Assessing 20th century tidal range changes in the North Sea

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TIDEDYN

DFG Deutsche Forschungsgemeinschaft

Introduction 1

Tide gauges in the southeastern North Sea show significant changes in the local tidal regime since the middle of the 20th century. While Mean Sea Level (MSL) roughly follows the global trend over the last 150 years, analyzes of mean tidal high and low waters show clearly diverging trends. For instance, tidal high waters have been rising significantly faster than the MSL, while the tidal low waters show smaller or even negative trends. This results in a simultaneous increase in tidal range of up to 10 % since 1955. The magnitude of the observed increase is a globally exceptional phenomenon which cannot be explained physically until today. These changes have direct impacts on coastal protection, because they have the potential to amplify coastal erosion or land losses.

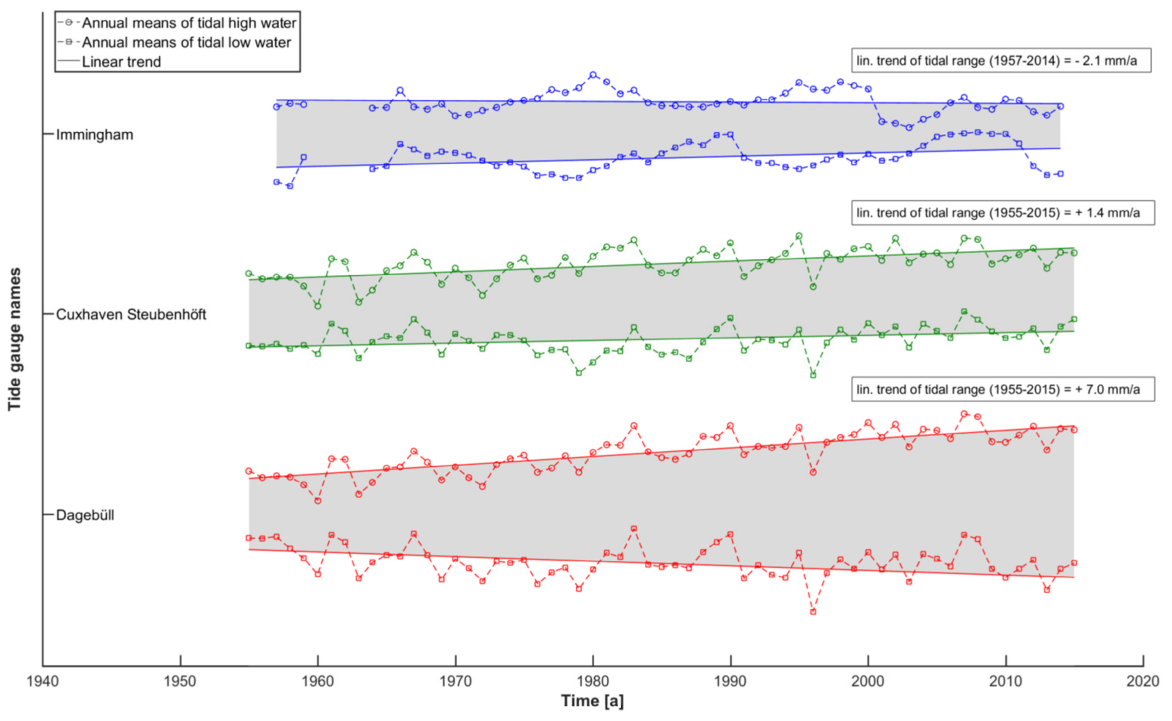

Fig. 1: *Comparison of the annual means of tidal low and high waters and the associated linear trends of the tide gauges Immingham, Cuxhaven and Dagebüll. The difference of the linear trends (shaded in grey) indicates the development of tidal range.*

Data 2

So far we have collected 64 tide gauges in the North Sea for our analyzes with different temporal resolutions. The data availability before 1955 is rather low and there are frequent data gaps, in particular before the 1970s.

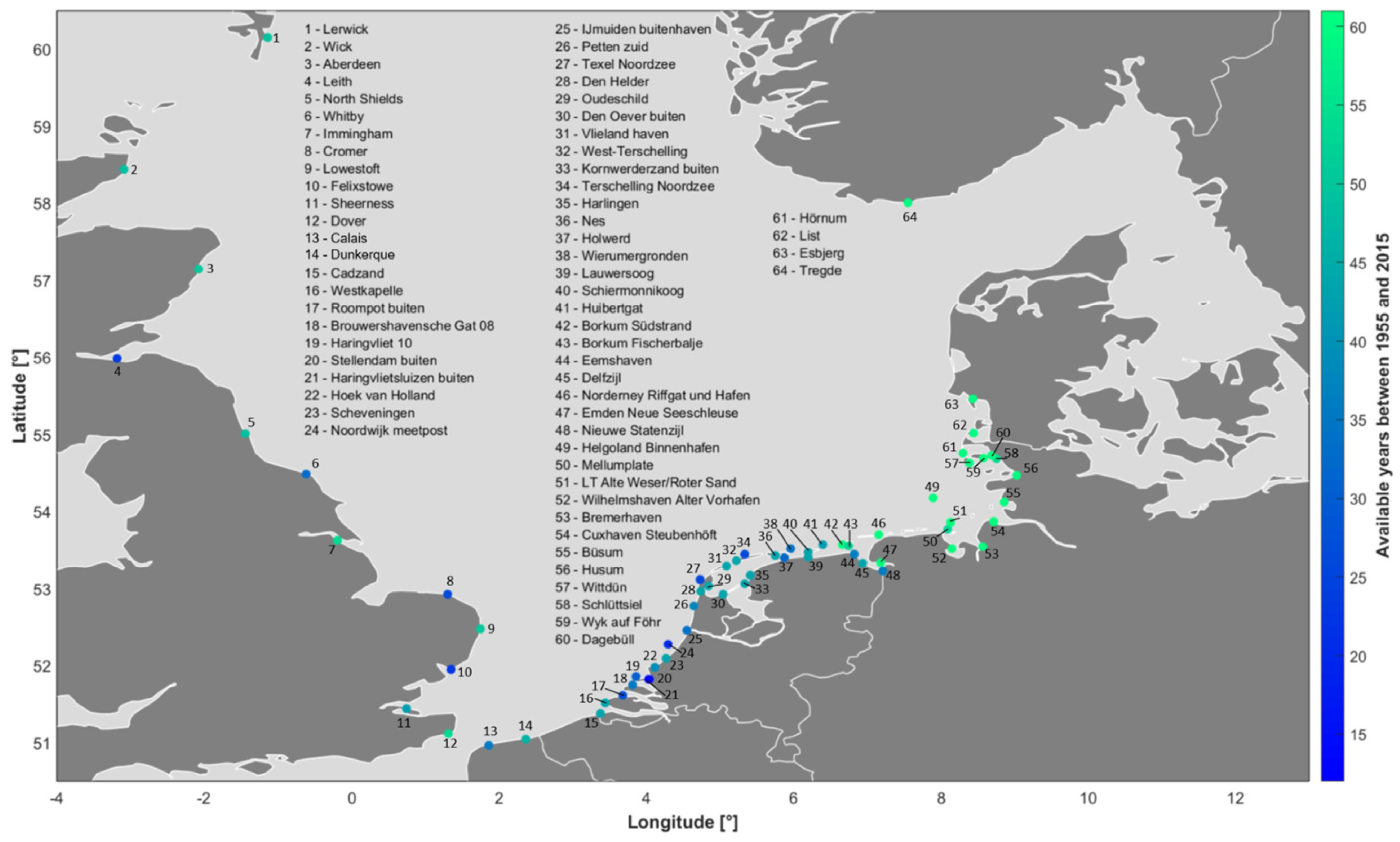

Fig. 2: *The 64 tide gauge locations in the North Sea used in this study. The color indicates the available years between 1955 and 2015 at each location.*

Observations and methods 3

To identify and to better understand the causes of the increase in tidal range we first focus on the assessment of spatial and temporal changes at individual tide gauges in the entire North Sea basin. To do so we apply linear and nonlinear trend approaches (here a Singular System Analysis (SSA)). Fig. 3 displays the differences in nonlinear trend development of tidal range between Immingham as representative of the east coast of the United Kingdom and Dagebüll and Cuxhaven as representatives of the southeastern coastline of the North Sea. While the trend for Immingham starts to slightly decrease in the 1970s, the trend for Dagebüll shows a strong increase since the 1950s. Cuxhaven on the other hand also begin to rise in the 1950s, but flattens out a little after 1980.

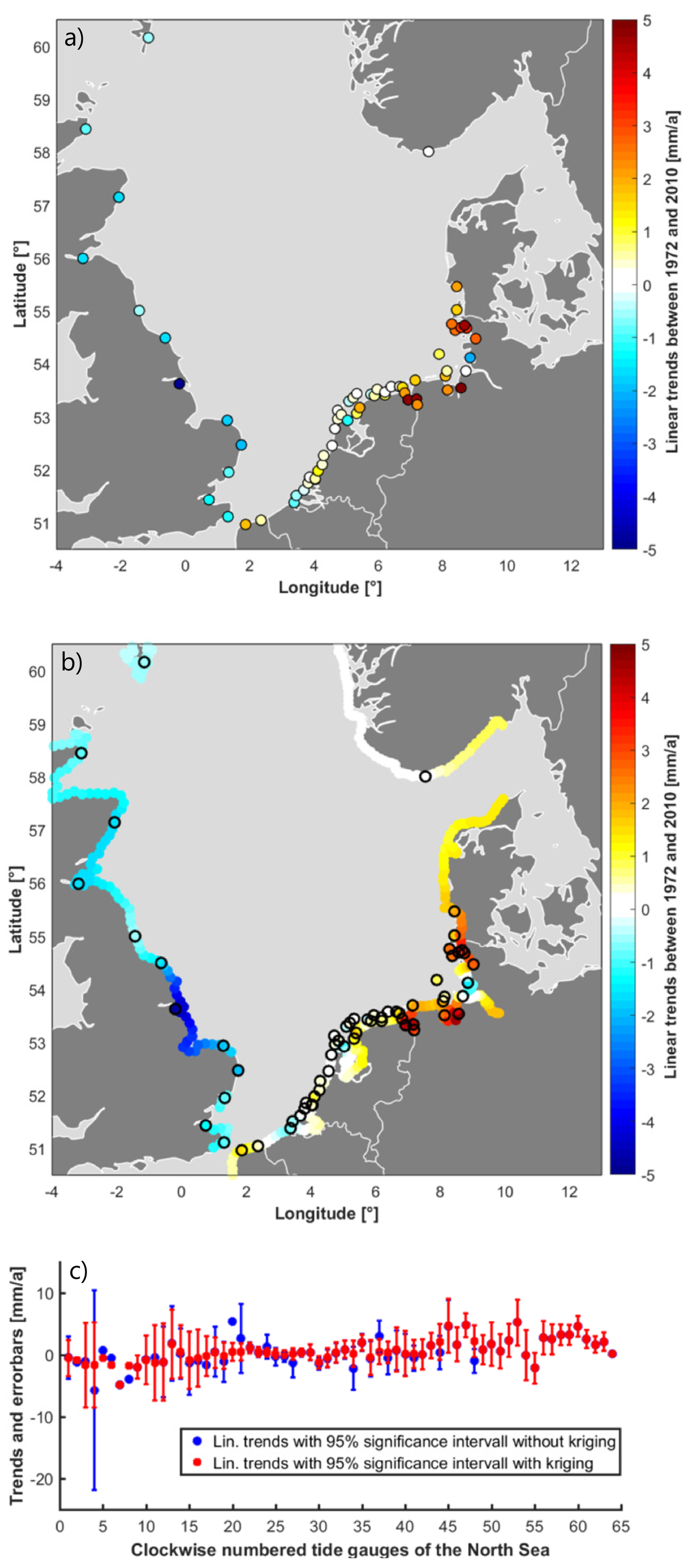

Fig. 4: *Linear trends of tidal range between 1972 and 2010 (a) for all 64 tide gauge locations without kriging, (b) along the entire North Sea coastline after applying the ordinary kriging algorithm (tide gauge locations are circled in black), (c) for all 64 tide gauge records before (blue) and after gap filling with ordinary kriging (red).*

Fig. 4 a) displays the linear trends of all tide gauges since about 1970 (where most sites offer enough data). In general, trends tend to be negative on the east coast of Great Britain and positive along southeastern North Sea coastline (Wadd-en Sea). However, a clear and homogeneous spatial pattern is hardly visible and often broken at individual locations. One reason for this could be differences in time series length due to data gaps in individual records. To solve this problem, we used a Gaussian Process Regression (Ordinary Kriging) for filling available data gaps and interpolate tidal range changes along the entire coastlines back to 1970. After filling available data gaps with Kriging, the spatial pattern becomes more homogeneous (Fig. 4 b, c) and the trend uncertainty is significantly reduced at several sites (Fig. 4 c).

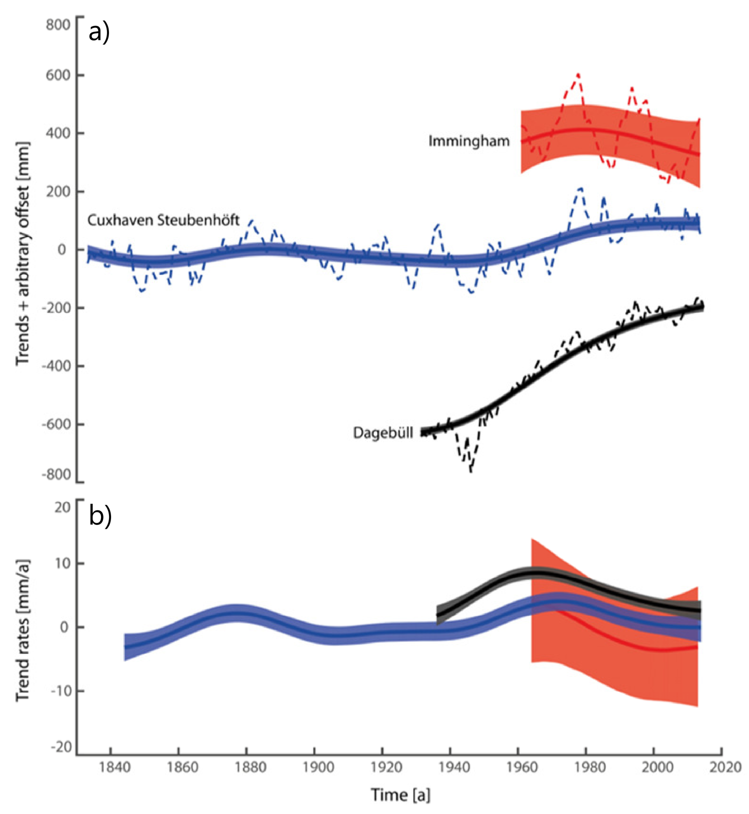

Fig. 3: *Comparison of the tide gauges Immingham, Cuxhaven and Dagebüll in (a) the annual means of tidal range (dashed), the nonlinear trend (solid) and its 95% confidence interval (shaded) and (b) the annual changes in trend (solid) with its confidence interval (shaded).*

Additionally, Kriging allows a spatial mapping along the entire coastline (Fig 4. b), which enables estimations of spatial patterns along the entire coastline. The divergent pattern of decreasing trends in the west and increasing trends in the east becomes more evident, but we still find local patterns, which counteract the spatial patterns seen at nearby sites. For example, along a small coastal stripe from Cuxhaven to Husum the observed changes in tidal range appear to be opposite to those obtained from the surrounding areas. We hypothesize that this is related to the embankment of the Meldorf Bight in 1978, which needs to be further assessed in numerical model simulations.

Furthermore, the large-scale pattern suggests a longitudinal shift of the major amphidromic point in the central North Sea. Other indicators for this assumption are also the linear trends of the M_2 partial tide, shown in Fig. 5, which suggest a similar spatial pattern as tidal range trends. Nevertheless, changes in the M_2 tide tend to be a magnitude smaller than the total tidal range changes.

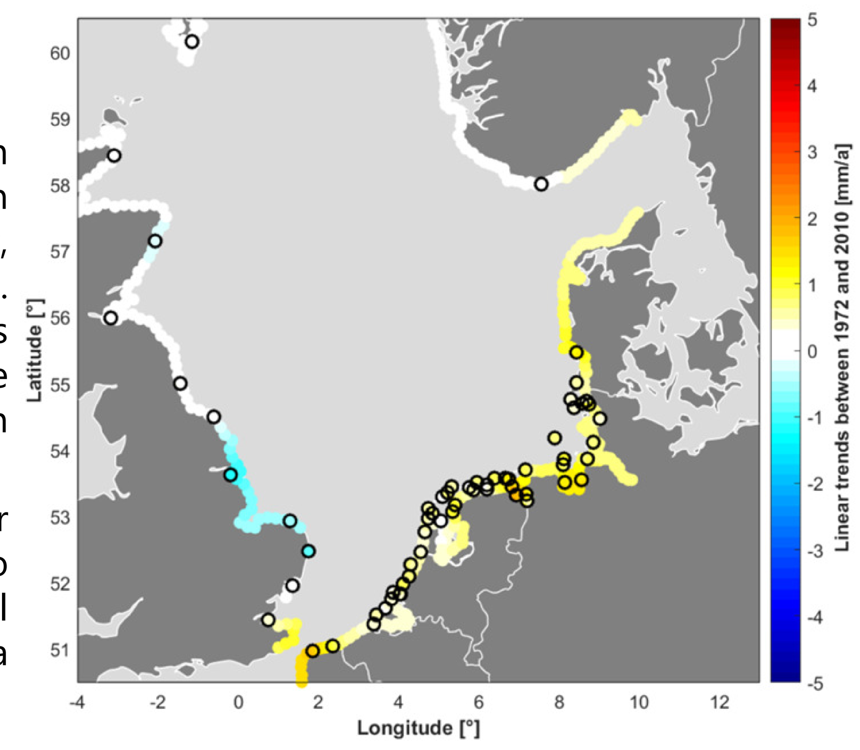

Fig. 5: *Linear trends of the amplitudes of M_2 tide between 1972 and 2010 for all 64 tide gauge locations along the entire North Sea coastline after applying the ordinary kriging algorithm (tide gauge locations are circled in black).*

Implementation of a numerical high resolution model

In addition to the methods of time series analysis, the numerical high-resolution model HAMSOM (Hamburg Shelf Ocean Model) is currently implemented. We use an Arakawa C-grid with a resolution of approximately 1.2 x 1.2 kilometres and 30 vertical levels (from -2.5 to -667 metres).

By comparing barotropic and baroclinic model runs with observations we aim to systematically characterize, model and explain the observed changes in the local tidal regime of the North Sea over the past 60 to 70 years. Numerical sensitivity studies (e.g. with and without varying topographies, sea level rise, and changing thermohaline boundary conditions) will be used to separate different processes from each other.

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Conclusions and Outlook 5

- **There are spatial and temporal changes in the tidal range as measured by tide gauges in the North Sea, in particular after 1950.**
- **To fill data gaps and spatially map the observed changes, we apply Gaussian Process Regression (Kriging), which reduces both the total scatter of linear trends between individual stations as well as the confidence intervals of trends (Fig. 4 c).**
- **While the tidal range is rising significantly in the southeastern North Sea, it is simultaneously falling along the eastern UK coastline and remains rather neutral around Belgium and Norway (Fig. 4 a and b).**
- **These developments suggest a longitudal shift of the major amphidromic point (also visible in the dominant M_2 tide).**
- **The causes of these changes are assumed to be both local and basin-wide in character.**
- **In a next step we will conduct sensitivity experiments with high-resolution 3D barotropic and baroclinic modell runs.**

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