Journal of Coastal Research	10	1	206–209	Fort Lauderdale, Florida	Winter 1994

Recent Anomalies in Mean and High Tidal Water Levels at the German North Sea Coastline

A. Töppe and A. Führböter

Technical University of Braunschweig
Leichtweiss-Institute for Hydraulics
Department for Hydromechanics and Coastal Engineering
Beethovenstrasse 51a
D-3300 Braunschweig, Germany

ABSTRACT

TÖPPE, A. and FÜHRBÖTER, A., 1994. Recent anomalies in mean and high tidal water levels at the German North Sea coastline. *Journal of Coastal Research,* 10(1), 206–209. Fort Lauderdale (Florida), ISSN 0749-0208.

At the German North Sea coastline, an increase in frequency, height and duration of storm floods, especially at the northernmost part of the coastline, since about 1960 can be observed. At the same time, an anomalously increase in MTR occurred because of a sudden decrease of MLW. The storm surge anomalies could only happen if the meteorological conditions have changed. But time series of mean air pressure and wind data in the German Bight which have been derived from geostrophic wind show no such change. The increase in storm surge activity is linked to a stronger atmospheric circulation which is a result of a higher temperature gradient between the equator and the Arctic. Therefore, there is a connection with larger area climatic changes.

ADDITIONAL INDEX WORDS: *North Sea, Germany, tidal water levels, anomalies, sea level rise, storm floods, frequency, duration.*

TIDE GAUGE STATIONS, DATA AND SEA LEVEL RISE

From time series of 10 stations along the German North Sea coastline (Figure 1), the annual mean high water (MHW), low water (MLW), tidal range (MTR) and half-tide level (MTL) have been combined to single time series of a fictitious tide gauge called "mean German Bight".

The 19-year running means of these time series (Figure 2) show the same constant rise until about 1955 for MHW, MLW and MTL, which leads to a constant MTR up to this time.

After about 1960, the MLW has been sinking, whereas the MHW further rose and lead to a sudden rise in MTR of about 15 cm until 1980. Since then, the MLW has risen again.

The actual sea level rise (arithmetic average of the up to 10 stations) of MLW, MHW and MTR for several periods until 1990 is shown in Table 1. In time series of annual means, the period with the highest amplitude is the astronomical nodal tide (18.6 years). In order to eliminate its influence, JENSEN *et al.* (1992) recommended at least two multiples of its period for investigations of sea level rise. The sea level rise within one to three nodal cycles is, therefore, also included in Table 1.

93053 received and accepted 29 May 1993.

Sea level rise or sink is computed as a linear trend of a time series. Its value depends on the location, on the chosen tidal datum, and on the length of the time series. It varies from one of these parameters to another. If the location, tidal datum, and investigation period are constant, a rise until the actual years $x_i, x_{i+1}, x_{i+2}, \ldots, x_{i+n}$ can be determined and plotted as a function of time. This has been done for the MTR time series of 9 stations with a period of 56 years (three nodal cycles) and the results are shown in Figure 3.

For Borkum to Cuxhaven, the last point of the function indicates the sea level rise of MTR from 1936 to 1991 (56 years); whereas for Büsum to List, the last period is 1935 to 1990. The functions do not behave uniformly: at Borkum, Emden and Husum, the rise accelerated within the latest years; at Norderney, an almost constant rise is to be seen; and at Wilhelmshaven, Bremerhaven, Cuxhaven, Büsum and List, MTR decreases a little bit.

STORM SURGE PROBABILITIES

The time series of annual maximum water levels (HHW) can be fitted with certain fitting distributions, *e.g.* JENKINSON-C or FÜHRBÖTER '76 (FÜHRBÖTER *et al.,* 1988; CONRING, 1991) and a water level with a probability of, for ex-

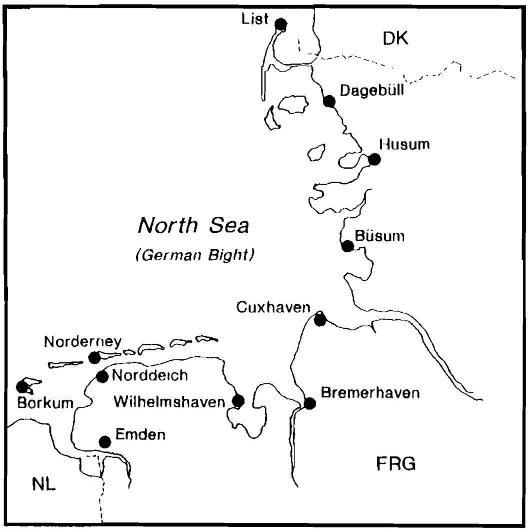

Figure 1. Tide gauge stations at the German North Sea coast.

ample, once in a hundred years (H_{100}) can be computed. This value is not a constant, but varies in time. If H_{100} is extrapolated from *e.g.* 50 years of a longer time series and this 50-years-window is moved from year to year, the result is the time dependent function of H_{100}.

Such functions of H_{100} have been plotted in Figure 4 for the stations Norddeich, Wilhelmshaven, Cuxhaven, Büsum, Husum and Dagebüll with every extrapolated H_{100} at the end of the actual window. The stations cover the German North Sea coastline from the west to the north. Both functions show an almost constant difference. The dis-

Table 1. *Averaged sea level rise from 10 stations (mm/year).*

Period	MLW (mm/year)	MHW (mm/year)	MTR (mm/year)
1891–1990 (100 years)	1.1	2.7	1.6
1941–1990 (50 years)	−0.5	3.4	3.9
1966–1990 (25 years)	1.7	4.9	3.5
1935–1990 (56 years = three nodal cycles)	−0.3	3.1	3.4
1954–1990 (37 years = two nodal cycles)	−0.2	4.3	4.4
1972–1990 (19 years = one nodal cycle)	5.8	7.5	1.6

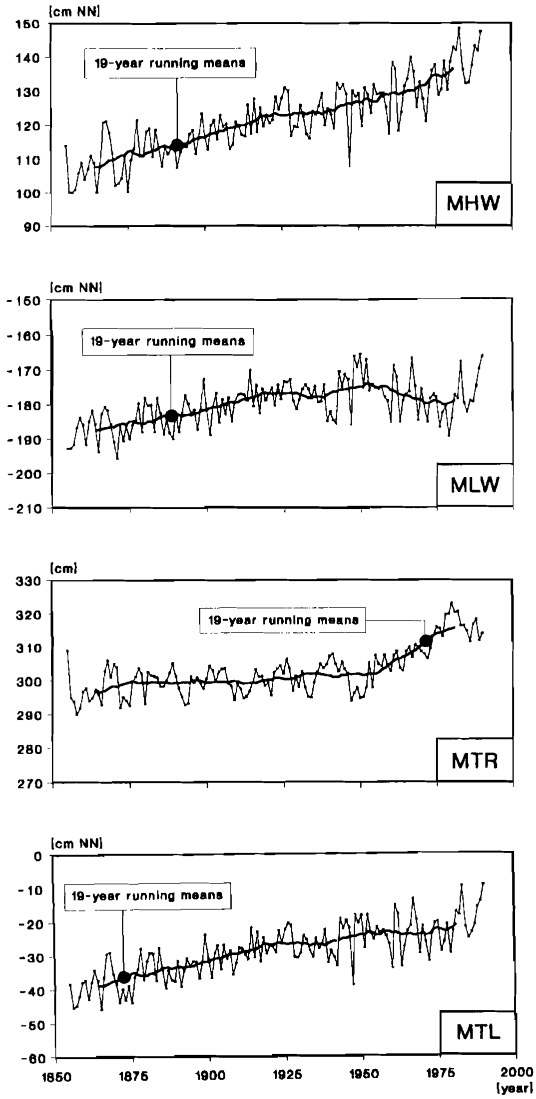

Figure 2. Time series of MHW, MTL, MLW and MTR of tide gauge "mean German Bight" (thick line: 19-year running means).

continuities result from very high annual water levels coming into or going out of the window. At Norddeich, the negative discontinuity of 1956 depends on the storm surge of 1906 (the highest known at this station, max. HHW) and the positive ones of 1962 and 1976 on storm surges of the same years. There is a strong decrease in both functions until 1962 and no apparent tendency since then. At Wilhelmshaven, almost no trend

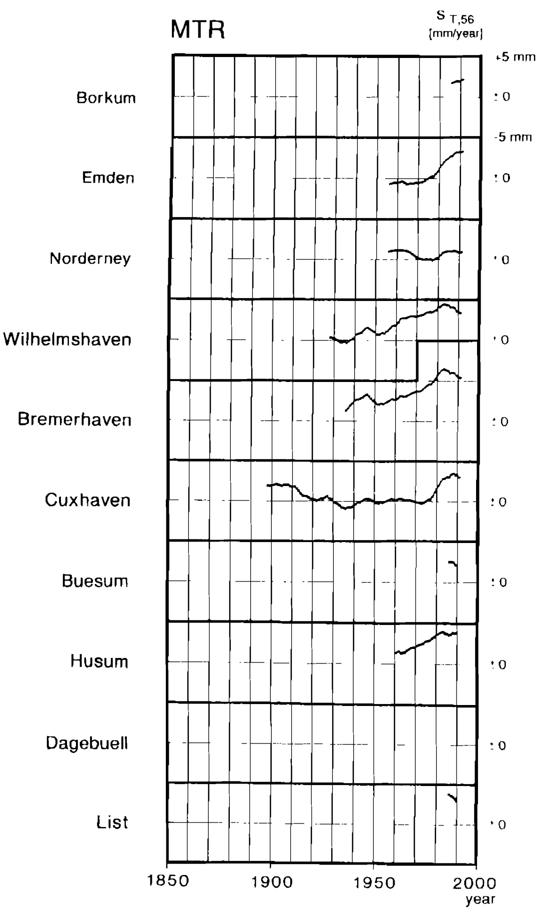

Figure 3. Functions $s_{T,56}$ for MTR of 9 stations.

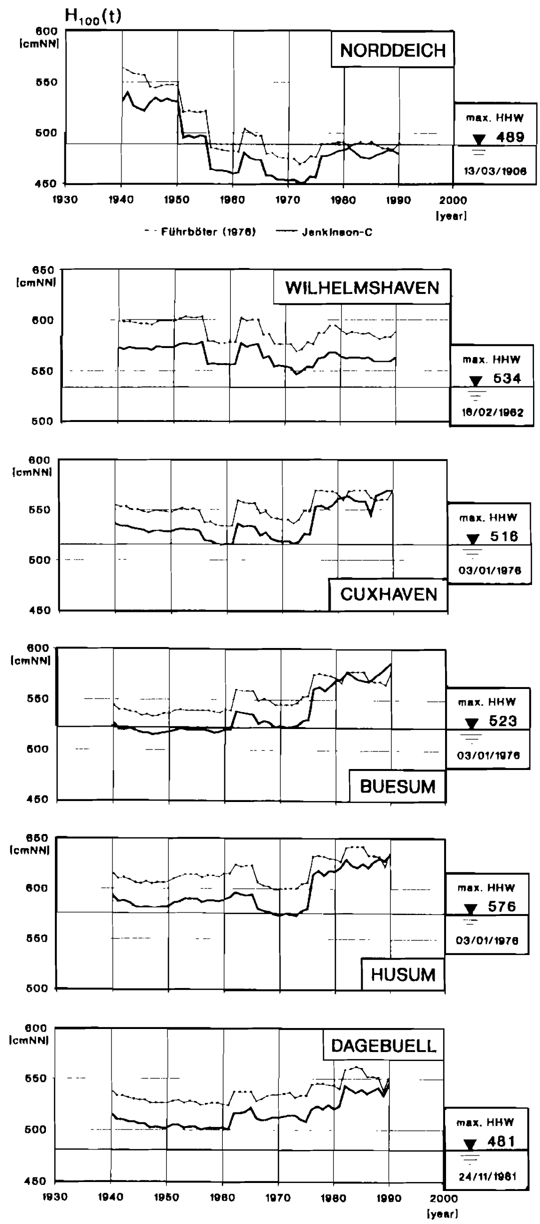

Figure 4. H_{100}-functions and max. HHW from 6 stations.

can be seen. From the tide gauges of Cuxhaven up to Dagebüll, an increase of the H_{100}-functions is evident. The strongest positive discontinuities correspond with the years of the max. HHW at the stations.

The changes in the storm surge probabilities, here expressed by H_{100}, are a direct result of the storm surge activity within the last decades. At Norddeich in the west, the max. HHW is still from 1906. From Wilhelmshaven to Dagebüll, this value has been extended in 1962 and from Cuxhaven to Dagebüll again in 1976. At Dagebüll, one more high storm surge happened in 1981. This height has almost been reached by the latest surge in 1990, which affected the coastline from Cuxhaven northwards. A tendency for more and higher storm surges at the northern coastline is obvious.

DURATION OF STORM SURGES

Time series of annual storm surge frequencies from the tide gauge stations at Cuxhaven (mouth of the Elbe river) and List (island of Sylt) from the year 1900 until now show an increase in storm

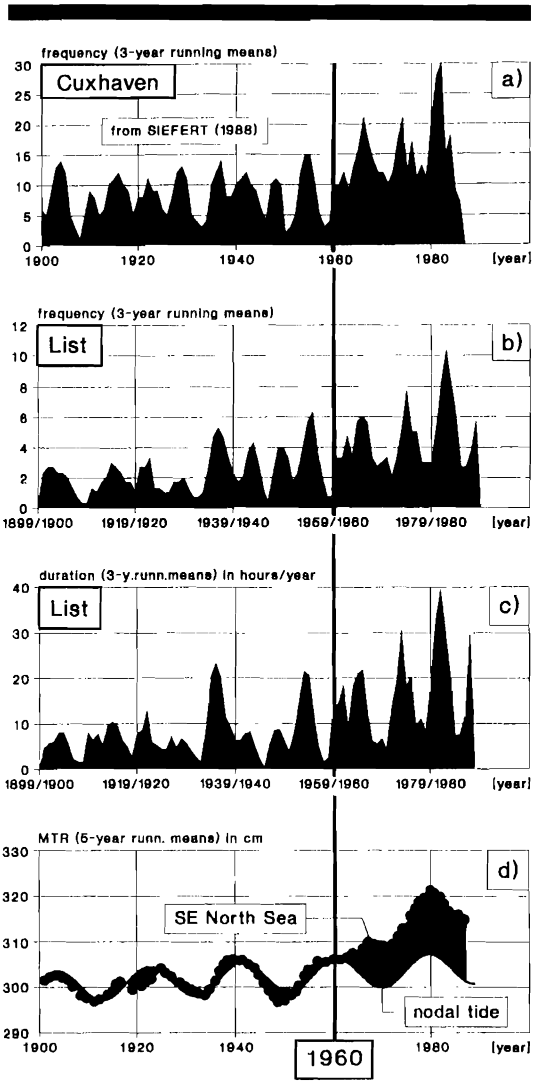

Figure 5. (a) Station Cuxhaven: Frequency of storm floods (SIEFERT, 1988), (b) Station List: Frequency of storm floods, (c) Station List: Durations above NN + 2 m, (d) 10 gauges: Mean tidal range. (a) to (c) 3-year running means, (d) 5-year running means.

surge activity since about 1960 (see Figures 5a and b).

Because the damage potential of a storm tide arises not only from its height but also from its duration, the durations of water levels above NN+2.0 m have been investigated (Figure 5c). NN is the official German datum for geodetical surveys and NN+2.0 m is about 1.3 m above MHW at List. The durations can be considered as a measure for the frequency of storm tides, and this parameter also increased after about 1960.

The time series of MTR (tide gauge "mean German Bight") is shown on Figure 5d together with the astronomical nodal tide. Another anomaly seems therefore to be present in the mean tidal levels since about 1960. This anomaly cannot be explained by increased wind set-up due to a possible change in the predominance of main wind directions. If the wind set-up would have increased, it would have a stronger influence on low water levels than on high water levels; and as a consequence, the tidal range would have to decrease. At time series of air pressure, wind speed, and direction over the Southern North Sea, no change in the last three decades can be seen and the anomalies cannot be explained by changes in the meteorological conditions. This leads to the conclusion that effects in a larger scale area such as trends in the climate development of the North Atlantic region are reflected here.

ACKNOWLEDGEMENTS

Financial support was given through the German Federal Ministry for Research and Technology (project MTK 0479-0), which we gratefully acknowledge.

LITERATURE CITED

Conring, I., 1991. Analyse der Wasserstände am Pegel Norddeich. Diplomarbeit an der TU Braunschweig, Abt. Hydromechanik und Küstenwasserbau (unpublished).

FÜHRBÖTER, A.; JENSEN, J.; SCHULZE, M., and TÖPPE, A., 1988. Sturmflutwahrscheinlichkeiten an der deutschen Nordseeküste nach verschiedenen Anpassungsfunktionen und Zeitreihen. *Die Küste*, 47, 163–186.

JENSEN, J.; MÜGGE, H.E., and SCHÖNFELD, W., 1992. Analyse der Wasserstandsentwicklung und Tidedynamik in der Deutschen Bucht. *Die Küste*, 54.

SIEFERT, W., 1988. Einige Anmerkungen zur Sturm flutentwicklung im Nordsee-Küstengebiet. *HANSA Schiffahrt-Schiffbau-Hafen*, 125(20), 1301–1306.