Determining Storm Surge Return Periods: The Use of Evidence of Historic Events

Madsen, Kristine S.; Sørensen, Carlo Sass; Schmith, Torben; Nielsen, Jacob Woge; Knudsen, Per

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After a long period of westerly winds, the mean sea level of the Baltic Sea was about 0.5 meters above normal, with a tilt towards north and east. A heavy low pressure system caused winds from north east over the entire area, releasing and enforcing a seiche of the tilted water and at the same time blocking outflow to the North Sea. This caused a “quiet storm surge” – a surge without a storm – on the south western Baltic shores, with sea levels of 1.57 meters just south of Copenhagen in Køge and 0.5 meters above normal, with a tilt towards north and east. A heavy low pressure system passing from the Atlantic, but a small increase in the highest wind speeds over the north eastern Baltic Sea. Massive flooding occurred, including areas that are now urban.

With present day statistics, this was considered a 100 year event. The surge was well forecasted, minimizing damages and avoiding casualties. In many places, including Copenhagen, serious flooding would have occurred if the water had been a few 10s of centimeters higher.

Materials

The present study focuses on the bay of Køge, just south of Copenhagen, where the sea level of historic events, corrected to land and changes in the wind. The sea level of a statistical 100-year or 1000-year storm surge event and similar statistical measures are used for spatial planning and emergency preparedness. These statistics are very sensitive to the assessments of past events, and to future sea level change.

The probability of a major storm surge from the Baltic Sea hitting the Copenhagen metropolitan area is officially determined by the Danish Coastal Authority based on tide gauge records. We have a long history for tide gauge measurements, with 120 years of data available for the calculations. However, the oldest of these tide gauge stations was set up after a major storm surge in 1872, and no events of similar severity have occurred since.

Including the evidence of the historic events from the 18th century changes the return period statistics, with a best estimate of a 100 year event changing from 1.5 meters (Sørensen et al. 2013) to 2.6 [2.2 – 2.8] meters (present study) in Køge just south of Copenhagen. Thus, with the tide gauge-based statistics, the storm surge on January 4 2017 was a 100 year event, but with the revised statistics using historic evidence, much larger events can be expected.

Further, we assess the very large impact of sea level rise on the storm surge statistics. As an example, according to the official statistics of southern Copenhagen, the flooding of a present day 100 year event will statistically occur every 10 years with just 27 cm of mean sea level rise.

Future Storm Surges

There are two key parameters for the effect of climate change on storm surges: mean sea level changes (relative to land) and changes in the wind. Mean sea level changes are expected to have the highest impact, massively changing return periods for a given level of flooding. The figure illustrates the change in return period of a present day 100 year event as a function of mean sea level rise for Aabenraa (based on Sørensen et al. 2013). For instance, a present day 100 year event will occur every 10 years with 0.26 meters of mean sea level rise. Figures are very similar for Danish stations within the southwestern Baltic region, including Copenhagen.

The effect of changing wind patterns is less certain. Ensemble studies of regional climate models show a decrease in the mean wind speed over the North East Atlantic, but a small increase in the highest wind speeds over the south western Baltic Sea. Since the Arctic region is heated more than the global average, we speculate that Type 2 storm systems will become less likely in the future, and the largest storm surges will be from Type 1 storms. However this needs further investigation.

Abstract

Storm surges are a major concern for many coastal communities, and rising levels of surges is a key concern in relation to climate change. The sea level of a statistical 100-year or 1000-year storm surge event and similar statistical measures are used for spatial planning and emergency preparedness. These statistics are very sensitive to the assessments of past events, and to future sea level change.

Results

The best fit of the historic events are obtained with a frequency of exceedance of 0.06 events per year, scale parameter of 0.96 [0.64 – 1.53] meters, shape parameter of 0.8 [0.3 – 1.3], and a K-S test value of 0.9. This results in a 100 year event of 2.6 [2.2 – 2.8] meters and a 1000 year event of 2.9 [2.6 – 3.1] meters.

With the revised statistics, the storm surge on January 4, 2017 was thus far from a 100 year event, yet a 10 year event.

Future Storm Surges

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-Determining Storm Surge Return Periods: The Use of Evidence of Historic Events

Kristine S. Madsen1, Carlo Sørensen2, 3, Torben Schmith1, Jacob Woge Nielsen1, Per Knudsen2

1 Danish Meteorological Institute, Denmark, kma@dmi.dk, 2 DTU Space, Denmark, 3 Danish Coastal Authority, Denmark

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