Combining High and Low Resolution Sea Level Data for MSL Computations in Shallow Seas

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I. Introduction

Whereas regional and global sea level rise (GSLR) are subjects of many recent scientific publications, the mean sea level (MSL) and its variability over the last centuries in the German North Sea area has not been investigated in detail. In this poster, we present results from analyzing sea level rise (SLR) since 1844 on the basis of two selected gauge stations (Figure 1).

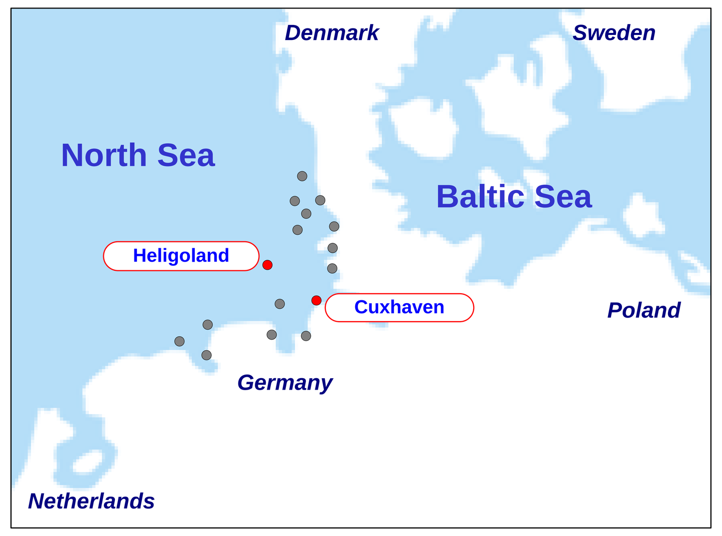

Figure 1. Investigation area with the two gauges analyzed in this poster and fourteen others.

Although the difference between MSL and mean tide level (MTL) is small in most areas, it is found to be up to 25 cm at the German coast due to its shallowness. We present methods to combine high and low resolution sea level data and to analyze the resulting time series. The results contribute to the verification of regional climate models and provide first indications of SLR for regional and local planning issues.

II. Data and Method

All results are based on the available data sets of the tide gauges Cuxhaven and Heligoland (see Figure 1 and Figure 2). The first one provides the longest record for the German North Sea with permanent data since 1844. The latter one provides high quality sea level data (1953-2007) due its exposed location. All data sets are corrected for local datum shifts and glacial isostatic adjustment (GIA) [*Peltier, 2004*]. To combine the MSL time series resulting from the high resolution data and the MTL time series resulting from the low resolution data, a monthly k-factor time series is estimated. The dimensionless k-factor is a reference value for the difference between MSL and MTL and is calculated as

$k = (MHW-MSL)/MTR$,

where MHW is the monthly mean high water, and MTR is the monthly mean tidal range. Before using the k-factor for mixing MSL and MTL data, it has to be tested whether it is a stationary parameter for the investigated gauge station or not. Therefore we apply two tests on stationarity. The first one is a sliding-window test [*Mudersbach, 2008; van Gelder, 2008*], the second one a two dimensional non-parametric Kolmogorov-Smirnov test [*Chen and Rao, 2002; Mudersbach, 2008*].

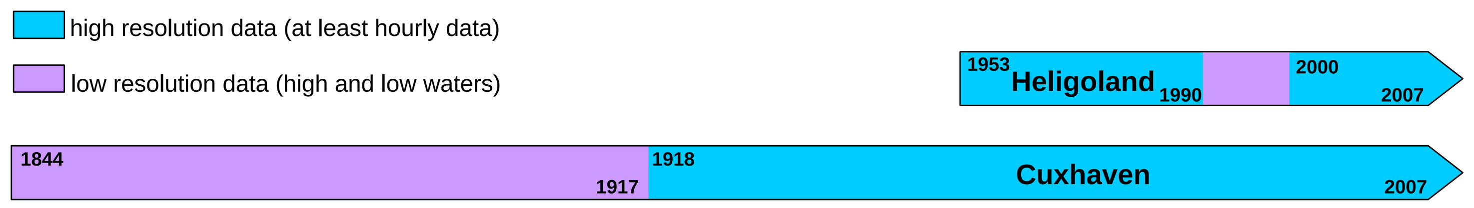

Figure 2. Available gauge records and the related resolution in time.

To analyze the resulting MSL time series we use a Matlab routine conducting the following computational steps: first and second order polynomial functions are fitted to the time series. Overlapping 20-year linear trends are estimated. A simple moving average (MA) and Singular Spectrum Analysis (SSA) are applied to analyze the non-linear behavior. For padding the time series we use the 'minimum roughness' criterion (MR) [*Mann, 2004*], a variation of the 'minimum roughness' criterion (VMR) [*Jevrejeva et al., 2006*] and a method we call Monte-Carlo Autoregressive Padding (MCAP). The latter is done by first detrending the original time series, before 10,000 surrogate data sets are generated using an AR1 model. The surrogate data sets are two times the chosen embedding dimension longer than the original time series.

After re-including the linear trend, the ends of the surrogate data sets are used for padding. For SSA reconstruction, those EOFs providing trend information are extracted, again using tests on stationarity. We are most interested in the behavior near the posterior boundary. Therefore the reconstruction providing the smallest mean squared error (MSE) for the last part of the time series (one embedding dimension) is selected.

III. Results

Both k-factor time series are found to be stationary. Figure 3 shows the results of the sliding-window test with a window length of twelve month for the monthly k-factor time series of Heligoland. It is tested, how many of the means exceed the 95% confidence bounds of the mean of the reference window. From 20,000 Monte-Carlo simulations we found that exceedance rates up to 60% are possible with stationary time series.

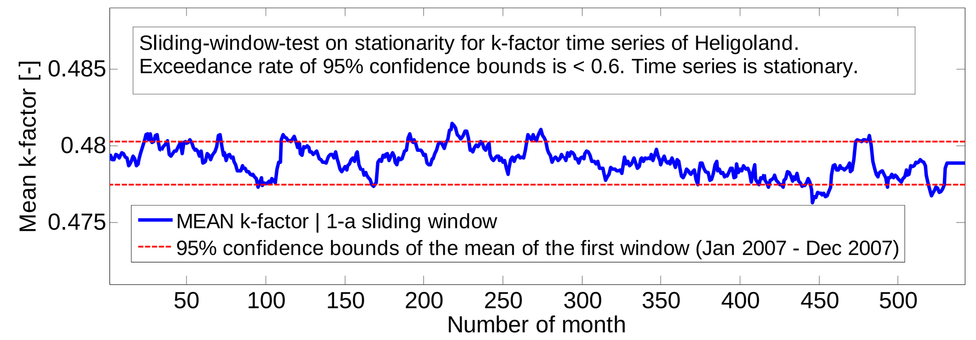

Figure 3. Results of the sliding-window test with a window length of one year for the monthly k-factor time series of Heligoland.

For the Cuxhaven time series a second order polynomial fit provides the smallest MSE. Although the weak negative acceleration of -0.0006 mm/a^2 (twice the quadratic coefficient) is not significant, the results are not overall consistent with those from global analyzes, showing a positive acceleration over a similar or even the same period [*Church and White, 2006; Jevrejeva et al., 2008*]. The estimated long-term trend since 1844 is 1.9 ± 0.1 mm/a, the one for the twentieth century 1.5 ± 0.15 mm/a (all quoted errors are one standard deviation). For Heligoland the trend since 1953 is found to be 1.8 ± 0.4 mm/a. The results fit well with those from other regional and global studies [*Church and White, 2006; Woodworth et al. 2009*].

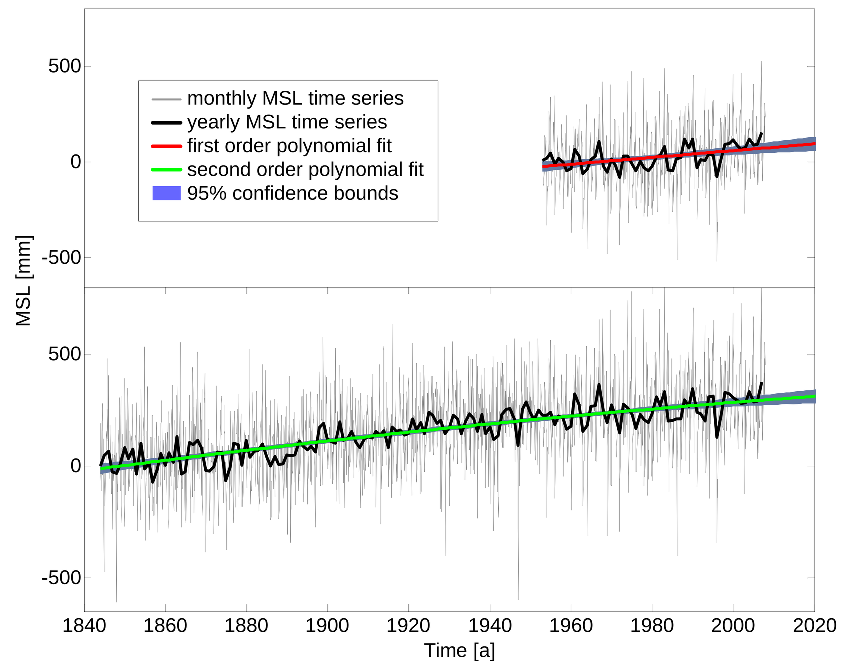

Figure 4. Results of parametric fitting. First and second order polynomial functions are used.

The overlapping 20-year linear trends show the highest rates around 1895 and also high rates around 1917. The inflection point at the end of the 19th century is remarkably close to that found in 1880 from the Liverpool gauge data and in 1890 from the Brest gauge data [*Woodworth, 1999; Wöppelmann, 2006*].

Furthermore, figure 5 shows high recent and actual rates, whereas the uncertainties are higher for the rates near the boundaries.

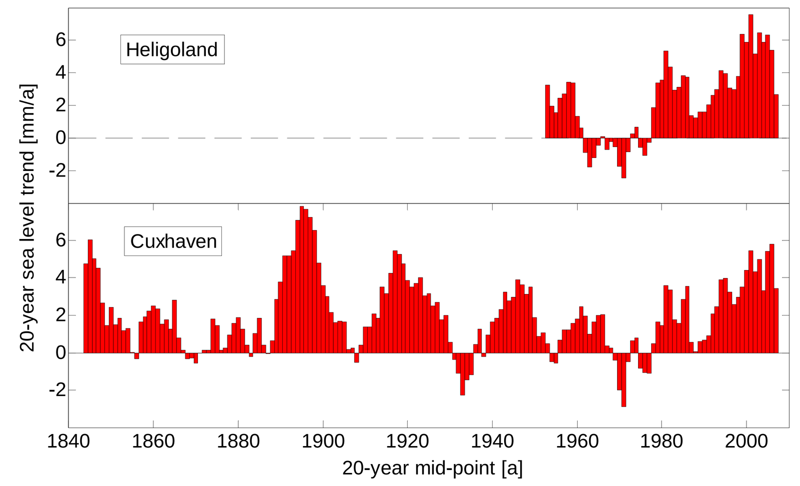

Figure 5. Linear trends in sea level estimated from overlapping 20-year periods.

The non-linear trends from SSA reconstruction indicate a strong acceleration from the mid of the 1970s. From 1976-2007 the Heligoland time series shows a significant acceleration of 0.12 mm/a^2 (Cuxhaven 0.08 mm/a^2). The linear trend for the same period is 4.2 ± 0.9 mm/a (3.1 ± 1.0 mm/a for Cuxhaven). The one for the reduced period 1993-2007 is 8.9 ± 2.7 mm/a (6.5 ± 3.5 mm/a for Cuxhaven). The latter is more than twice the global rate of 3.36 ± 0.41 mm/a found from altimetry data [*Beckley et al. 2007*]. However, Figure 6 shows, that the method used for padding the original time series influences the results. MR reacts very sensitive to the last value(s). Thus, for high variability time series, as found for MSL in the German North Sea, it might lead to an over- or underestimation near the boundaries. VMR, which means preserving the local trend at the boundaries, leads to similar results than MCAP for the investigated time series. MCAP, also not being a totally, but here the most objective method, seems to be useful to avoid misinterpretation of the non-linear trends near the boundaries.

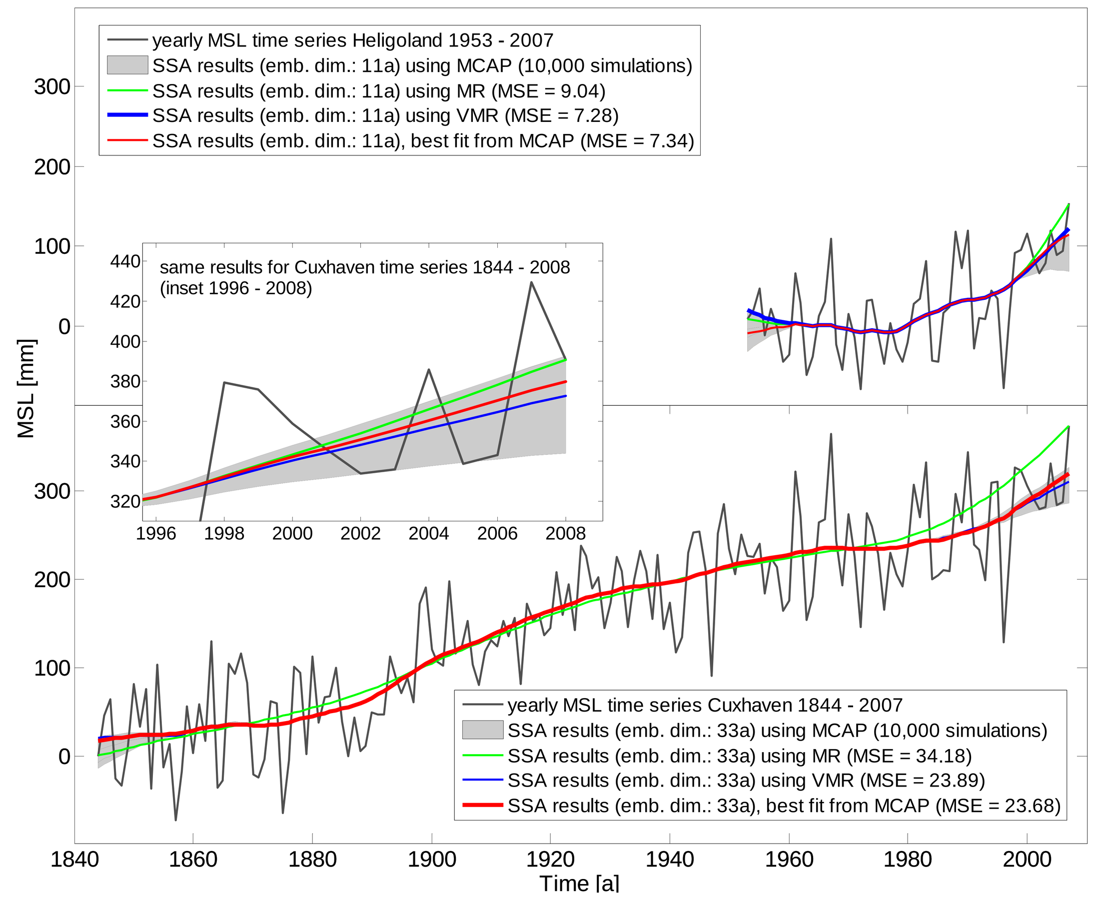

Figure 6. Non-linear trends from SSA reconstruction using different methods of prior padding.

IV. Conclusions and Outline

- The detected long-term trends of the investigated gauges are similar to those found from other regional and global studies.
- The time series of Cuxhaven shows a weak negative acceleration since 1844, which is not overall consistent with results from global or other regional estimations.
- A significant positive acceleration is observed since the mid of the 1970s and the rates since 1993 are much higher than those obtained from global altimetry data.
- In a next step, MSL time series of fourteen other gauges will we generated and analyzed in the same way and a virtual German North Sea gauge station will be estimated.

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