EGU2014-5191 Storm surges in Danish waters: tide gauge data as proxy for storm winds

Peter Thejll[1], *(1) Danish Meteorological Institute, Danish Climate Centre, Copenhagen, Denmark (pth@dmi.dk)*

Tidal Gauge Data

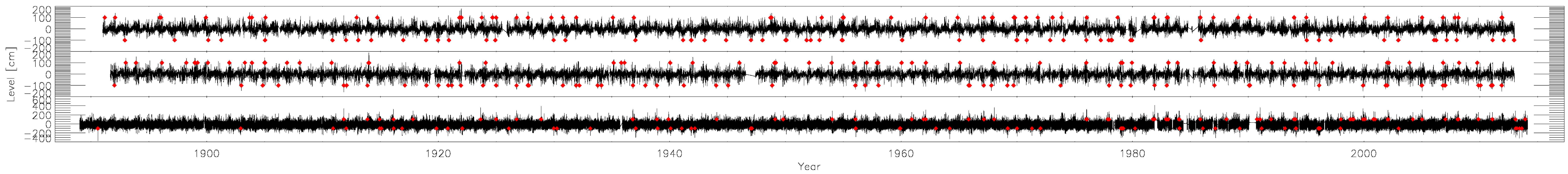

FIGURE 1: From bottom: Esbjerg, Gedser and Hornbæk tidal gauge series. A decadal-length sliding window-smoothing has been subtracted. Red symbols indicate 1%-ile (upper and lower) extremes.

Introduction

Tidal gauges measure the level of the ocean, and if the ocean level changes locally due to e.g. winds then gauge-readings could be used as a proxy for wind conditions. Along the Danish coastline the ocean rises at times due to storms and the stemming of the water against the coastline, or at the Belts connecting the North Sea to the Baltic. At DMI we have at least three centuries-long observed ocean level series starting in 1891, with readings many times a day. We will analyze these series (see map in Figure 2). We will correct for a slight isostatic rebound occurring at the rate of a few cm per century, and **we will look at the occurrence rates of high-percentile events (i.e. extreme high and low water)**. Due to the geography of Denmark, high water may occur in one place as water is pressed against the coastline, while low water simultaneously occurs nearby but on the opposite side of narrow land-masses as wind drives water away from the coast. In this work-in-progress report we shall look at whether once-a-year and once-a-decade storms are showing signs of changing their occurrence rates.

The analysis can yield **insight into rates of climate change**, and is **independent** of traditional wind-based approaches. Similar analysis has been performed on Atlantic hurricanes (Grinsted et al. 2012).

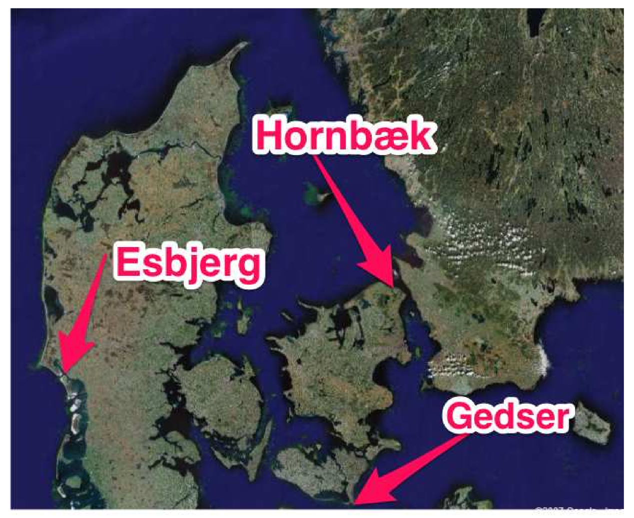

FIGURE 2: Map of Denmark, showing location of Esbjerg, Hornbæk and Gedser. These beaches are nice for kids - Hornbæk is low, with pebbles and sand, while Gedser and Esbjerg are sand-only. You should come. No, really.

Observations, Data preparations

We remove the decadal trend (see Figure 3) in order to subtract isostatic rebound since the ice-age, and thermal expansion of the Ocean.

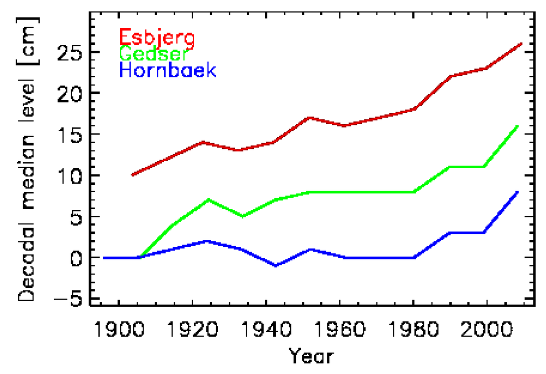

FIGURE 3: Decadal-bin median sea levels for each station. A linear interpolation between the decadal-median values are used to subtract isostatic rebound and ocean expansion from the records shown in Figure 1.

What roles do winds and air pressure play in high water? To understand, we generate correlation plots of the two factors against the Esbjerg sea level. We correlate the NCEP 2 1979-2013 winds at the 925 HPa surface with the de-trended Esbjerg sea level, taking monthly means from the former and monthly maxima for the latter.

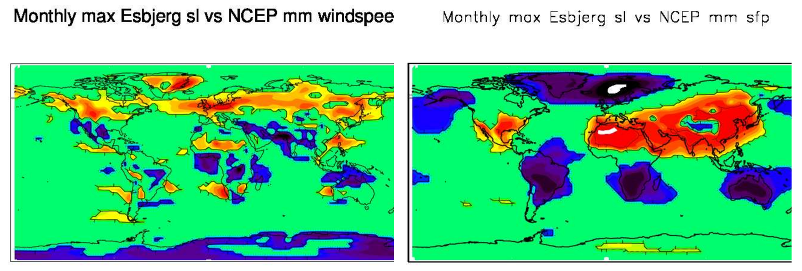

FIGURE 4: Correlation map between (left panel) NCEP 2 monthly-mean wind speed in the 925 HPa surface and monthly maximum sea levels in detrended Esbjerg observations. (right panel) sea level at Esbjerg against monthly mean surface pressure. Reds indicate positive correlations, blues negative.

Kolmogorov-Smirnov test for rate changes in extremes

We investigate whether extreme-high and extreme-low sea level occurs at rates that are demonstrably changing at the stations. After removing the trend-like evolutions, we inspect each week of the records and determine the highest and lowest water level for that week. We do not remove any tidal signals as they are present throughout the 20th century - no bias will occurr by leaving them in the sea level data. We apply the two-sided KS test against the null hypothesis of uniformly distributed events. We find the probability that a set of observed extremes (defined by the percentile they exceed) could be drawn form a uniform distribution.

%-ile	P	n_{early}	n_{late}	notes
lower 1%	16.9	27	39	Esbjerg, DM removed
upper 99%	0.005	17	49	Esbjerg, DM removed

FIGURE 5: For various percentiles considered we give the two-sided KS probability that the series of extremes are drawn from a uniform population. We only show interesting results - i.e. those that may constitute proof or support that extremes are changing their rate of occurrence. "P" gives the chance in percent that the observed number of events n_{early} and n_{late} could be found in a uniform distribution. n_{early} and n_{late} give the number of observed highs or low at the specified percentile in the first ('early) or second ('late') halves of the 20th century. 'DM removed' indicates that the decadal mean level has been subtracted prior to KS testing.

The results in the table in Figure 5 indicate that the observed rate of e.g. extreme high water events in Esbjerg after 1950 is unlikely to be due to chance. Rates of low water in Esbjerg has a less remarkable significances but supports a picture of more highs and lows in the sea level.

Contingency-Table test

A contingency-table test allows additional insight into changes in rates of extremes. Comparing to a uniform distribution we ask whether the observed extremes (highs and lows), after de-trending, could be due to chance. Only highs at Esbjerg are clearly not consistent with the null hypothesis of a uniform occurrence rate. The high extremes detected occur at the **intra-annual to annual rate** - more rare events (decadal and above) are not statistically significant in our tests.

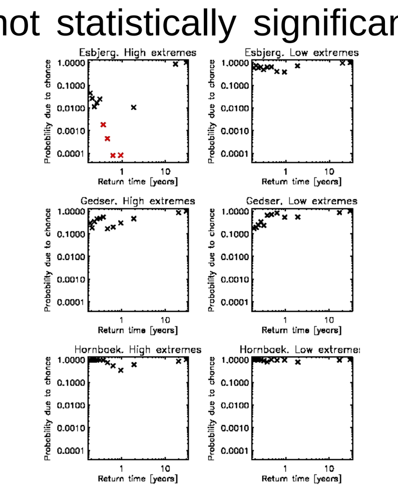

FIGURE 6: Probabilities (based on χ^2) that extreme events occurring at the shown return rates could be due to chance.

Discussion: What drives high (or low) water in Denmark?

It is common to see high water levels on the west coast of Denmark during strong storms - westerlies drives the North Sea into the German Bight and waters rise as they cannot flow away at a sufficient rate into Kattegat or down the English Channel. Simultaneously East of Jutland low waters occur as the wind drives the ocean away from the coastline.

Summary

In testing three Danish tide-gauge stations for evidence of changes in rates of occurrence of extreme high and low water, we find that in Esbjerg there is **evidence that** in the second half of the 20th century **extreme high waters become more common**. **Linear trends**, potentially due to slow changes in isostatic rebound, as well as gradual expansion of the sea level due to global warming, **have been removed.** An independent check against wind data is needed, although a coincidence of high waters at Esbjerg and low waters at Gedser **supports that the extremes are wind driven**. 18 coincidences were found; no coincidences were found between Esbjerg and Hornbæk or between Hornbæk and Gedser. Coincidences of low water at Esbjerg and high water at Gedser were found.

We conclude that there is evidence for an increasing storm rate through the 20th Century in the North Sea.

References

Grinsted, A., J. C. Moore, and S. Jevrejeva, 2012: Homogeneous record of Atlantic hurricane surge threat since 1923. *Proceedings of the National Academy of Sciences of the United States of America*, **109 (48)**, 19 601–5, doi: 10.1073/pnas.1209542109.