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Regional patterns of sea level change in the German North Sea in a worldwide context

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Abstract

This contribution focuses on presenting the results from analysing mean sea level changes in the German Bight, the south-eastern part of the North Sea. Data sets from 13 tide gauges covering the entire German North Sea coastline and the period from 1843 to 2008 have been used to estimate high quality mean sea level time series. The overall results from nonlinear smoothing and linear trend estimations for different time spans are presented. Time series from single tide gauges are analysed as well as different 'virtual station' time series. An accelerated sea level rise in the German Bight is detected for a period at the end of the 19th century and for another one covering the last decades. In addition, different patterns of sea level change are found in the German Bight compared to global patterns, highlighting the urgent need to derive reliable regional sea level projections to be considered in coastal planning strategies.

1 Introduction

Sea level rise (SLR) is one of the major consequences we are facing in times of a warming climate and it is obvious that a higher sea level influences the heights of occurring storm surges and thus results in a higher risk of inundation for the affected coastal areas.

Therefore, regional and global sea level rise are subjects to many recent scientific publications. In contrast, the mean sea level (MSL) and its variability over the last centuries in the German North Sea area have not been analysed in detail up to now. A methodology to analyse observed sea level rise in the German Bight, the shallow south-eastern part of the North Sea, is presented. The contribution focuses on the description of the methods used to generate and analyse high quality mean sea level time series. A virtual station time series for the German Bight is estimated, analysed in detail by applying parametric and non-parametric fitting approaches and compared to two global sea level reconstructions (Church & White 2006, Jevrejeva et al. 2008).

2 Data and Methods

The data sets of 13 tide gauges covering the entire German North Sea coastline are considered for the analyses (figure 1). Figure 2 shows that data sets with a resolution in time of at least one hour are available since the end of the last century for most of the tide gauges. To combine the MSL values with the mean tide level (MTL) values, estimated from tidal high and low waters, the k-factor method is used (Wahl et al. 2010, 2011). Different tests are applied (Kolmogorov-Smirnov-Test, Mann-Kendall-Test, Sliding-Window-Test) to prove stationarity of the k-factor time series.

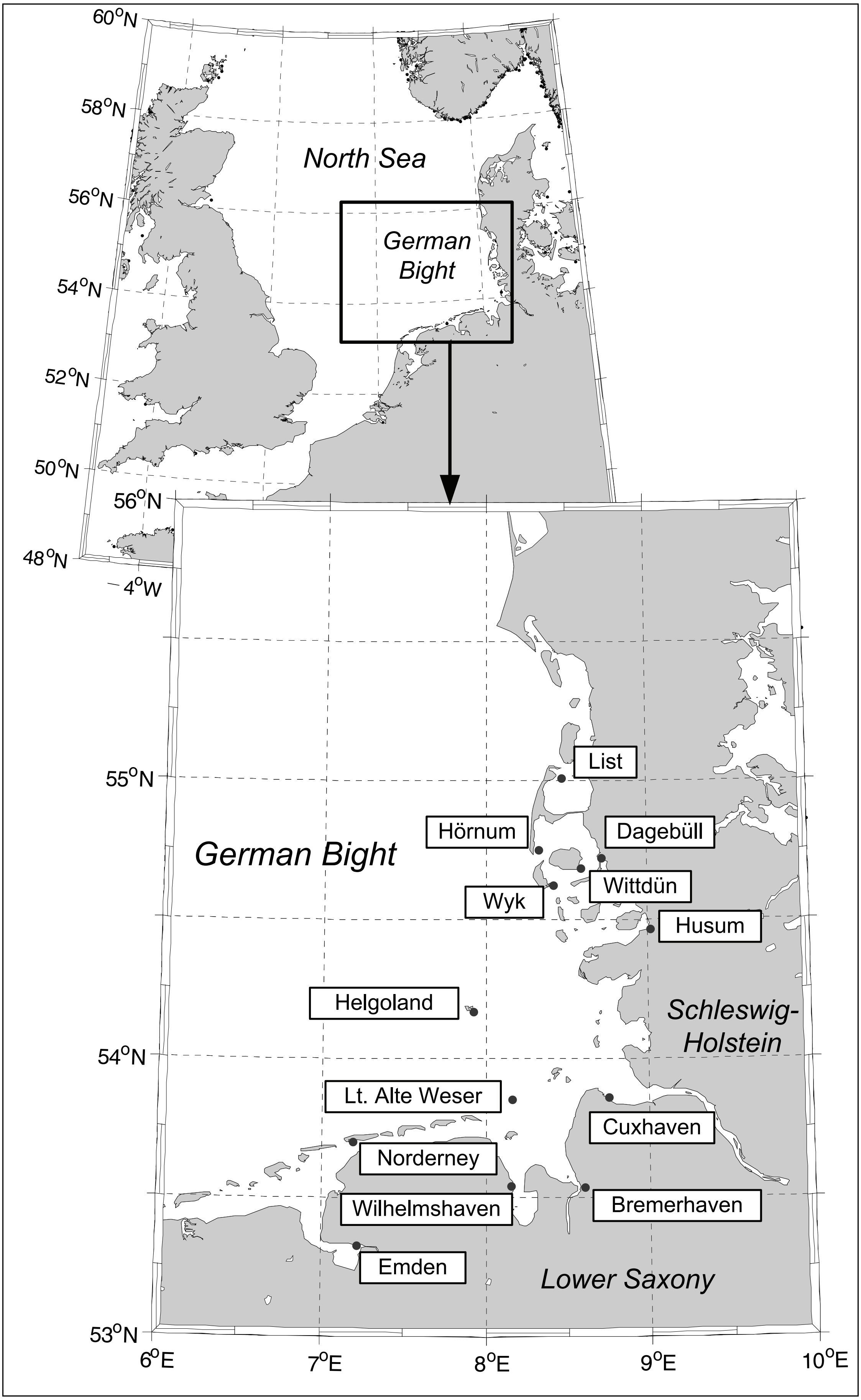

Figure 1: Investigation area.

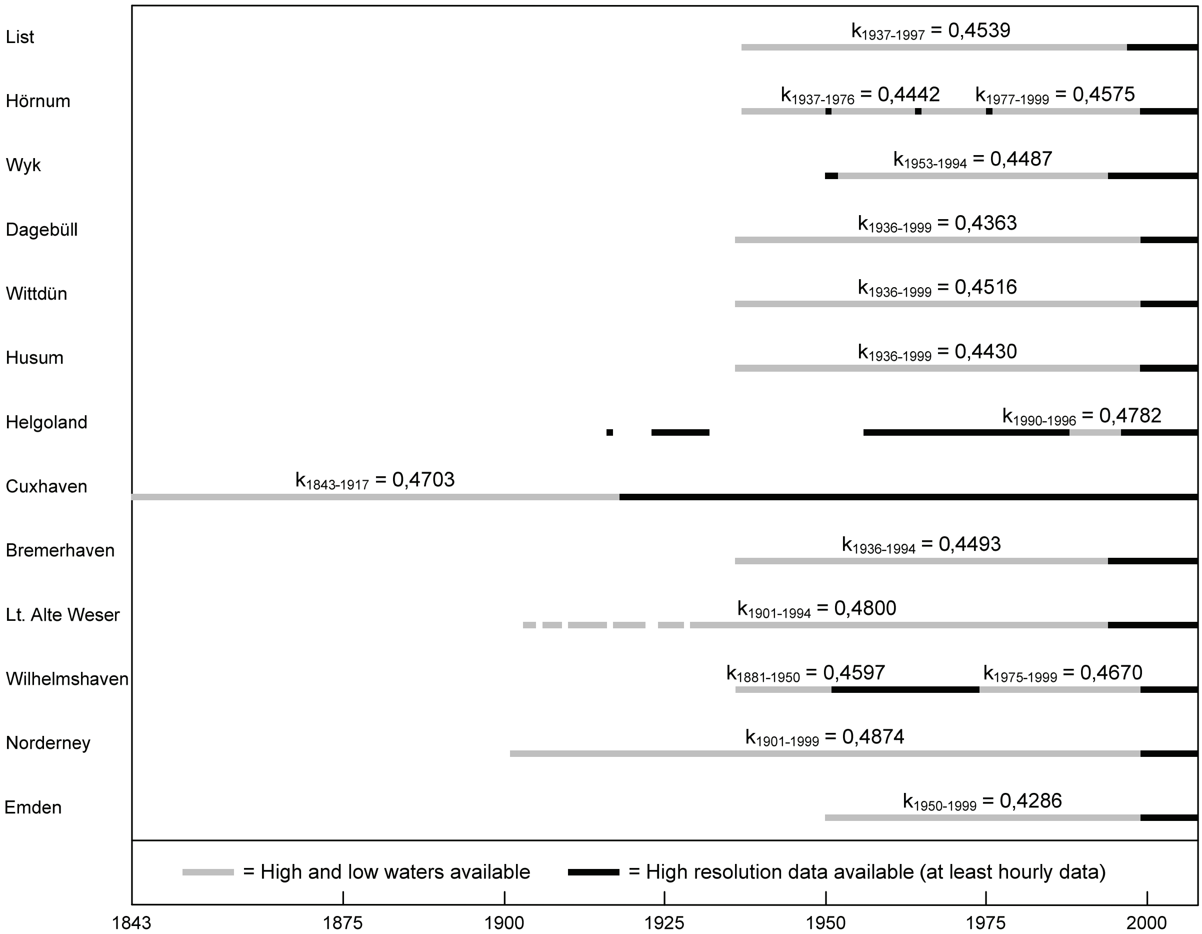

Figure 2: Available data sets and the estimated k-factors for different time periods.

Afterwards, a virtual station time series for the German Bight is estimated by integrating the averaged rates of SLR per year of the different gauges. Parametric fitting approaches as well as non-parametric data adaptive filters, such as Singular System Analysis (SSA), are applied to the resulting time series. For padding non-stationary sea level time series, an advanced approach named Monte-Carlo autoregressive padding (MCAP) is used. This approach allows the specification of a kind of uncertainties of the behaviour of smoothed time series near the boundaries. Finally, the reconstructed time series for the German Bight is connected to global sea level reconstructions.

3 Results

Figure 3 (top) shows the estimated virtual station time series of the German Bight. This relative mean sea level time series has a linear trend of 2.01 ± 0.08 mm/a for the entire period since 1843. The estimated trend is 1.68 ± 0.14 mm/a for the period since 1901, 1.96 ± 0.26 for the period since 1937, 2.14 ± 0.39 mm/a for the period since 1951 and 3.60 ± 0.74 mm/a for the reduced period since 1971 (quoted errors are 1-σ standard errors).

In addition, figure 3 (top) shows the results from analysing the virtual station time series using SSA with an embedding dimension of 15 years and 75,000 MCAP simulations to achieve stable results for the reconstruction near the boundaries. Figure 3 (bottom) shows the first differences of the reconstruction providing the best fit for the observed data. The results indicate that an acceleration of SLR took place at the end of the 19th century and was followed by a deceleration. Another period of accelerated SLR obviously started around 1970 and has declined in recent years.

Actual rates of relative SLR in the German Bight are in the order of 4-5 mm/a (note that the uncertainties increase near the boundaries).

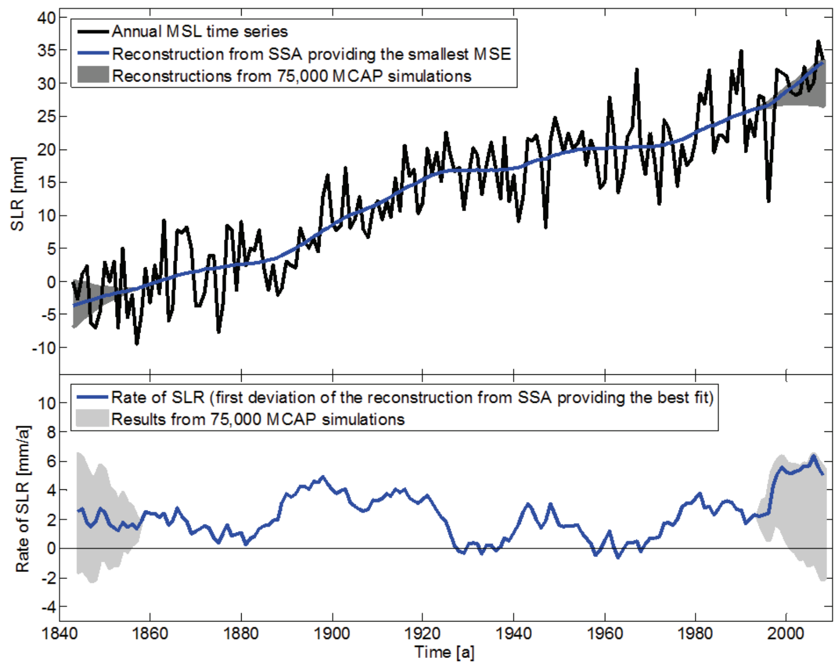

Figure 3: Virtual station for the German Bight and results from SSA reconstruction using the MCAP approach.

Figure 4 shows the results from estimating running linear trends for different time spans of the virtual station time series. The results for 30-, 40- and 50-a time spans approve the existence of a period of acceleration at the end of the 19th century and another one with its starting point around 1970. A window length of 20-a seems to be too short to achieve meaningful results for the underlying time series, showing a high variance.

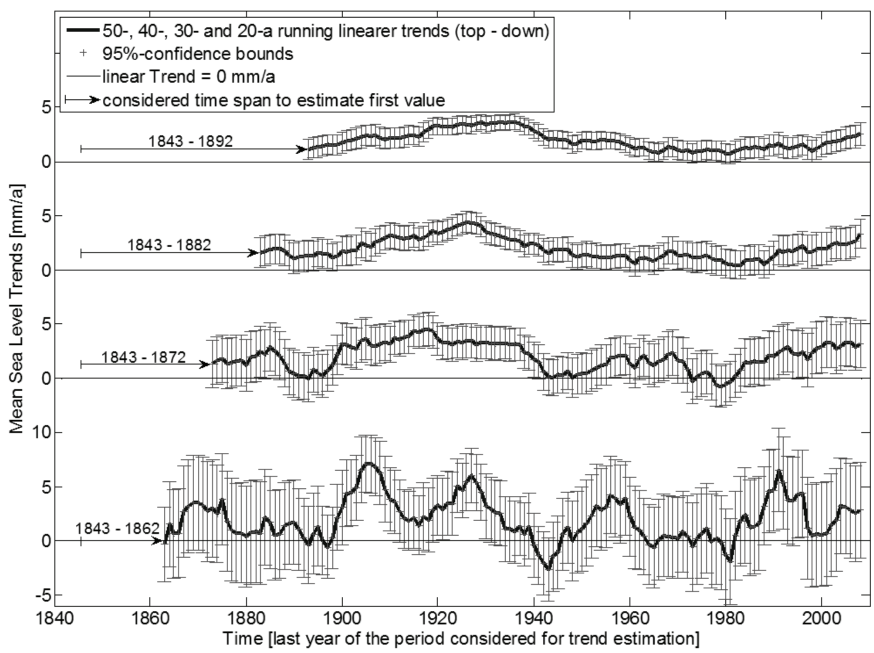

Figure 4: Running linear trends for different time periods of the virtual station time series.

Figure 5 shows the results from comparing the virtual station time series of the German Bight with two global sea level reconstructions (Church & White 2006, Jevrejeva et al. 2008). The reconstruction by Jevrejeva et al. (2008) is based on tide gauge data and provides MSL values for the period of 1700 to 2002. The reconstruction by Church & White (2006) considers tide gauge data as well as altimetry data and provides MSL values for the period of 1870 to 2007. Both reconstructions were GIA corrected. They are also analysed using SSA with an embedding dimension of 15 years in combination with MCAP. Figure 5 (top) shows the differences between the rates of SLR estimated from the GIA corrected reconstruction for the German Bight and the global reconstructions. Higher rates in the German Bight are observed for a period around 1850, a period around 1900 and the period covering the last 10 to 15 years.

The results clearly reveal the existence of different patterns of sea level change, which is approved by estimating 20-a running correlation coefficients (figure 5, bottom). Insignificant correlations are present for most of the periods of the considered time span (significance levels were estimated by applying t-test statistics).

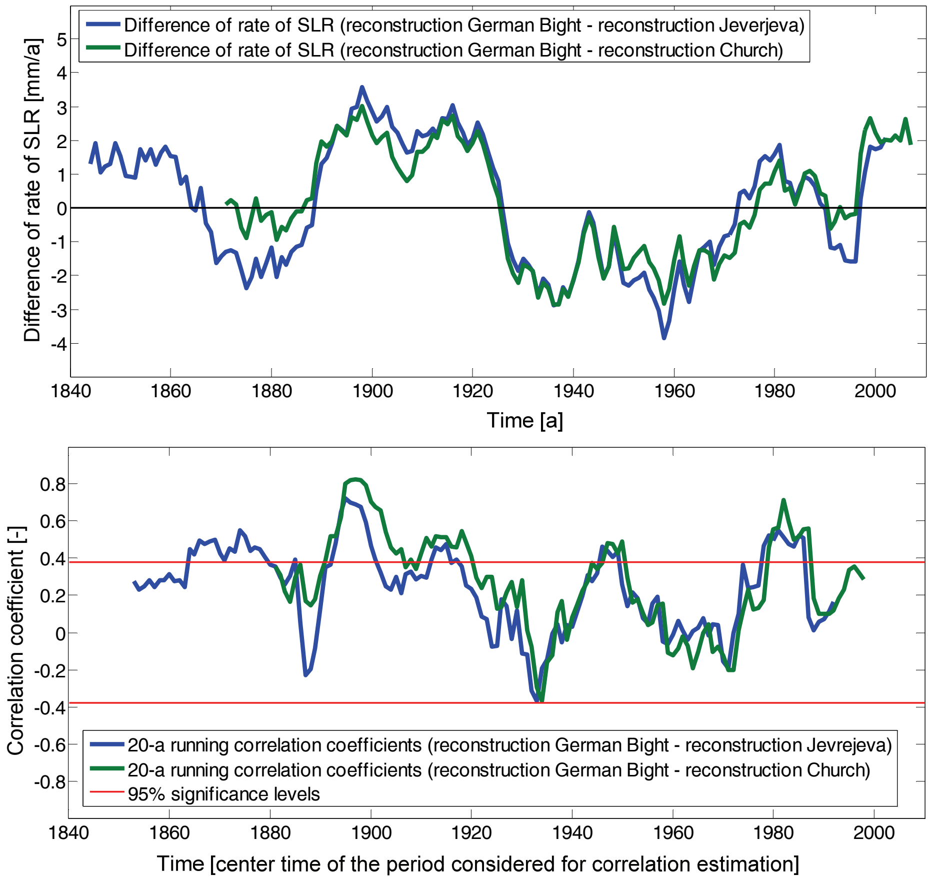

Figure 5: Difference of rate of SLR and 20-a running correlation coefficients between the virtual station for the German Bight and two global sea level reconstructions.

4 Conclusions and Outline

In this paper observed MSL changes in the German Bight over the last 166 years are presented. Analyses have been conducted for relative mean sea level time series from 13 tide gauges covering the entire German North Sea coastline and for a virtual station comprising the time series from single gauges. It was found that the considered MSL time series are of very good quality showing high correlation with the estimated virtual station for the entire German Bight. Non-linear smoothing techniques are applied to identify the underlying long-term variability, which includes the identification of periods with considerably high or low rates of SLR.

To sum up the key findings, it was found that an acceleration of SLR occurred at the end of the 19th century followed by a deceleration. Another acceleration with its starting point in the 1970s and intensification from the 1990s on cannot be denoted as unusual or possibly attributed to anthropogenic impacts considering the last 166 years of observations. Nevertheless, the reported findings highlight the necessity for further studies and a regular update of the presented results.

The regional patterns of sea level change in the German Bight are identified by analysing a virtual station comprising all considered tide gauges. The comparison with a global sea level reconstruction reveals different patterns of sea level changes. Further studies including the application of more complex methods are necessary to compare time series on different time scales and to achieve a better insight into the underlying processes the consideration of additional climate related parameters seems to be useful.

To conclude, the presented results indicate the importance of regional sea level studies based on long and high quality sea level observations and it is recommended to put some efforts in further digitisation exercises and data archaeology. That will provide longer time series to better understand the underlying physical processes, which is essential to improve the accuracy of regional sea level rise scenarios to be considered in coastal management strategies.

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