, 1986).

MATERIAL AND METHODS

Recently, 10 gauges at the German North Sea Coast were selected for a detailed study of tidal water levels (Jensen, 1984; Führböter & Jensen, 1985).

The selection was based on the requirement that the time series of data should be as long as possible and free of significant man-made effects, such as those caused, for example, by dredging, training works, etc. The gauges selected are located both on islands and on the mainland (Fig. 1).

The series of the annual mean high water (MHW) of 10 gauges is shown in Figure 2, of the mean low water levels (MLW) in Figure 3 and of the mean tidal ranges (MTR) in Figure 4, respectively.

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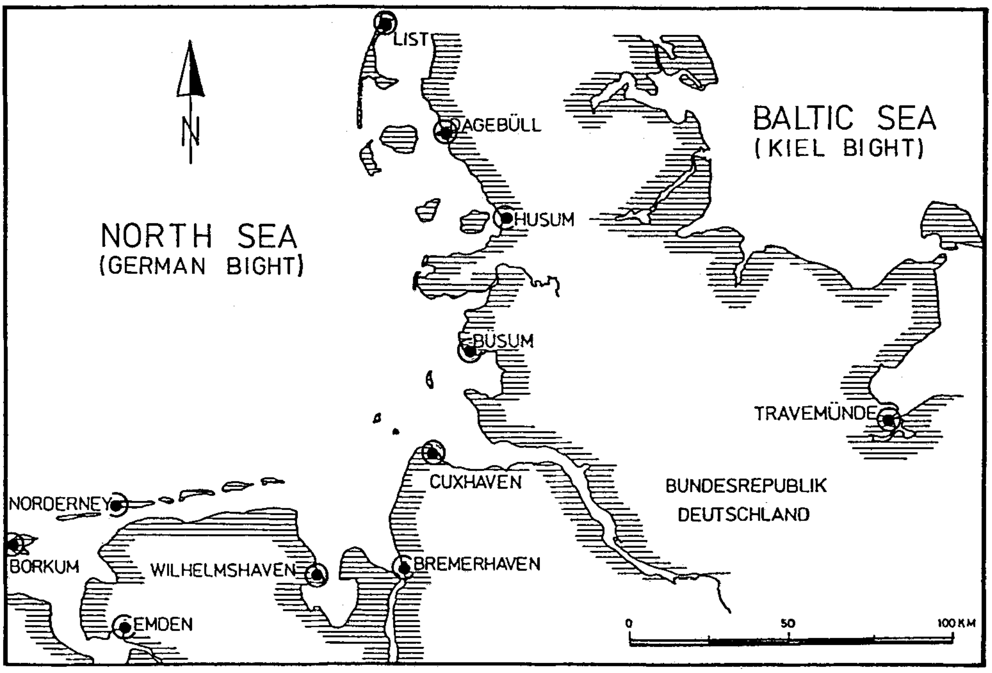

Fig. 1. Location map of gauges selected for the study of tidal water levels

RESULTS

Generally, the following tendencies can be seen in Figures 2 to 4:

(1) For the annual MHW was well as for the MLW, characteristic yearly fluctuations at all 10 stations exist. These fluctuations are mainly due to the mean meteorological conditions (barometric and wind effects), and appear simultaneously for MHW and MLW at all gauges. Note particularly the strong negative peak in 1947 which is known as a year with predominant high barometric pressures and prevailing easterly winds.

(2) In order to eliminate local effects, such as errors of the reference levels, the time series of average values from the 10 gauges are shown in Figures 2 and 3.

(3) Time averages of the mean residuals, like the 5-year running mean for MHW and MLW (Figs 2b and 3b), display in both cases long-period fluctuations. Up to about 1950, MHW and MLW rise uniformly. Since about 1950, however, the MHW increase has accelerated while the MLW has decreased. This is still evident from the 19-year running mean for MHW and MLW (Figs 2c and 3c).

(4) The fluctuations in the annual mean tidal range MTR (Fig. 4), the differences between MHW and MLW, appear to be weaker because they involve both the time series with similar fluctuations of MHW and MLW (see Figs 2 and 3). As a consequence of the rising MHW and the falling MLW in the last decades, a strong rise in the MTR occurs for all 10 gauges. This is particularly evident in the longer-term averages in Figures 4b and 4c.

In the 5-year running mean the well known nodal tide with a period of 18.6 years is

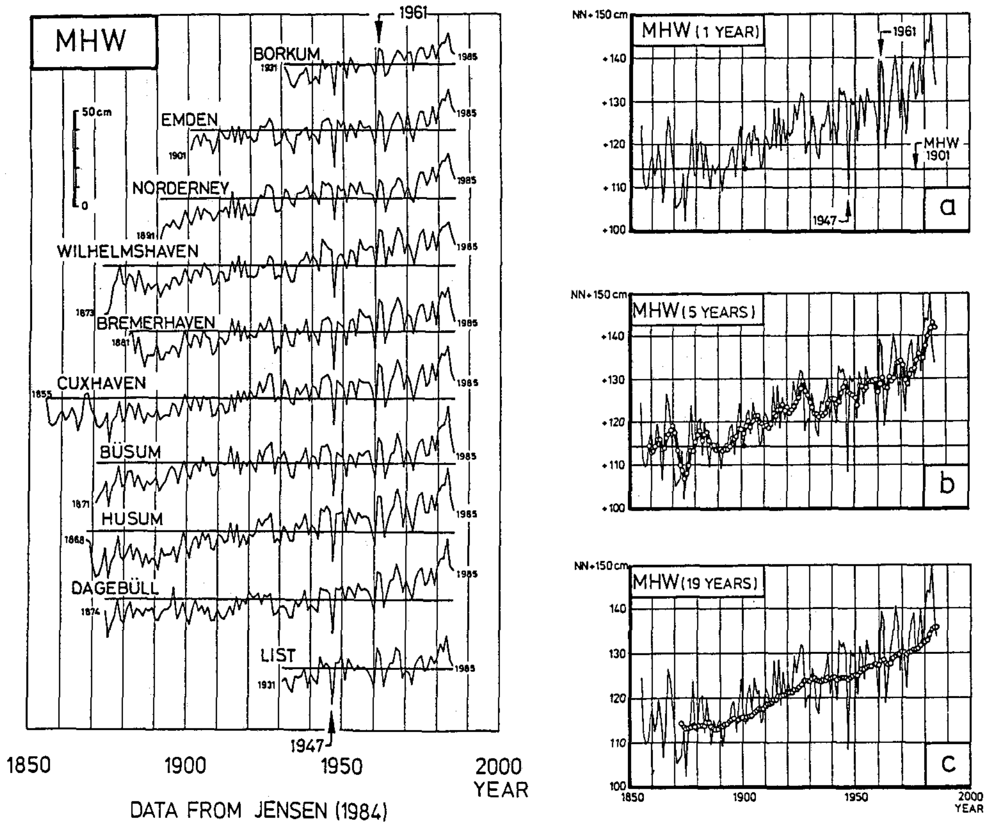

Fig. 2. Time series of the MHW at the German North Sea coast for the 10 gauges studied. Time series of yearly mean high water, MHW (left). Average MHW for the 10 gauges (right). a: annual mean values; b: as (a) plus a 5-year running mean (e.g. 1985 = mean 1981 to 1985); c: as (a) plus a 19-year running mean (e.g. 1985 = mean 1967 to 1985)

clearly present. The 19-year running mean eliminates this period and the changed secular trend in MHW and MLW is clearly evident in the strong rise of the MTR after 1960 (Fig. 4c).

This MTR anomaly also occurs on the eastern part of the coast of the Netherlands and on the southern Danish North Sea coast. Neither meteorological nor astronomical influences can be made responsible for this phenomenon. A possible explanation is a non-linear reflection of the tidal wave, especially from the tidal flats (Wadden Sea), in response to the rising global sea level. This hypothesis will be examined by a numerical tidal model of the complete North Sea with its special boundary conditions.

It may be of interest to observe the response of the Baltic Sea which, connected with the northern North Sea by Skagerrak and Kattegat, acts like a moderate tidal gauge. In Figure 5, the sea level trend at the station Travemünde (see Fig. 1) is in general agreement with the mean trend for the MHW of all 10 gauges at the North Sea (see Fig. 2), while the correlation to the MLW (see Fig. 3b) is weak, as indicated by the correlation coefficients k = 0.84 for the MHW and k = 0.45 for the MLW (North Sea) (Figs

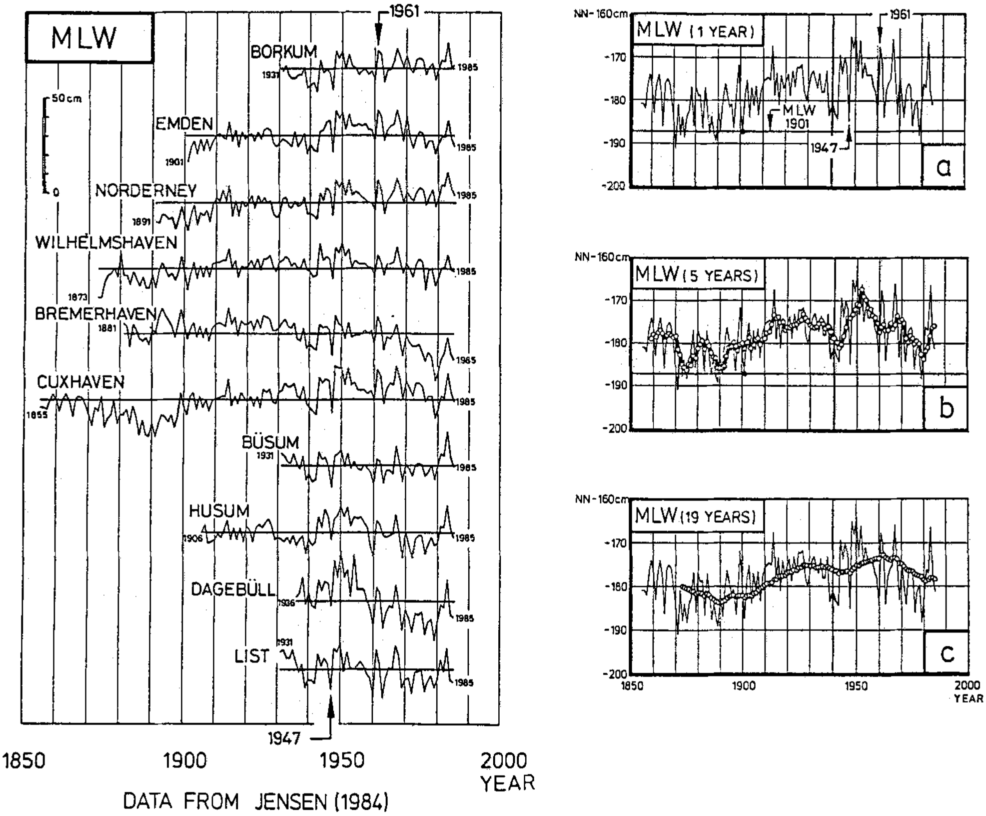

Fig. 3. Time series of the MLW at the German North Sea coast for the 10 gauges studied. Time series of yearly mean low water, MLW (left). Average MLW for the 10 gauges (right). a: annual mean values; b: as (a) plus a 5-year running mean (e.g. 1985 = mean 1981 to 1985); c: as (a) plus a 19-year running mean (e.g. 1985 = mean 1967 to 1985)

5b and c). Thus, MHW of the North Sea represents the mean trend of the Baltic Sea better than computed MSL which contains the MLW with its non-linear components (see Fig. 3).

The rise in MSL is also confirmed by the data from the USA Atlantic coast. The data by Barnett (1984) from 24 stations covering about 50 years, from 1926 to 1975, indicate an average increase rate of 33.7 ± 7.2 cm/100 years. For the same time period, the MHW from the 10 gauges on the German North Sea coast (according to Fig. 2a) gives 32.5 ± 9.5 cm/100 years, which is in good agreement with the US data from Figure 6.

Here, also, the question has to be posed regarding a future sea level rise due to climate changes (including human impacts). As discussed by Barnett (1984) the definition of a global rise of a "World Ocean" is very difficult. He evaluated from a selected number of stations around the earth, within a set of restrictions, a mean sea level rise of 14.3 ± 1.4 cm/100 years for the period of 100 years from 1881 to 1980 and of 22.2 ± 2.3 cm/100 years for the period from 1930 to 1980 (51 years). His estimation is that a tendency for acceleration as low as 10 % could be detectable from measurements of only one more decade.

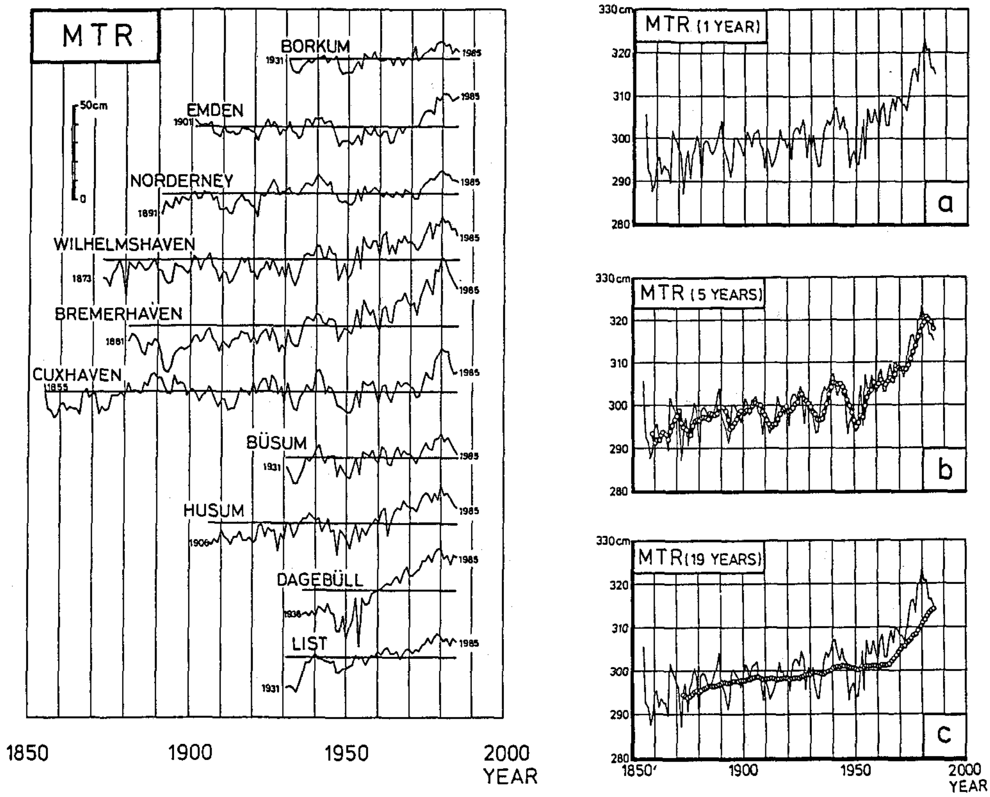

Fig. 4. Time series of the MTR at the German North Sea coast for the 10 gauges studied. Time series of yearly mean tidal range, MTR (left). Average MTR for the 10 gauges (right). a: annual mean values; b: as (a) plus a 5-year running mean (e.g. 1985 = mean 1981 to 1985); c: as (a) plus a 19-year running mean (e.g. 1985 = mean 1967 to 1985)

Evaluated (after the method of least squares) from the MHW data of the 10 stations at the North Sea, according to Figure 2, the results are:

100 years from 1886 to 1985: 25.4 ± 4.0 cm/100 years
50 years from 1936 to 1985: 30.4 ± 6.4 cm/100 years
25 years from 1961 to 1985: 43.8 ± 14.8 cm/100 years

It must be strongly emphasized that the numbers derived from 50- and 25-year series are only increase rates and not prognoses. Also, the earlier mentioned non-linear reflection behaviour must be discussed with its apparent amplifying effect. However, considering all the factors which influence the short- and long-period fluctuations of the time series for MHW (see Fig. 2), the likelihood of a tendency towards an acceleration in the rise of the sea level is present.

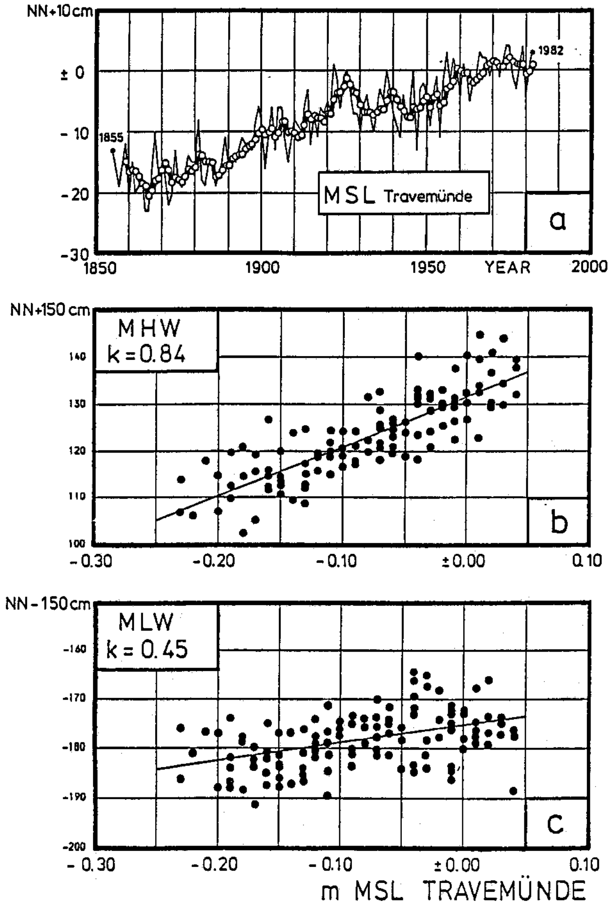

Fig. 5. Mean Sea Level (MSL) at Travemünde/Baltic Sea (a); correlations between MHW (North Sea) and MSL (Travemünde) (b) and between MLW (North Sea) and MSL Travemünde (c)

DISCUSSION

The extremely important consequences for the future will not be treated here (see Bruun, 1962), but the results presented are already significant for the present. Since in the last 25 years the mean high water levels (MHW) have risen more than 1 dm, accompanied by a fall in the MLW, the mean tidal range has increased by 1.5 dm or more, and the consequences for coastal defence works and waterways are already being felt. The consequences for the Wadden Sea are, a higher wave energy supply to the tidal flats, higher velocities in the tidal channels due to increasing tidal volumes, and consequential acceleration of erosion processes. For the gauge at List/Sylt, Figure 7 shows the development of duration (Führböter, 1979) of water levels higher than NN + 200 cm. The long durations after 1960 are also partly a product of increased storm surge activities during the last decades, an aspect which can only be touched on here (Führböter, 1976).

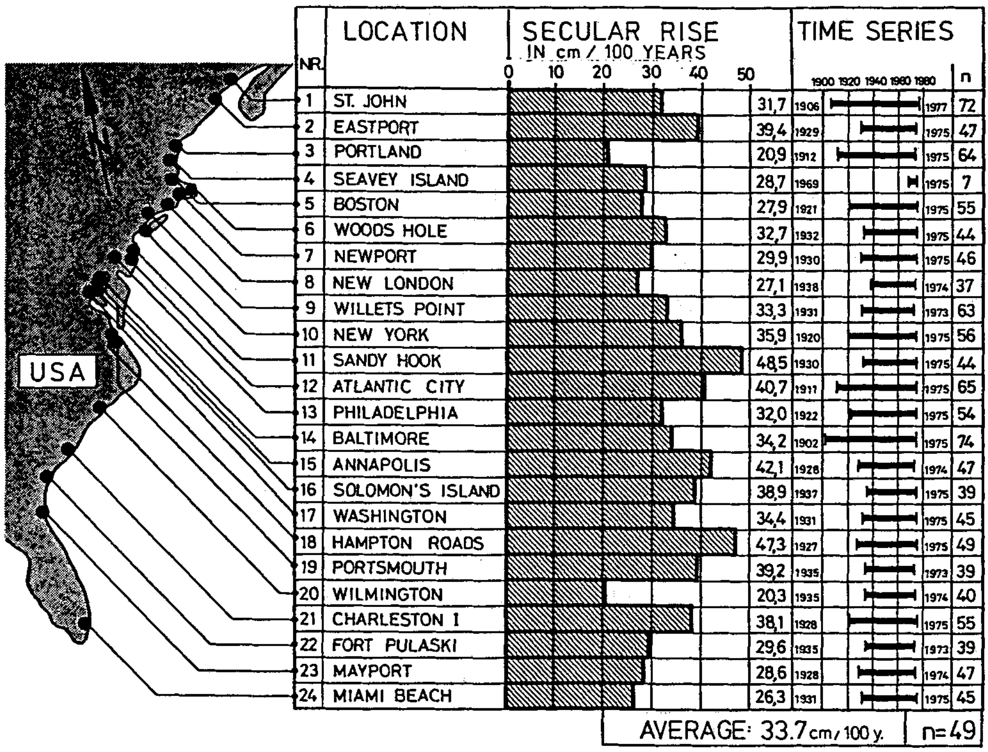

Fig. 6. MSL at the US Atlantic coast. Sea level rise at 24 stations (Data after Barnett, 1984)

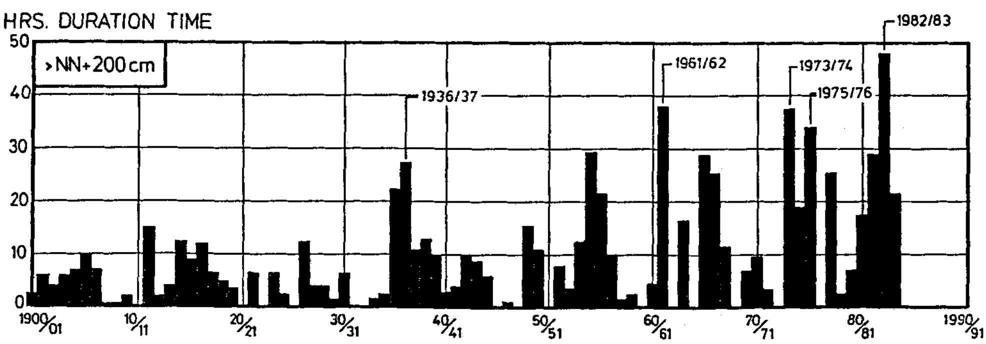

Fig. 7. Increase of water levels higher than NN + 200 cm at List (Sylt)

Being a very shallow sea, the North Sea might be regarded as a sensitive measuring device for global changes in climate and water levels; therefore, the developments at this site should be observed very carefully.

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