The 1872 super-storm surge in the Baltic – the Danish perspective

Peter Aakjær[1] and Erik Buch[2]

[1] Former Director General of the Danish Meteorological Institute, now retired, peter.aakjaer@privat.dk
[2] Former Director of the Oceanographic Department at the Danish Meteorological Institute, now retired

Summary

The super-storm surge (water levels above 3m) that hit the Danish and German coastlines in the western Baltic Sea on November 13, 1872, is the worst natural disaster in modern Danish history.
The meteorological and oceanographic causes for this extreme event have been analysed using the relatively few observations from November 1872 combined with re-analysis outputs from modern operational forecasting models. Key findings for the days November 11-14, 1872, are:

- The Baltic Sea was exposed to north-easterly storm to hurricane force winds
- The extreme water levels were solely wind generated.
- Theories of backwash of water from eastern Baltic or higher than normal water level in the Baltic Sea is refuted. The extraordinary water levels on 13 November 1872 can most likely be attributed to the length of the storm/hurricane.
- The western Baltic Sea, in particular the Arkona Basin area, was exposed to 8-10 m waves.

The combination of a super-storm surge and extreme waves caused severe damage along the Danish Baltic Sea coastlines. Around 90 people drowned in the Danish coastal areas, especially in the flat southern parts of the two islands of Lolland and Falster. Houses and local infrastructure were destroyed leaving thousands homeless the following winter. Additionally, an unknown number of sailors drowned when several hundred sailing ships shipwrecked during the storm. A nationwide collection of money to help the many victims was initiated and successfully implemented.
Super-storm surges will inevitably hit the Baltic Sea again. A detailed high-water statistics, including historical surge registrations, reveal a return period of around 300 years for a 1872 size super-storm surge.
In preparing for the next super-storm surge, it is, however, important to consider the sea level rise due to climate change. According to national authorities, the sea level in the Danish waters will rise around 0.5 m before 2100.

Keywords

Baltic Sea, Super-storm surge, L.A. Colding, hurricane, ocean models, waves, destruction, economic help, return period, sea level rise

Zusammenfassung

Die Supersturmflut mit Wasserständen von über 3 m über Mittelwasserstand, die am 13. November 1872 die dänischen und deutschen Küsten in der westlichen Ostsee traf, ist die verhängnisvollste Naturkatastrophe in der modernen dänischen Geschichte.
Die meteorologischen und ozeanographischen Ursachen für dieses Extremereignis wurden anhand der relativ wenigen Beobachtungen vom November 1872 in Kombination mit Re-Analysen moderner operationeller Vorhersagemodelle analysiert. Die wichtigsten Ergebnisse für die Tage vom 11. bis 14. November 1872 sind:

- *Die Ostsee war nordöstlichen Stürmen mit Orkanstärke ausgesetzt.*
- *Die extremen Wasserstände wurden ausschließlich durch Wind verursacht.*
- *Theorien über einen Rückschwapp-Effekt von angestauten bzw. hohen Wasserständen aus der östlichen Ostsee sind widerlegt.*
- *Die außergewöhnlichen Wasserstände am 13. November 1872 sind höchstwahrscheinlich auf die Dauer des Sturms zurückzuführen.*
- *Die westliche Ostsee, insbesondere das Gebiet des Arkonabeckens, war 8-10 m hohen Windwellen ausgesetzt.*

Die Kombination aus einer Supersturmflut und extremen Windwellen verursachte schwere Schäden an den dänischen Ostseeküsten. Rund 90 Menschen ertranken in den dänischen Küstengebieten, insbesondere in den flachen südlichen Teilen der beiden Inseln Lolland und Falster. Häuser und die örtliche Infrastruktur wurden zerstört, so dass Tausende im folgenden Winter obdachlos wurden. Außerdem ertrank eine unbekannte Zahl von Seeleuten, als mehrere hundert Segelschiffe während des Sturms Schiffbruch erlitten. Ein landesweiter Spendenaufruf zur Unterstützung der vielen Opfer wurde danach initiiert und sehr erfolgreich durchgeführt.
Extreme Sturmfluten werden die Ostsee unweigerlich wieder heimsuchen. Eine detaillierte Hochwasserstatistik, einschließlich historischer Sturmflutregistrierungen, zeigt eine Wiederkehrperiode von etwa 300 Jahren für eine Sturmflut der Größenordnung von 1872.
Bei der Vorbereitung auf die nächste extreme Sturmflut muss jedoch auch der Anstieg des Meeresspiegels infolge des Klimawandels berücksichtigt werden. Nach Angaben der nationalen Behörden wird der Meeresspiegel in den dänischen Gewässern bis zum Jahr 2100 um etwa 0,5 m ansteigen.

Schlagwörter

Supersturmflut, Ostsee, L.A. Colding, Hurrikan, Ozeanmodelle, Wellen, Zerstörung, wirtschaftliche Hilfe, Wiederkehrperiode, Meeresspiegelanstieg

1 Introduction

The storm surge on November 13, 1872, was the worst natural disaster in Denmark during the past 2–300 years. Approximately 90 people drowned, and thousands were without a home the following winter. More than 250 ships grounded or wrecked along the Danish coasts, and nearly 200 sailors drowned. Especially the very flat southern parts of the two islands, Lolland and Falster, were severely damaged.

The present article summarizes information on the 1872 storm surge that was recently published in a book (in Danish) by the two authors (Aakjær and Buch 2022 – in the following called AaB22). Here we discuss the newly-made reconstructions of the weather, water levels and waves, as well as evidence from contemporary eyewitness accounts. It will appear that the two sources of information, although 150 years apart, support each other well.

Storm surges in the Baltic were not unknown to the local population in 1872. The low-lying areas were protected by dikes that were large enough to protect against a normal storm surge. However, the unprecedented hurricane wind force, water levels around 3 m and up to 10 m waves took everybody by surprise. The existing dikes were inadequate and were quickly broken down by the storm surge, and large areas were flooded.

In AaB22, the term super-storm surge is introduced based on the following arguments:

- The official Danish definition of a storm surge is a water level with a return period of 20 years or more.
- For most Danish water level stations in the Baltic Sea, this criterion corresponds to a water level of about 1.5 m.
- A super-storm surge is defined as a storm surge with a maximum water level twice the operational storm surge criterion, i.e., 3 m or higher.

The definition makes the 1872 storm surge a super-storm surge, and historic records display only very few super-storm surges in the Baltic Sea in the past.

2 Ludvig August Colding – a Danish scientist and water engineer

An operational network of weather or water level stations did not exist in Denmark in 1872. The Danish Meteorological Institute (DMI) was founded in April 1872 with only four employees. So by November 1872, the institute had not been able to implement an operational observation network nor to issue weather forecasts or warnings of storms and storm surges.

Still, due to the initiative and hard work of Ludvig August Colding (1815–1888), there is an extensive database of basic meteorological parameters and water level observations in the Danish region from the days around November 13, 1872. Colding was a Danish scientist and hydraulic engineer. He worked most of his life as a chief engineer in Copenhagen, where he introduced running water and gas as well as an efficient sewer system in the 1850s and 1860s. Until then, Copenhagen was a crowded, dirty, and unhealthy city with several cholera epidemics.

Figure 1: Ludvig August Colding (1815–1888). From Wikipedia.

Besides his practical skills, Colding also performed several more theoretical studies on energy conservation, tropical cyclones, and water flow. Colding saw the storm surge as a great opportunity to test the theories he had developed in the 1850s from flow measurements in the harbour of Copenhagen for a larger basin. He announced an invitation in all Danish newspapers to send him observations of air pressure, wind, temperature, and water level. Luckily, he received hundreds of replies, which made it possible for him to write a thesis on his observations and other findings from the 1872 storm surge (Colding 1881).

In addition to the collection of observational data, he did pioneering theoretical work. In his thesis from 1881, he showed that the water level above the mean sea level, H, was related to the square of the wind velocity, V, the wind fetch, d, and the inverse of the water depth, D,

$$H = const \times V^2 \times \frac{d}{D} \tag{1}$$

This means high winds and shallow water give rise to high water levels. He also found that the entire Baltic Sea was influenced by the 1872 storm surge, with water levels above 3 m in the western part of the Baltic and 1 m below normal in the eastern part. Finally, he showed that a line from Stockholm in Sweden to Pillau in Kaliningrad was not affected by the storm surge. Thus, he discovered the nodal line for the Baltic Sea seiche.

3 A hurricane from the northeast

Based on Colding's work and data from many other sources, Rosenhagen and Bork (2009) produced a comprehensive analysis of the sea surface pressure and surface winds for the period November 1 to 14, 1872.

The wind analysis shows hurricane winds 32–33 m/s just east of the island of Falster, when the wind culminated at 06 UTC on November 13 (Figure 2). It is remarkable how persistent the storm/hurricane was both in time and space. East of Falster, the hurricane winds lasted for 9 hours, and the area was subject to storm conditions for almost 24 hours.

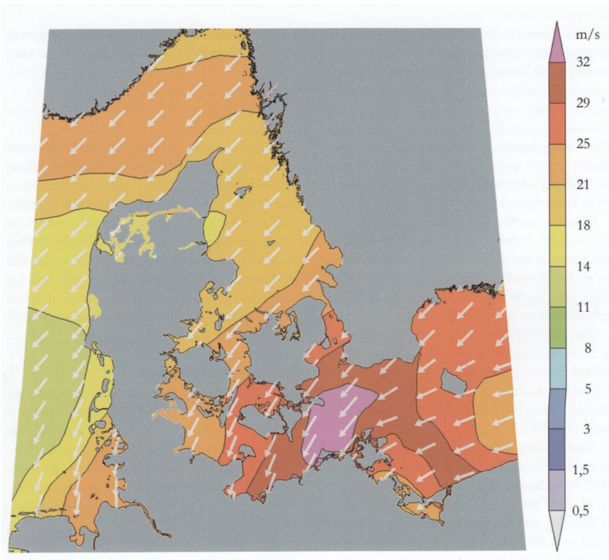

Figure 2: Wind speeds at 06 UTC in the morning of November 13. Hurricane winds are seen east of the island of Falster. From AaB22.

The time evolution of the wind speeds in a cross-section along the 55°N is displayed in Figure 3. It is seen that the centre of the storm/hurricane was stationary for almost 24 hours, which is very unusual for a strong low-pressure system. This made it possible for the water levels and waves to develop over a long time and reach the very high levels shown in the next chapter.

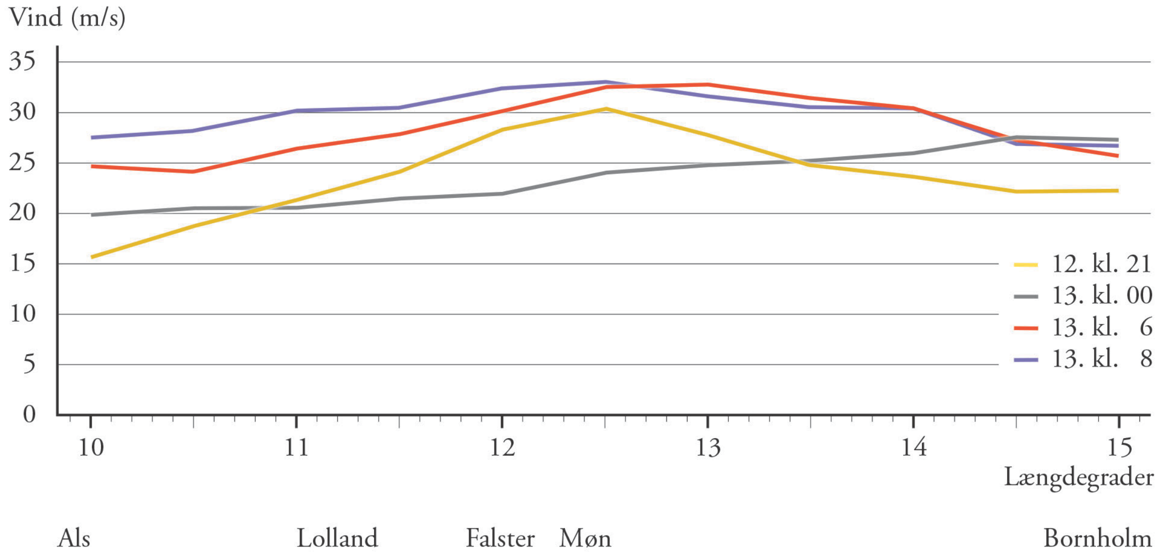

Figure 3: Development of the wind speed along 55°N. From AaB22. Yellow: 21 UTC November 12. Green: 00 UTC November 13. Orange: 06 UTC November 13. Red: 08 UTC November 13.

Additionally, Figure 3 shows that the storm/hurricane had two phases. The north-easterly winds increased during November 12, and at 21 UTC, it reached almost a hurricane force of 31 m/s east of Falster (yellow curve). From 21 UTC until midnight, the winds decreased to a storm force of 25 m/s (green curve), but just 6 hours later, the winds reached their maximum force of full hurricane 32–33 m/s (orange curve).

4 Storm surge and waves

In Denmark, an operational network of water level stations was not initiated until 1884. In November 1872, the water level observations were taken by local harbour authorities using a simple staff gauge. The quality of these observations can naturally be questioned since no national reference level existed, and the water level board was extremely difficult to read under the severe weather conditions around November 13, 1872. Nevertheless, they represent the best available water level information from that time. Colding (1881) collected water level observations from around 140 locations in Denmark for the period November 12–14, 1872. The maximum water level for selected localities is displayed in Figure 4.

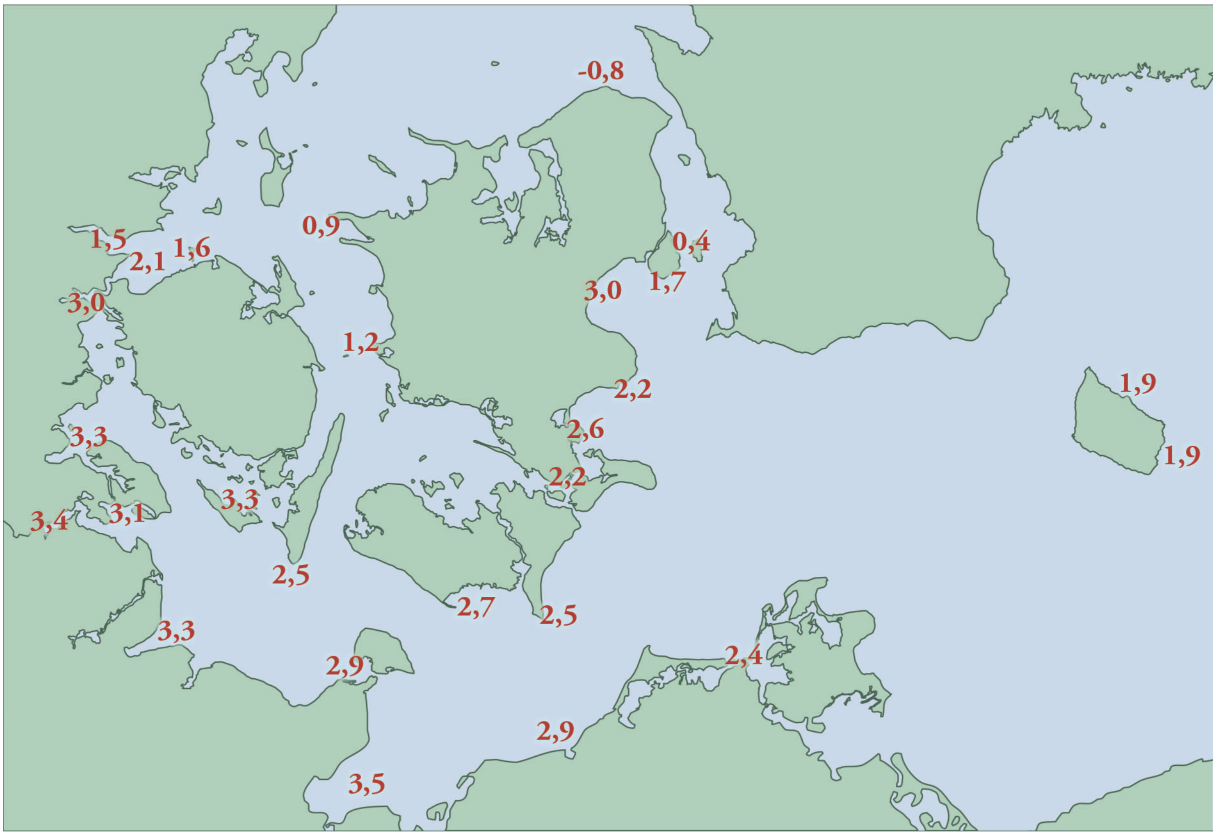

Figure 4: Maximum water levels (m) in the western Baltic on November 13, 1872. From AaB22.

The maximum water levels range from 1.9 m on the island of Bornholm to 3.3 m along the southeast coast of Jutland. This makes the November 1872 storm surge one of the worst storm surges ever to hit the Danish Baltic coastline.

The Danish Meteorological Institute (DMI) has analyzed the extraordinarily high water levels by running their operational storm surge model forced with meteorological fields based on the surface pressure analysis by Rosenhagen and Bork (2009) (DMI 2022a). A couple of examples of the model simulation results are shown in Figure 5.

The highlights of the model simulations are:

- The water level in the western Baltic started to rise already around midnight between November 11 and 12, 1872. On the evening of November 12, the water levels reached the storm surge criterion of 1.5 m, and it lasted until the morning of November 14.
- The time of maximum water level moved from east to west. The high water peaked November 13 in the morning at Bornholm, around noon at eastern Zealand and Falster, and in the early evening at South Jutland.
- The good agreement between the model output and the observed water levels confirms that the storm surge was entirely wind-generated. The main reason for extreme water levels can be attributed to the fact that the atmospheric pressure systems generating the north-easterly storm and hurricane were relatively stationary for an unusually long period ranging from November 11 to 14, 1872.

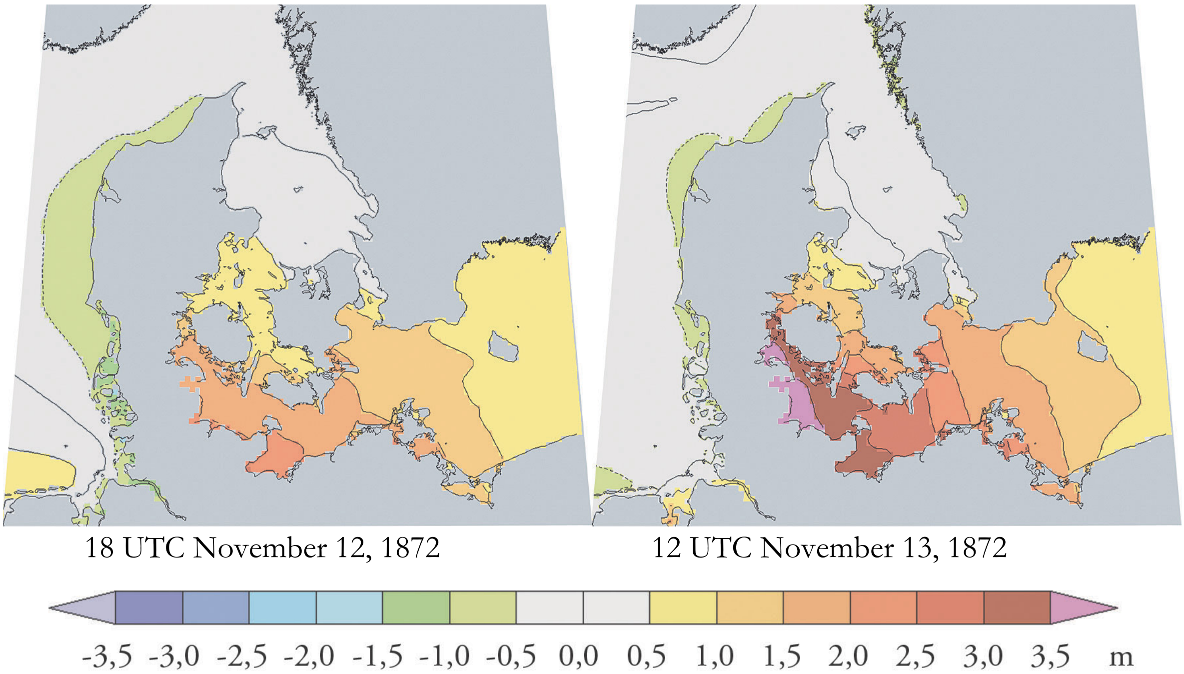

Figure 5: Model simulated water level distribution in the western Baltic Sea on 18 UTC November 12, 1872, and 12 UTC November 13, 1872. From AaB22.

A small but vital detail in the development of the storm surge is reflected in evidence from contemporary eyewitness accounts following the storm surge. According to these reports, local people noted that around 21 UTC on November 12, 1872, the wind and the water level started to weaken. They took this as a sign that the worst part of the storm and the surge was over. They went reassured to bed just to wake up a few hours later to discover that the wind and water levels were increasing fast. This temporary weakening of the storm surge is well reflected in the model simulations, see Figure 3 and 6.

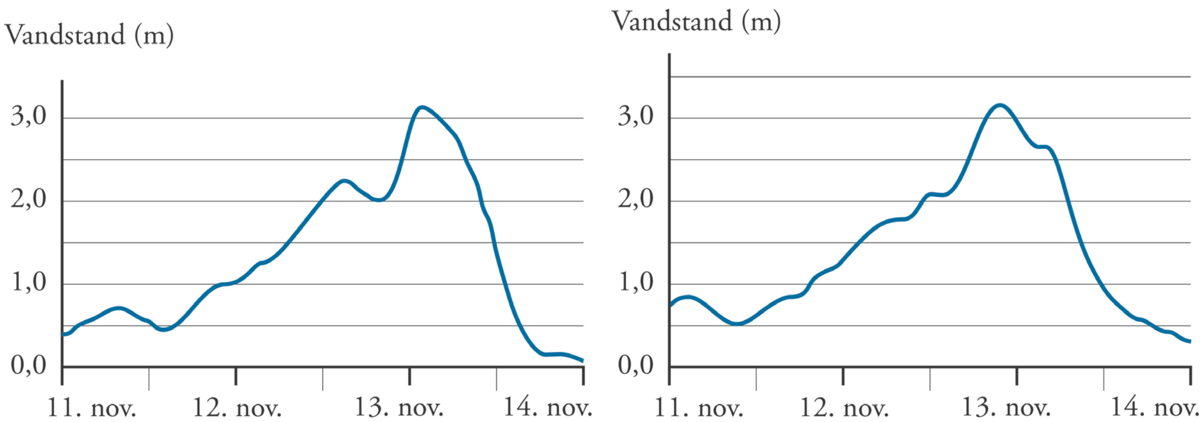

Figure 6: Model simulation of the water level development between 12 UTC November 11 to 12 UTC November 14 at two localities A: Gedser, B: Kolding. From AaB22.

The wave field in the western Baltic during the November 1872 hurricane has been calculated using DMI's operational wave model (DMI 2022a). Ocean waves of 8–10 m dominated the Arkona Basin area, see Figure 7. These extreme waves, on top of a 2–3 m water level, caused severe damage along all the coastlines in the region. In northern Bornholm, the harbours of Allinge and Svaneke were destroyed, and along the southeast coast of Falster, the dikes and houses were completely wiped out.

Additionally, the hurricane winds and high waves were disastrous to the ship traffic in the western Baltic, which in 1872 was primarily composed of sailing ships. A study by Ejdorf (2002) revealed that more than 250 ships grounded or wrecked along the Danish Baltic coastline on November 13, 1872, and nearly 200 sailors lost their lives.

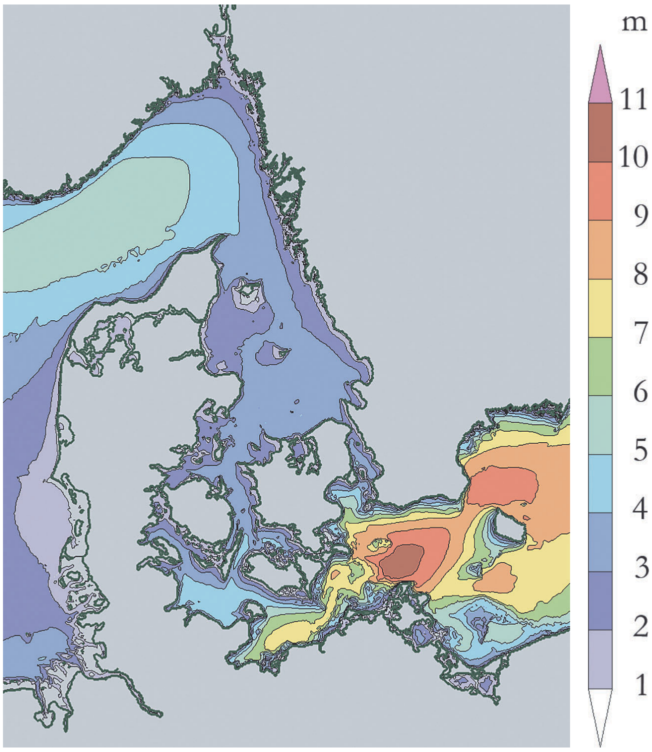

Figure 7: Wave heights in the western Baltic Sea 09 UTC November 13, 1872. From AaB22.

5 Damages and help

The damages along the Danish coasts have been described in detail in AaB22. This chapter will give some examples of the most serious damage to the coasts, buildings, and people. It will also describe the incredible help to the victims both from the local population and from people all over Denmark.

5.1 The Island of Falster

The storm surge made a very large impact on the two lowland islands, Lolland and Falster. 80 people drowned here and many hundreds or thousands were homeless in the following winter.

In 1872 the two islands looked very different from today. The southern part of Falster at that time is displayed in Figure 8A. The area was dominated by an open sea area, Bøtø Nor, with the low-level barrier, Bøtø, to the east, mainly composed of sand, and only inhabited by 120 people. The people in Falster were used to storm surges. High water levels happened almost yearly but were normally not much higher than 1.5 m. The dikes toward the Baltic Sea were built to protect them against this type of frequent flooding, but against a super-storm surge, they didn't stand a chance. In this area, the storm, water levels and waves were at a maximum. In combination with the low-lying landscape and the insufficient dikes, Bøtø was completely flooded (Figure 8B), and 26 out of the 120 inhabitants drowned under circumstances that are described in the many heart-breaking eyewitness reports.

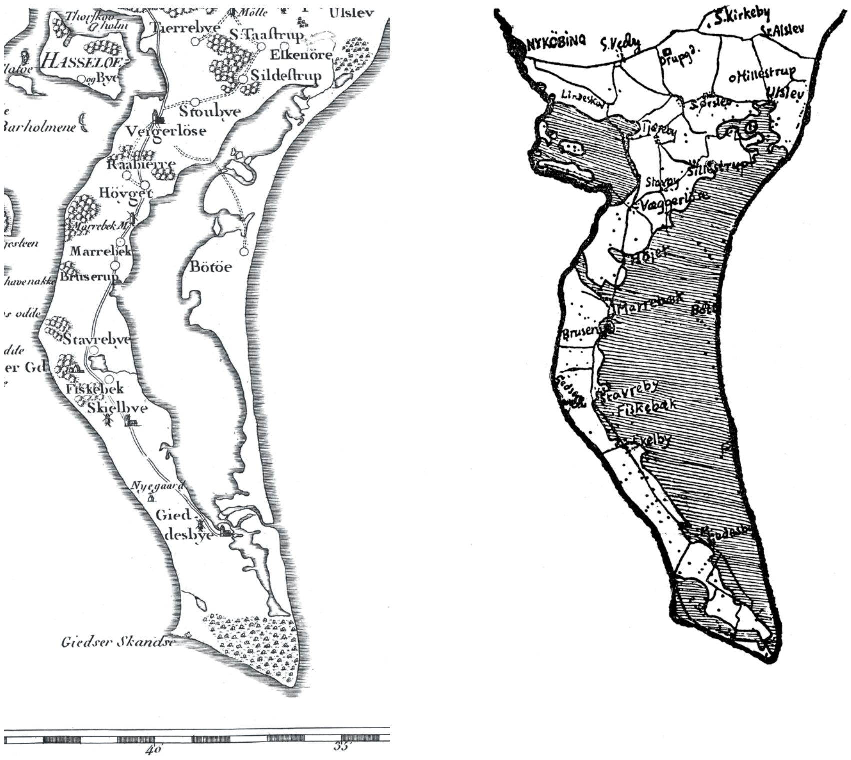

Figure 8: A, left: Map of southern Falster from 1776. In 1872 the landscape looked about the same with open water, Bøtø Nor, in the middle. B, right: Map of the large, flooded areas in November 1872. From AaB22.

Most of the houses in the flooded areas were of poor quality, half-timbered with clay walls. These types of houses have been used in Denmark since the stone age. They can easily persist heavy rains, but the clay walls will disintegrate quickly during a flood and render no real protection against the fierce weather. Many houses were broken down by the water, and people tried to survive by climbing the thatched roofs and hoping for the best. Figure 9 shows such a house that survived the flooding.

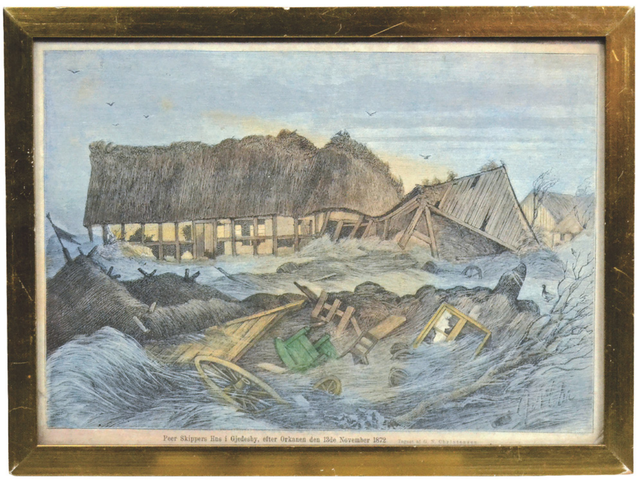

Figure 9: Coloured drawing of Per Skippers house in Gedesby close to the southern tip of Falster. From Museum Lolland-Falster.

5.2 The island of Bornholm

Bornholm is situated isolated from the rest of Denmark in the Baltic Sea. Unlike the rest of Denmark, Bornholm rises steeply from the seashore, and as such, Bornholm is not the most potentially flood-prone part of Denmark. There exist, however, some unique photographs from Allinge and Sandvig on the northern tip of Bornholm showing the devastating powers of the 1872 super-storm surge (Figure 10).

Figure 10: Two outstanding photographs from Bornholm the day after the storm surge by the local photographer Gottlieb Støckel. A, left: The schooner Robert was thrown up on the quay in Allinge. The bow thruster went through one of the windows of a house along the quay and broke off. B, right: The British brig Caledonia stranded near Sandvig. Caledonia was thrown far up on the rocks and broke into two parts. From Museum Bornholm.

The maximum water levels on Bornholm were around 1.9 m above normal. From Figure 10, it is obvious that a flood of 1.9 m is not able on its own to lift the heavy ships as it is seen in the photographs. However, as seen in Figure 7, the waves were up to 10 m just off the northern tip of Bornholm near Allinge and Sandvig. It is therefore likely that the combined effect of 1.9 m water levels and up to 10 m waves was the reason for the devastating destruction of the harbours of Allinge and Svaneke on the north coast of Bornholm.

5.3 The storm surge heroes

Several rescue actions did successfully save people from drowning during the super-storm surge. Many of them were described in detail in the newspapers, and the stories went around Denmark. In April 1873, the stories also reached the Danish king's ear, and he gave 41 of these hero's honours, mostly in terms of medals of honourable rescue at sea. Two examples of the most spectacular actions are illustrated in Figure 11.

On the east coast of Zealand, the three-masted Norwegian bark, Atlas, was stranded at the foot of the 40 m high cliffs of Stevns (Figure 11A). The local people, who gathered on top of the cliff, saw the crew fight for its life in the 6–8 m waves. After a while, the 40-year-old farmer, Niels Andersen cried out: *"This is no time for talking, we need to act!"* He and a few others got a robe around the waist, and they miraculously succeeded in saving 12 sailors up the ladders of the 40 m high cliffs in the extremely fierce weather.

The iconic drawing from Falster displaying the rescue action made by the two brothers Olsen is seen in Figure 11B. They rowed in a small boat against the storm and high waves to get to a farm, Nørrevang on Bøtø, where 22 people were stranded in the attic. After the super-storm surge broke the insufficient dikes, Nørrevang was flooded, and only the roof could be seen in the waves. Nørrevang was at the time in a better state than the surrounding farms and houses, so people had gathered in the attic of Nørrevang to save their lives. The two brothers succeeded in reaching the farm, but due the fierce weather conditions they had to wait until the storm had ceased a little before they could row the 22 stranded people in security. The brothers and three other persons, who did a similar rescue action got medals for their heroic actions from the Danish king in April 1873.

Figure 11: A, left: Postcard from the 1920'es showing the 40 m high cliffs of Stevns with the ladders the locals used to get access to the sea. Archive for Local History, Stevns. B, right: An artist's impression of the terrifying situation in southern Falster during the storm surge. It shows the action of the two brothers Olsen, who rescued 22 stranded people in a rowboat from the attic of a flooded farmhouse. From Museum Lolland-Falster.

5.4 The economic help

The many stories on the injuries and tragic fates of the storm surge victims in Danish newspapers made a great impression in Denmark. A nationwide collection of money to help the victims started. The big job of collecting the money and distributing them to the neediest was placed into the hands of a private organization in Copenhagen called the Central Committee. They asked the local authorities to list every loss, person by person, together with their economic situation. The Central Committee would only give help to the poor people and not to the richer.

On the other hand, the Danish government refused to give any financial help, so the victims of the storm surge were left to get help from family, neighbours, or the Central Committee in Copenhagen. During November and December 1872, the Committee collected more than 1 million rigsdaler, which compares to more than 250 million Euros in today's money. Almost one third of this money was given to the heavily damaged areas in Lolland and Falster.

5.5 Building 80 km of new dikes

After the flood, the lowlands of Lolland and Falster were completely open to the sea, and a new even minor storm surge. The Danish government quickly sent several hundred soldiers to build temporary protection. It was, however, soon realized that the task of building new dikes that could protect the low areas from a super-storm surge like the one in 1872, was not possible to undertake locally. In May 1873, a law for building new and much higher dikes, therefore, was passed in the Danish Parliament.

Many discussions went into deciding on the new dikes. In Falster, it was straightforward to place the new 17 km dike along the eastern coastal line to a height of 4 m. In Lolland, however, it was after long discussions finally decided to place the new dikes as far out in the Baltic Sea as possible, making it possible to dam large shallow fjords and lakes. This led over the years to much new farmland. The large dike in Lolland was built to a height of 4 m along a 63 km coastline. The construction was all done by hand and took several years to build.

6 A new super-storm surge in a changing climate

Storm surges and flooding in the western Baltic Sea happen occasionally. However, the long timeseries of water level observations from Travemünde (Rosenhagen and Bork 2009) shows that the November 1872 storm surge is the most severe event and the only super-storm surge that has occurred in the area since the observations started in 1826. It was nearly 1 meter higher than the second most severe storm surge in 1904.

It seems inevitable that a super-storm surge will hit the western Baltic Sea again in the future. From a planning and disaster prevention perspective, it is of interest to know when this will happen. This question is impossible to answer, but it is possible to calculate the frequency of such an event through high water statistics.

The official Danish high water statistics are prepared by the Danish Coastal Authority at regular intervals and are based on water level observations of well-documented quality. The statistics are unfortunately biased by the fact that the first ten Danish water level stations were established between 1884–1893. The 1872 super-storm surge and other previous extreme surges are therefore not included in the statistic. This makes it impossible to calculate a proper value for the return period of an 1872-size storm surge.

The Danish consulting company COWI has, on behalf of the local authorities in Køge, proposed to overcome this by establishing a water level time series as far back in time as possible. The modern measurements were supplemented with water level information subtracted from historic accounts, knowing that the quality of these data is undocumented and, therefore, to some degree questionable.

The data for Køge (see Figure 12) was divided into four categories:

1. 1955 to 2017, observed data
2. 1825 to 1955, eyewitness accounts quality assured up against measured water levels from Travemünde and after 1891 also data from Gedser
3. 1500-1824, eyewitness accounts from Køge, southern Danish Baltic Sea and Germany. The period was characterized by the availability of print media
4. 1044 to 1499, eyewitness accounts – all in handwritten reports

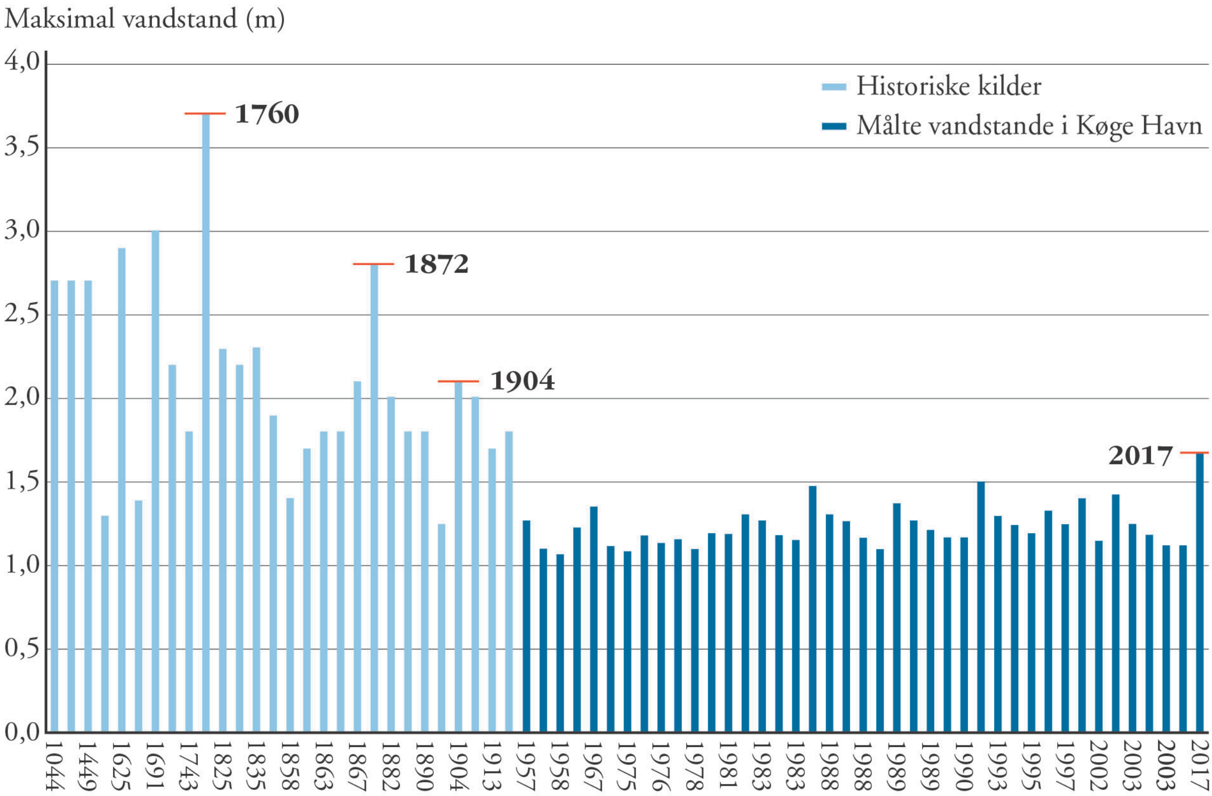

Figure 12: Maximum water levels in Køge the last approximately 1000 years, Dark blue columns = observed data, light blue columns = historical eyewitness accounts. From COWI (2016) and Køge Kommune (2018).

It is seen that historically there has been other super-storm surges than the one in 1872, especially the ones in 1625 and 1760 are relatively well-documented by eyewitness accounts.

Based on these data, COWI (2016) has prepared high water statistics for Køge as an alternative to the official one (see Figure 13). These statistics can be regarded as representative of most localities along the Danish Baltic Sea coastline. According to the alternative statistics, the return period for an 1872 size super-storm surge is around 300 years.

This value for the return period in Køge is smaller than the return period of 500–1000 years calculated for Travemünde in Jensen et al. (2022). The main difference in the two historical time series of water levels in the two statistical analyses is the inclusion of the storm surge in 1760, which hit the Danish east coasts. The 1760 storm surge is not reported in German files (Jensen et al. 2022), which might be because it was reported as an easterly storm which primarily affected the Danish coasts.

A future super-storm surge in the western Baltic Sea will undoubtedly cause damage on the vulnerable coastlines but not in the same order as in 1872 since:

- Parts of the coastline are well protected by dikes built after the 1872 storm surge.
- Houses and coastal infrastructures are built more solidly.
- Today there are weather and storm surge forecasts that well in advance can be communicated to authorities and the public allowing for preparedness actions to be initiated and implemented.

Severe damage must however be expected since many coastlines are still not well protected and many new houses, hotels etc. have been build close to the coastline in recent years.

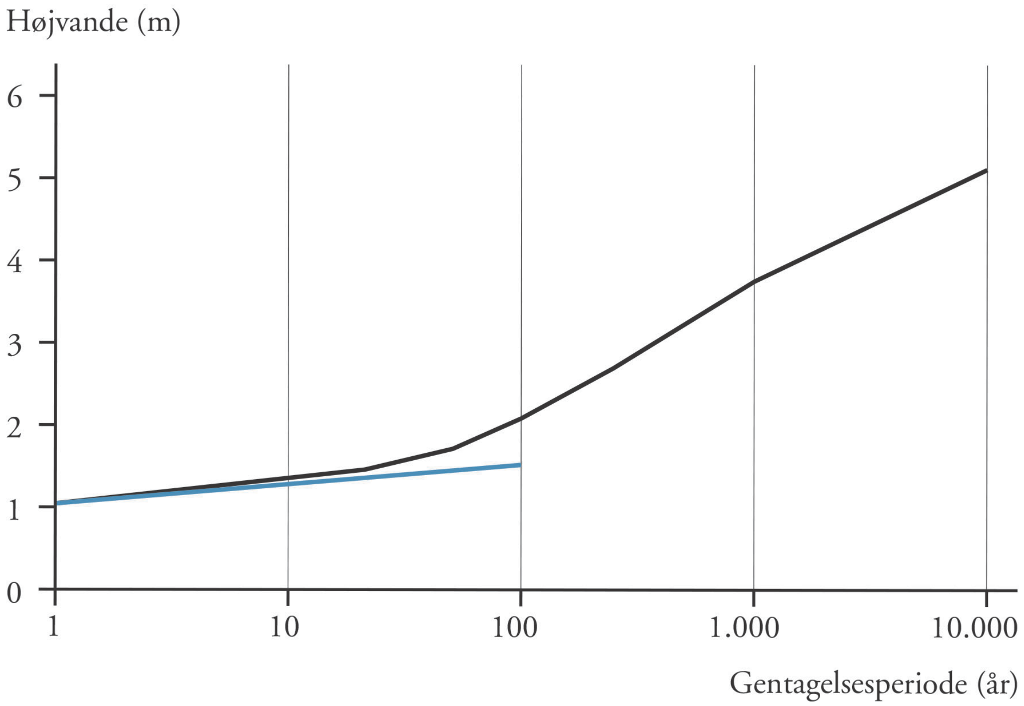

Figure 13: High water statistic for the city of Køge. Light blue curve = official statistic. Dark curve = alternative statistic including historical data. From COWI (2016).

In preparing for the next Baltic super-storm surge, an additional dimension must be added to the planning, i.e., sea level rises due to climate change. The Intergovernmental Panel on Climate Change (IPCC) settled in the first part of its sixth assessment (IPCC 2021) that the earth has warmed with approx. 1.1 °C compared to the mean temperature for the period 1850–1900. The IPCC further predicts that the temperature is likely to increase by 2.5–4.0 °C before the year 2100. This is significantly above the goal articulated in the Paris Agreement in 2015: *"Limit the global heating to well below 2 °C, preferably to 1.5 °C compared to pre-industrial levels"*.

Global heating means sea level rise in the world ocean due to the expansion sea water due to heating and melting of glaciers and the Greenland and Antarctic icecaps. IPCC (2021) predicts the global sea level to rise between 0.3–1.0 m before 2100. The actual rise will strongly depend on how effectively the international society manages to reduce carbon dioxide emissions.

Atmospheric and ocean circulation will be altered due to climate change and land masses will sink or rise, which effects regional differences in the sea level rise. DMI (2022b) has estimated that the sea level in Danish waters will rise around 0.5 m before the end of the present century. In practise, this means that a super-storm surge in 2100 will be 3.5 m above the present mean sea level, or 0.5 m higher than in 1872. This is important to consider when planning storm surge prevention initiatives.

7 References

Aakjær, P.; Buch, E.: Stormfloden 1872 – da Østersøen druknede Danmark. In Danish. Epsilon, Copenhagen, 2022.

Colding, L. A.: Stormen over Nord- og Mellem-Europa af 12–14 November 1872 og den derved fremkaldte Vandflod I Østersøen. In Danish. Videnskabernes Selskab, Skrift 6, Copenhagen, 1881.

COWI: Havvandsstatistik for Køge Bugt. Køge Kommune. In Danish, https://www.koege.dk/~/media/Files/Pdf/Borger/Natur%20milj%C3%B8%20og%20energi/Klimatilpasning/Kystbeskyttelse/Havvandsstatistik_Notat_001_v2_1.ashx, 2016.

DMI: Personal Communications, 2022a.

DMI: In Danish. https://www.dmi.dk/klima-atlas/data-i-klimaatlas/?paramtype=sea&maptype=kyst, 2022b.

Ejdorf, K: Stormfloden den 13. november 1872. In Danish. Skib Forlag, 2002.

IPCC: Climate Change 2021 – the Physical Science Basis, https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Full_Report_smaller.pdf, 2021.

Jensen, J.; Habib, M.; Beckmann, S.: Best estimates for historical storm surge water level and MSL development at the Travemünde/Baltic Sea gauge over the last 1,000 years. In: Die Küste, 92, https://doi.org/10.18171/1.092102, 2022.

Køge Kommune: Stormflodssikring, Dispositionsforslag for Køge. In Danish, 2018.

Rosenhagen, G.; Bork, I.: Rekonstruktion der Sturmflutwetterlage vom 13. November 1872. In: Die Küste, 75, 51–70, https://doi.org/10.18171/1.092103, 2009.