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Resumé

Historical extreme high water levels along the coastline of Denmark

The highest ever recorded extreme sea water levels are mapped along the coastline of Denmark. Based on a division of the coastline into 36 coastal sections the highest extreme water levels within each section are presented. For each coastal section a data sheet provides information on the primary tide gauges present within the section and the five highest water level events recorded. Additionally, the data sheets contain information on the location specific difference between the Danish vertical reference level of DNN (old) and DVR90 (present) as well as an approximation of the annual local relative sea level rise since 1990. The water levels are ranked relative to their trend-free (2020) reference level.

More than 100 tide gauge station data series have been analyzed up to May 2020. A few tide gauges have time series extending back to 1890, whereas others have only been operating a few years, and some are no longer in operation. Furthermore, historical extreme sea water levels are implemented from historical sources when water level measurements or reports are available. The validity of the historical water levels is assessed before implementation; meaning that some events are rejected and others are adjusted in the extreme water level. For selected storms where sufficient data is available with evidence of extreme water levels at multiple locations, but the geographic distribution of tide gauge stations is scarce, the storm events are modeled and the water levels are included. Tide gauge measurements, historical reports and hydrodynamic models thus form the basis data input to the presented work.

Resumé (dansk)

Historiske ekstreme havvandstande langs de danske kyster

De højeste målte havvandstande kortlægges langs den danske kystlinje. Kortlægningen følger en inddeling af Danmarks kyster i 36 kystsektioner. Resultaterne er præsenteret i et opslagsark for hver kystsektion, hvor de fem storme, der har foranlediget de højeste vandstande inden for hver sektion, er listet med den højeste registrerede vandstand. Hertil følger en beskrivelse af området og målestationerne inden for sektionen, som er inkluderet i opgørelsen. Til disse stationer er information vedrørende deres placering, niveauforskellen mellem højdesystemerne DNN og DVR90 samt den stationsspecifikke årlige relative havspejlsstigning siden 1990 angivet. Vandstandene er gjort trendfri med 2020 som basisår og er rangeret herefter.

Måleserier fra over 100 vandstandsmålere er inkluderet i analysen, der indeholder data frem til maj 2020. Enkelte måleserier strækker sig tilbage til 1890, mens andre kun dækker de seneste år. Endvidere er nogle målestationer ikke længere aktive. Yderligere er historiske storme inkluderet fra historiske kilder, hvor vandstande er angivet. Validiteten af disse observationer er vurderet, inden de er implementeret i opgørelsen, og enkelte historiske hændelser er udeladt, mens andre er justeret i niveau. For enkelte historiske hændelser med begrænsede vandstandsobservationer, hvor tilstrækkelige klimadata er tilgængelige, er storme modelleret og vandstande implementeret i opgørelsen for udvalgte lokaliteter og sektioner. Vandstandsserier, historiske kilder og hydrodynamiske modeller udgør samlet det primære data input.

Introduction

The primary objective of this research is to identify the highest ever recorded extreme water water levels along the Danish coastline, where the coastline representation is divided into 36 sections. Considering the diversity of coastline configuration, exposure *etc.* many different storm events may over time have led to storm surges/extreme events; also in relation to the most severe. Besides seeking to identify the highest water levels ever recorded, it is also of interest to identify less severe events that have occurred at any given location or within each section.

Extreme water levels may cause extensive flooding in coastal areas and pose a threat to housings, infrastructure and in extremely severe cases; human lives. Coastal protection and other measures can help to mitigate the risk of flooding through the incorporation of extreme still water levels and wave conditions in the design criteria; this is usually expressed in terms of a return period, which states the occurrence probability of a flood level that is considered acceptable to the local area. Since the 1980s, DCA (Danish Coastal Authority) has produced and updated extreme water level statistics in 5-year intervals (e.g. Sørensen *et al* 2013b and Ditlevsen *et al* 2018) based on measured water levels. Historical storm surges, which have taken place prior to the installment of the tide gauges, are not included. However, data records are usually short compared to the return period design criteria and extreme sea level projections can therefore contain large uncertainties when extended beyond the data record. Historical events can be included in extreme statistics, however the precision and validity of such measurements are not always credible, and therefore a thorough assessment of these reports is required before implementing them as a means of design criteria. Even then, their effects in local extreme value analysis methods and statistics have to be thoroughly investigated.

Tide gauge (TG) records provide much of this information, where ten TGs hold data series extending back to the late 19th century (*c.* 1890 - 2020); refer *e.g.* to Hansen (2018). Since the mid-1970s most TG series are recorded in a digital format but before then analogue recordings (paper sheets, manually read, *etc.*) were the norm. Only three of the long TG series (Esbjerg, Gedser and Hornbæk) have been digitized in full (Andersen *et al*, 2017; Sørensen *et al*, 2013a).

Some analogue data series are still kept in data depositories, whereas others remain unidentified or have been lost (Andersen *et al*, 2017; DCA, 2018). Today more than 80 TGs are in operation and an additional number of stations measures river water levels under marine influence, which may aid the identification and assessment of extreme levels particularly in sections with a poor TG coverage. In some instances, *e.g.* in relation to port activities, logs have been kept by the Danish Coastal Authority, port authorities or the navy to yield some information on water levels, as well as the Danish Meteorological Institute (DMI). In the first half of the 20th century, DMI collected information about extreme water level events from informers around the country (*e.g.* Egedal, 1949). Otherwise, historical written evidence exist from eyewitness reports, scientific work, and previous compilations (*e.g.* Baensch, 1875; Colding, 1881; Gram-Jensen, 1985, 1991; MPW, 1922; Piontkowitz and Sørensen, 2011).

Beyond the task to identify the highest ever measured water level at each location from the historical literature and data, efforts have been made to quality assess this data, and to search for, investigate, and validate additional information. Furthermore, partly beyond the scope of this work, it is important to get as firm and robust evidences regarding all historic events, or, to at least settle for some 'interval of uncertainty' around extremes' estimates and acknowledge, particularly going back in time, that scarcity in information about events (and their impact) may be prohibitive of evaluation of that event in any quantitative manner. Here, a scarcity of evidence may to some extent in itself be an indication that the event was not too severe.

Changes in the governing physical parameters, also including the development in society like urbanization, leads to non-stationarity in data. For instance, mean sea levels change over time; and *e.g.* land-use changes and urbanization in conjunction with coastal protection schemes may reveal that a past event in terms of both the experienced water level and damages may deviate considerably compared to the same (magnitude) event occurring today. There is also non-homogeneity in data: some records are eyewitness reports of the highest water level (perhaps including wave run-up) which may have occurred far inland in river systems or landward fringes of marshlands *etc.* Also, coastal TGs may record the maximum water level or provide averaged or instantaneous water levels of 10, 20, 30 or 60-minute intervals, for instance. Altogether, this yields some uncertainty in individual records and in the comparison between events of the maximum water level recorded.

The main objective is to identify the highest-ever reported or recorded water level within each of the 36 coastal sections. Instead of presenting the “top event” only, however, a total of five events with corresponding water levels are included in the investigation. Because water levels along the coast in the sections may vary considerably for individual events, and because the main emphasis is on the most extreme water level, the 2nd to 5th ranking is not as certain. Also, not all lists may be complete regarding these events (2.-5.). The lists do provide the option of an overall evaluation of the extremity of water levels within each section, however.

Coastal Sections

In connection with the 2nd period of implementation of the EU Floods Directive (2007/60EF) by DCA (2020) and consequently adopted in the Climate Atlas (https://www.dmi.dk/klimaatlas/) provided by DMI, Denmark is divided into six main coastal areas (Table 1) and further subdivided into 36 coastal sections (Figure 1). Here, the coastal sections are applied when identifying the highest ever recorded water level within each section.

Table 1: The six main Coastal Areas. See Figure 1 for a complete overview of the Coastal Sections

The main Coastal Areas		
Abbreviation	**Name (Danish)**	**Name (English)**
VH	Vadehavet	The Wadden Sea
VK	Vestkysten	Jutland west coast
LF	Limfjorden	The Limfjord
OJ	Østjylland	Eastern Jutland
SD	Syddanmark	Southern Denmark
SJ	Sjælland	Zealand

For some coastal sections the extent of the polygon coverage may introduce complications when ascribing a single water level to these, as the physical environments (coastal configurations *etc.*) and extreme water levels may vary significantly within a section. For coastal sections where such uncertainties are believed to become significant, the water level gradients or expected variations within the section are described.

The results are compiled in the supplementary data sheets. A data sheet is produced for each of the 36 coastal sections and includes the five highest water level events identified within the section. To avoid having the same event listed several times within sections where more than one TG is present, any specific storm is only included once and is represented by its highest reported or recorded surge elevation. The water levels are provided a) in centimeters above DVR90 and b) as trend-free water levels with 2020 as basis year. Furthermore, the data sheets contain a brief description and a map of the coastal section along with a list of the tide gauge stations present within the section.

Selected historical storms are described in more detail. These storm descriptions can be found in Appendix A along with other relevant information regarding *e.g.* gradients in maximum water levels within specific coastal sections. Also, selected storms have been modeled to verify and/or estimate maximum water levels for areas, which are known to have been exposed to extreme water levels during specific events, but are scarce in water level measurements.

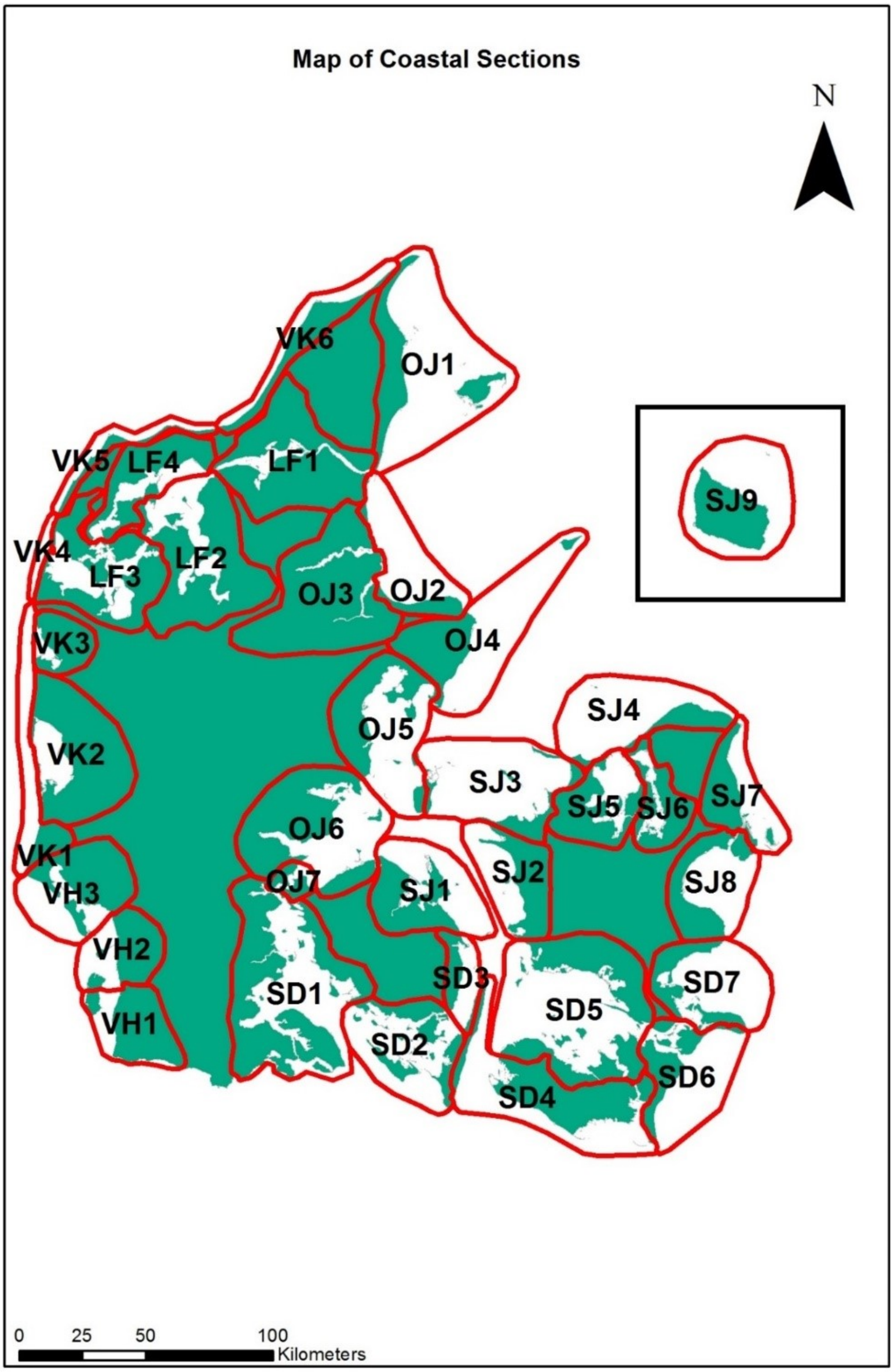

Figure 1: Overview of the 36 coastal sections

Physical characteristics of study area

An extreme water level is an extraordinarily high water level caused by special wind and weather conditions. An extreme water level event in the Danish waters occurs as the result of one or more isolated or coincident factors (revised from Sørensen *et al,* 2013b):

- Onshore persistent winds of gale force or stronger lead to a direct piling up of water along the coast (wind set-up).
- Elevated mean sea level in semi-enclosed basins prior to high wind conditions. This is usually due to persistent westerlies, *e.g.* by forcing North Sea water masses into the Kattegat and Baltic Sea.
- Inverse barometer effect, whereby an atmospheric low raises the general water level (and potentially including meteo-tsunami)
- Long period waves entering the North Sea from the North-East Atlantic (external surges). Likewise, Baltic storms may have distant effects on shores experiencing perfectly calm weather (silent surges).
- Seiches, or standing waves (aka the “bathtub effect”); a phenomenon of enclosed or semi-enclosed seas and basins whereby water shifts along the basin axes.
- Tidal high coinciding with timing of high winds
- Wave set-up whereby the transport of water towards the coast through waves action increases coastal sea level.

Figure 2: Denmark and main surrounding water bodies.

Extraordinarily high water levels thus occur as the result of strong sustained winds and the distribution of high- and low pressure systems across the northern European area in combination with other factors such as tides and different types of coastal configurations.

There are large regional and local variations regarding the height of extreme water levels. In the Wadden Sea area water levels can reach in excess of 6.0 m DVR90 while the water levels in the Ringkøbing and Nissum Fjords inland from the North Sea coast rarely reach 1.5 m. Along the coasts of Skagerrak, Kattegat, the Limfjord and in the Belts, water levels rarely exceed 2.0 m DVR90. In the Western Baltic, due to the vicinity of the vast Baltic Sea, sea levels are known to have exceeded 3.0 m (see Figure 2). The maximum water levels therefore, in general, depend largely on the size of the water body to which the coast is exposed: a) largest, the North Sea with the Atlantic connection, b) second largest, the Baltic Sea, c) third largest, Kattegat. Exceptions are regions with only deep-water exposure: Skagerrak and Bornholm, where high waters get less extreme. Fjords may experience higher or lower extreme water levels, depending on the exact nature of the connection to the open water body.

In Denmark tides are mainly semidiurnal and tidal ranges vary significantly, decreasing from west to east in the propagation direction. In the Danish Wadden Sea area the tidal range is about 1.8 m (c. 1.6-2.0 m) decreasing to c. 1.0 m along the west coast of Jutland. In the inner Danish waters the tidal range varies from 0.3 – 0.5 m, decreasing to an insignificant height (0.1 m) in the Baltic Sea, due to the low-pass filtering effect of the Danish straits. Tides are independent from the weather conditions and it is therefore to some extent a matter of chance, whether the tide and high winds will interact destructively or constructively.

The absolute water level during a storm surge is known as a storm tide, thus also accounting for the tidal excursion. When a storm surge coincides with high tide, the vertical and horizontal water displacement can become considerable. The maximum water level along any surge exposed coastal stretches will vary spatially as a result of meteorological conditions and of the local coastal configuration. As meteorological conditions with strong onshore winds often lead to considerably raised water levels along the North Sea coast, and because of the amount of people that depend on dikes *etc*. for their protection, a common perception in society has been that extreme storm surges are less frequent in the inner Danish coastal areas. Numerically the maximum water levels of the Danish inner waters are far lower than in the Wadden Sea, but flooding starts to occur for much lower water levels and historically large storm surges affecting the inner Danish coasts are just as severe in terms of damage as storm surges along the North Sea coast.

Data and Methods

The primary objective is to locate and evaluate the highest ever recorded extreme sea water level within each coastal section. In some areas, a single extreme water level event (like the November 1872 Southwest Baltic Sea storm surge) is significantly larger than all other events recorded. Therefore, in order to represent also less severe and more frequent events, it was decided to extend the list and include five extremes per coastal section. A consequence of this approach is that within any given coastal section the same storm event may stand out at several locations and therefore any event is only included once. The final data-sheets thus present a ranked list of the five storm events, which produced the highest trend-free water levels within each coastal section; please refer to section on trend-free water levels below. Since the primary objective is to validate the highest recorded or reported water level within each section, the investigation of additional storms is not as consolidated by the authors. Therefore, some uncertainty regarding their rank is stated. Altogether the lists do provide information about the general extremity of storm surge levels within the coastal sections.

In the following section the primary sources of data are presented. This is followed by an evaluation of the changes in mean sea level and how this is implemented in the calculation of trend-free water levels used for the direct comparison and ranking of extreme water levels within each coastal section.

Data sources

In the screening for historical extreme high water events the primary sources of information may be divided into ‘*Records’* and ‘*Reports’:*

Records (primarily in meters and centimeters relative to DNN until 1990 and DVR90 datum since then):

- Tide gauge data until May 2020 – See station list in appendix B
- Logs of water levels by port authorities *etc*.
- Sørensen *et al* (2013b).
- Ditlevsen *et al* (2018).
- Hansen (2018). Sea level data 1889 – 2017 from 14 stations in Denmark.
- Historical German high water events with special emphasis on Flensburg (Appendix A).

For a number of years the DCA has compiled extreme water levels and statistics for Danish waters (see Sørensen *et al,* 2013b and Ditlevsen *et al,* 2018). These statistics are updated every five years and comprise measurements from more than 60 gauge stations along the Danish coastline. The statistics are based on tide gauge records only (however, in the Limfjord area TG data are modified to account for physical changes in the fjord system over time), and serve as data collections of extreme records. Historical storm surge data prior to the application of tide gauge data are not included in the statistics. Additional tide gauges not covered by the extreme water level statistics, *e.g.* due to short time series in TGs, have been included and the 10 highest water level events were examined for each station. Since 2017 a number of storms have produced water levels sufficiently high to be included in the presented work. These storms have all affected different areas of the inner Danish waters.

- 4th of January 2017

- 29th of October 2017
- 2nd of January 2019
- 12th of February 2020

Reports (primarily in feet and inches related to ‘mean water level’):

- Gram-Jensen (1991) - 350 BC to 1981
- Colding (1881)
- Egedal (1949)
- Pedersen (1977)
- Supplementary literature screening for extreme events for areas and periods not covered by the abovementioned sources.
- Screening of literature for identified events concerning storm surge characteristics of individual storms.

Gram-Jensen (1985, 1991) published a detailed list of historic storm surges that have occurred in Denmark and Schleswig-Holstein (in Germany today) between 350 BC and 1981. Each event in Gram-Jensen (1991) is classified with an occurrence credibility (ranging from certain to wrong), along with an estimated scale of the storm surge. Please refer *e.g.* to Piontkowitz and Sørensen (2011) for a discussion of data availability and data quality in older records.

Gram-Jensen (1991) notes that water levels in feet and inches should be considered as approximations of the maximum water levels, as they are presented directly as reported by the historical sources. Furthermore, the standard measure of a foot and an inch has historically varied locally. Therefore, it is unknown whether the water levels are expressed as the Danish standard measurement or a local deviating measure (Gram-Jensen, 1991).

- A standard Danish foot is 31.39 cm
- A standard Danish inch is 2.61 cm (1/12 of a foot)
- A standard Danish alen is 62.78 cm

These length units are used directly when transforming reported surge levels to cm. Furthermore, as the measurements are not standardized they are not immediately comparable spatially or temporally: spatially because the water levels expressed vary in relation to their reference level, *e.g.* Dansk Normal Null (DNN), above mean sea level (a.m.s.l) and above mean high water level, where the latter two naturally differ locally and temporally.

Gram-Jensen’s list is used to locate verified (certain) storms and corresponding water levels, if stated. Cited water levels are used directly but not before their plausibility of occurrence are assessed. Several reported water level indications are assessed to be overestimated or exaggerated, likely because they include wave action and/or have not been assessed and referenced properly to the mean still water level. Some storm surge levels indicated in Gram-Jensen (1991) are expressed in intervals, *e.g.* 5 – 6 alen and the water level in centimeters is calculated as the mean of the interval unless otherwise stated. Water levels expressed with reference to the local mean sea level are used directly from the assumption that a.m.s.l. corresponds well to DNN. This is a crude assumption, but it is almost impossible to determine the ‘true’ level without comprehensive underlying data.

Similarly, Colding (1881) notes that water level indications can be encumbered with some degree of uncertainty regarding the actual maximum level. This is because the measurements included rely on local reports, which can be more or less precise: *e.g.* the reported water levels can include wave action and/or runup, or they may lack a precise reference level if no Local Null (LN) exists for the specific site.

A large proportion of reported historical storms are not accompanied by water level indications. Instead, they are often described by the extent of the flood and/or the damages caused by the event. It is beyond the scope of this project to quantify such events, and therefore extreme events where no water level observations exist are not included; unless the high water levels can be reasonably estimated or recreated using hydrodynamic models verified from water level observations close to the area of interest. This excludes extreme events which are well known historical disasters such as the Wadden Sea “first great man drowning” of January 1362.

Trend-free water levels

Due to the temporal variation in mean sea level, water levels are de-trended to a common vertical level of reference in order to compare extremes in relation to the excursion from mean water level in their year of occurrence. This makes them comparable relative to today’s height reference frame and sea level. High water levels measured 50-, 100 or 200 years ago occurred during times when the absolute mean water level was lower than at present. Therefore, surge levels are adjusted to account for the rise in sea level since their time of measurement. Thereby the trend-free water level expresses the approximate level of the storms if they were to occur in 2020. In the following sections, the factors that affect the change in local relative sea level are presented along with the method applied in calculating the trend-free water levels.

Relative Sea Level Rise

The global mean sea level is rising due to thermal expansion and because glaciers and ice sheets melt at an increasing rate. Relative sea level rise (SLR) refers to the rise in sea level observed from a reference point on land. The relative SLR is thus not only affected by the eustatic processes but also land processes such as subsidence and isostatic movement. Locally/regionally the interplay between these processes controls the relative SLR (SLR_{rel}).

$$SLR_{rel} = SLR_{abs} + GIA_{abs} + LOW_{abs}$$

where SLR_{abs} is the change in mean sea level, GIA_{abs} is the glacio-isostatic adjustment and LOW_{abs} is the local subsidence.

The absolute sea level rise is assumed uniform for the Danish waters, while GIA varies geographically. Local subsidence can be disregarded when looking at the overall changes in the relative sea level and is not included here. However, the local effects may be important in evaluating TG reference levels and/or for engineering purposes, *e.g.* when assessing local climate impacts and designing flood protection measures.

Relative sea levels have varied considerably in the past (see *e.g.* Watson, 2019; Church *et al*, 2010). Since the mid-19th century approximately, global absolute mean sea levels have been rising although with some year-to-year and decadal variability (*e.g.* Jevrejeva, Grinsted and Moore, 2009). Church and White (2011) found a rise in global mean sea level during the 20th century of 0.15-0.18 m (mean rate 1.5-1.8 mm/yr) and their results have been corroborated, however at a slightly lower rate (1.1

+- 0.3 mm/yr) by Dangendorf *et al* (2017). Corresponding values (1.4 +- 0.3 mm/yr) for the entire Baltic are found by Madsen *et al* (2019) and for the North Sea (1900-2011; 1.2-1.6 mm/yr) by Wahl *et al* (2013). There is little evidence that sea level rise in the 21st century in the North Sea region will differ significantly from the projected global changes. Therefore, it is typically justified to use global scenarios as a basis for deriving reliable relative sea level rise scenarios on a regional to local scale (Wahl *et al*, 2013). Also, to a first approximation, the general averaged rate of absolute sea level rise over the 20th century for Denmark may be assumed to be in the order of 1.5 mm/y. The recent decades have witnessed an increased rate of global sea level rise where Nerem *et al* (2018) and Dangendorf *et al* (2019) have documented acceleration. The current rate of global mean sea level rise is of the order of 3-4 mm/yr.

The other main contributing factor to the observed relative sea level changes is the glacio-isostatic adjustment, *i.e.* vertical land movement. For Denmark, present uplift rates of *c.* 0.2 - 2.6 mm/yr have been modeled by Knudsen *et al* (2016) (Figure 3). Their estimates compare well with the regional (Fenno-Scandic) model results of Vestøl *et al* (2019).

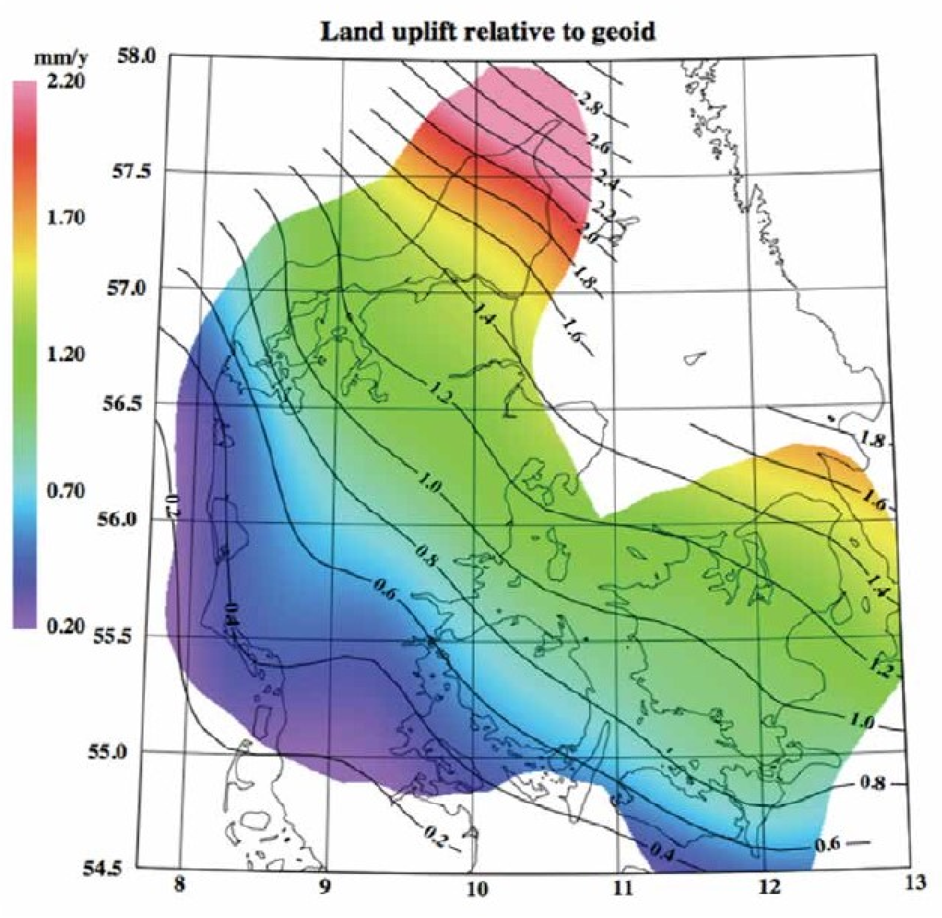

Figure 3: Uplift rates over Denmark (DTU Space / Knudsen *et al*, 2016).

Differences in Datum - DNN/DVR90

Contemporary water level measurements are related to the Danish Vertical Reference system (DVR90), which replaced the former system DNN (Danish Normal Null) around year 2000 as a consequence of the inhomogeneous relative sea level rise experienced since the introduction of DNN in the late 19th century. In both reference systems the zero-level represents the averaged mean water level along the Danish coastline; DNN for 1891 and DVR90 referenced for 1990.

The effect is a perceived (relative) sea level rise along a major part of the Danish coastline, brought on by the rise in global mean sea level, in combination with the glacio-isostatic adjustment. The DNN-DVR difference ranges from -2 cm to +13 cm with the largest relative changes in southwest Denmark (Schmidt, 2000). The DVR90 zero reference is based in Aarhus, which implies that the mean water level differs from zero at individual coastal locations at the time of implementation. Here, however a pragmatic approach have been applied in taking the difference between the DNN to DVR90 as representing the relative difference in mean sea level at the tide gauge stations for the period 1891-1990. More thorough investigations into the reference level (LN) of the individual tide gauges and its relation to DVR90 is desirable but beyond scope of the present study. Likewise, the water level could be related to the seasonal changes in mean water levels, *i.e.* as almost all extreme events occur during the winter months (October through March). Regional annual and decadal variations in mean sea level also affect not only the instant observations but also the trend of sea level rise. Wahl *et al* (2013) found a strong correlation between sea level variability and mean sea level pressure along northern Denmark when investigating decadal sea level variability, suggesting that MSL records should be corrected for the inverse barometer effect as this significantly reduces the variability at some tide gauge stations and thereby improves trend estimations. Such analyzes have not been conducted as part of this work. The same rate of mean sea level change (as 1891-1990) is assumed to have existed since 1840, i.e. no pre-industrial sea level rise is assumed, which, considering the large uncertainty in old reports, may be justified here but is not valid in more detailed sea level studies.

Similarly, the relative sea level rise since 1990 needs to be accounted for. Here, a conservative average rate of sea level rise of 3.0 mm/yr is applied for the period 1990-2020. The GIA increases from 0.2 mm/yr in the southwest to about 2.6 mm/yr in the northeastern part of Denmark (Figure 3). This means that GIA mitigates the effect of coastal SLR but with spatial variation. From the information on absolute sea level rise and the local glacio-isostatic adjustment the 1990-2020 approximate relative rise in sea level is calculated for Danish tide gauge stations (Figure 4).

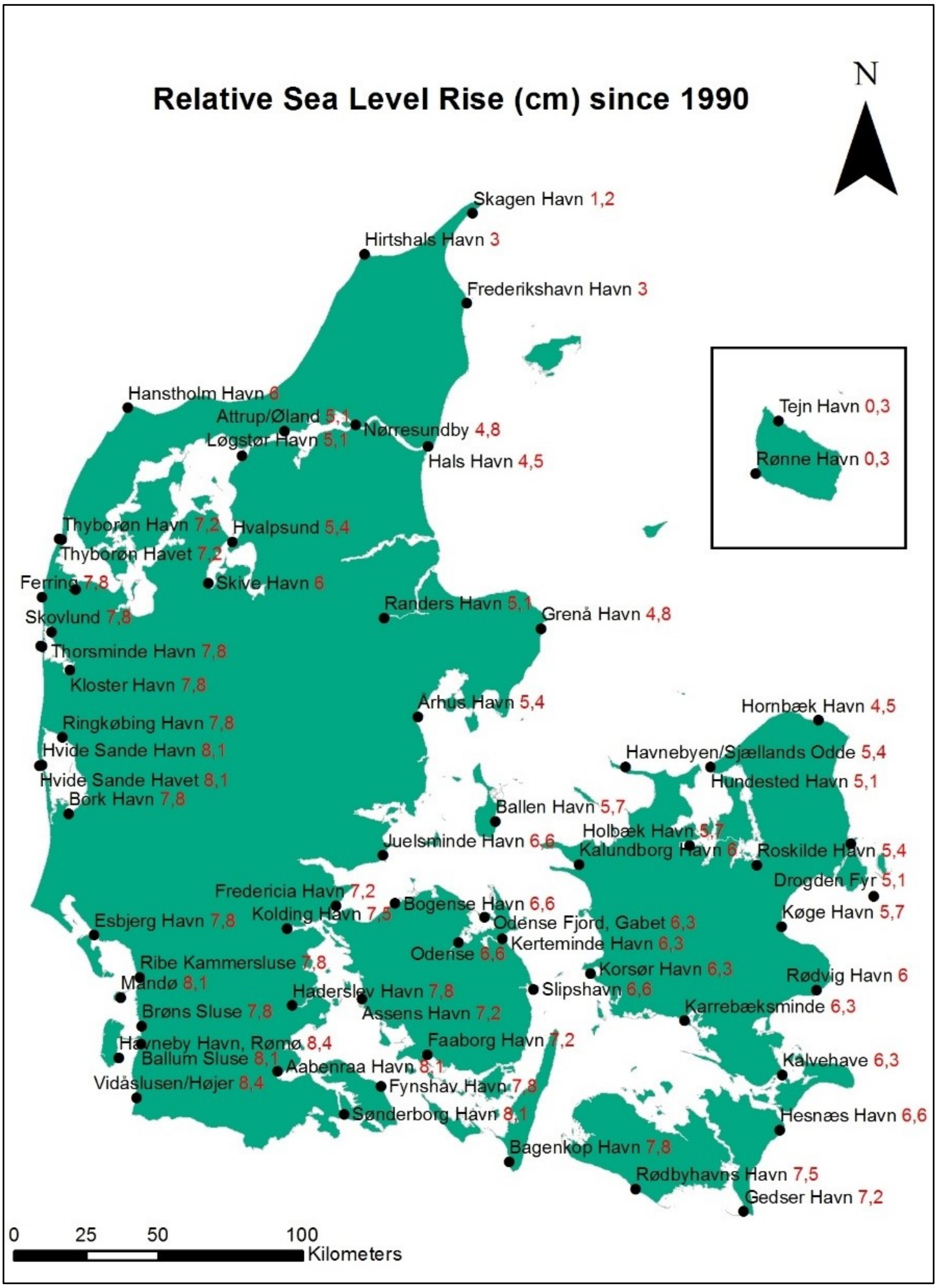

Figure 4: Relative Sea Level Rise (in cm) 1990-2020 for selected tide gauge stations.

Referencing sea level to 2020

For the comparison of extreme events' maximum water level within each section, these are related to the average mean sea level in 2020. This, as a first approximation, acknowledges that relative mean sea level has changed over time and thus that a storm surge level of, say, 3 meters in 1980 is less severe than the same event today in most places because of the relative sea level rise since that year. The stepwise de-trending calculation, referring first to 1990 and then to 2020, is illustrated by an example below and in Figure 5:

A Vidå/Højer storm surge in 1928 was recorded at 422 cm DNN, corresponding to 411 cm DVR90, since the (1891-1990) linear reference level change is 11 cm. Using the constants in Data Sheet VH1, the trend-free 1990 change amounts to

$$(1990 - 1928) \text{ years} * 11 \text{ cm}/99 \text{ years} = 6.9 \text{ cm},$$

The 1990-2020 relative sea level change (Figure 4) adds

$$(2020-1990) * 0.28 \text{ cm} = 8.4 \text{ cm}$$

for a total de-trended water level of

$$411 \text{ cm} + 6.9 \text{ cm} + 8.4 \text{ cm} = 426.3 \text{ cm} \approx 426. \text{ cm}$$

The first correction is truncated at 1840, so that no correction is applied for any time period before that year. For events later than 1990, only the second correction is applied, in proportion of the elapsed time since the year of the event.

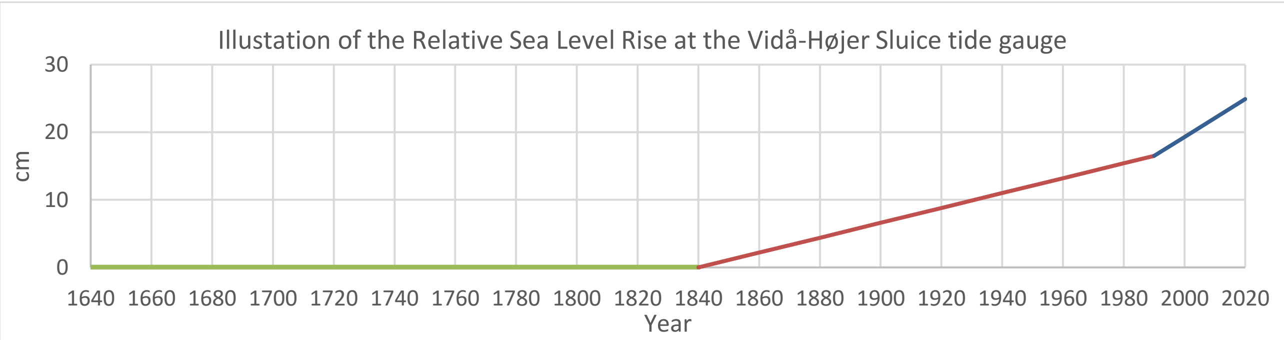

Figure 5: Illustration of a Relative Sea Level Rise curve. Prior to 1840 SLR is counterbalanced by GIA (green). From 1840 – 1990 the relative sea level rise is calculated from the difference between DNN and DVR90 (red). From 1990 to present day the relative sea level rise is calculated from the difference between the global sea level rise (3 mm/year) and GIA (0 – 2 mm/year) (blue).

When calculating the trend-free water levels, as a practical choice only the year of the event is taken into account. This time imprecision (not using the exact date), can reduce sea level precision by about 1 cm.

Because of the de-trending with 2020 as the reference year, the order in the ranking of individual events may change as older events are 'raised' more than recent ones to account for the relative sea level rise.

The maximum trend-free water level within each coastal section is depicted in figure 6.

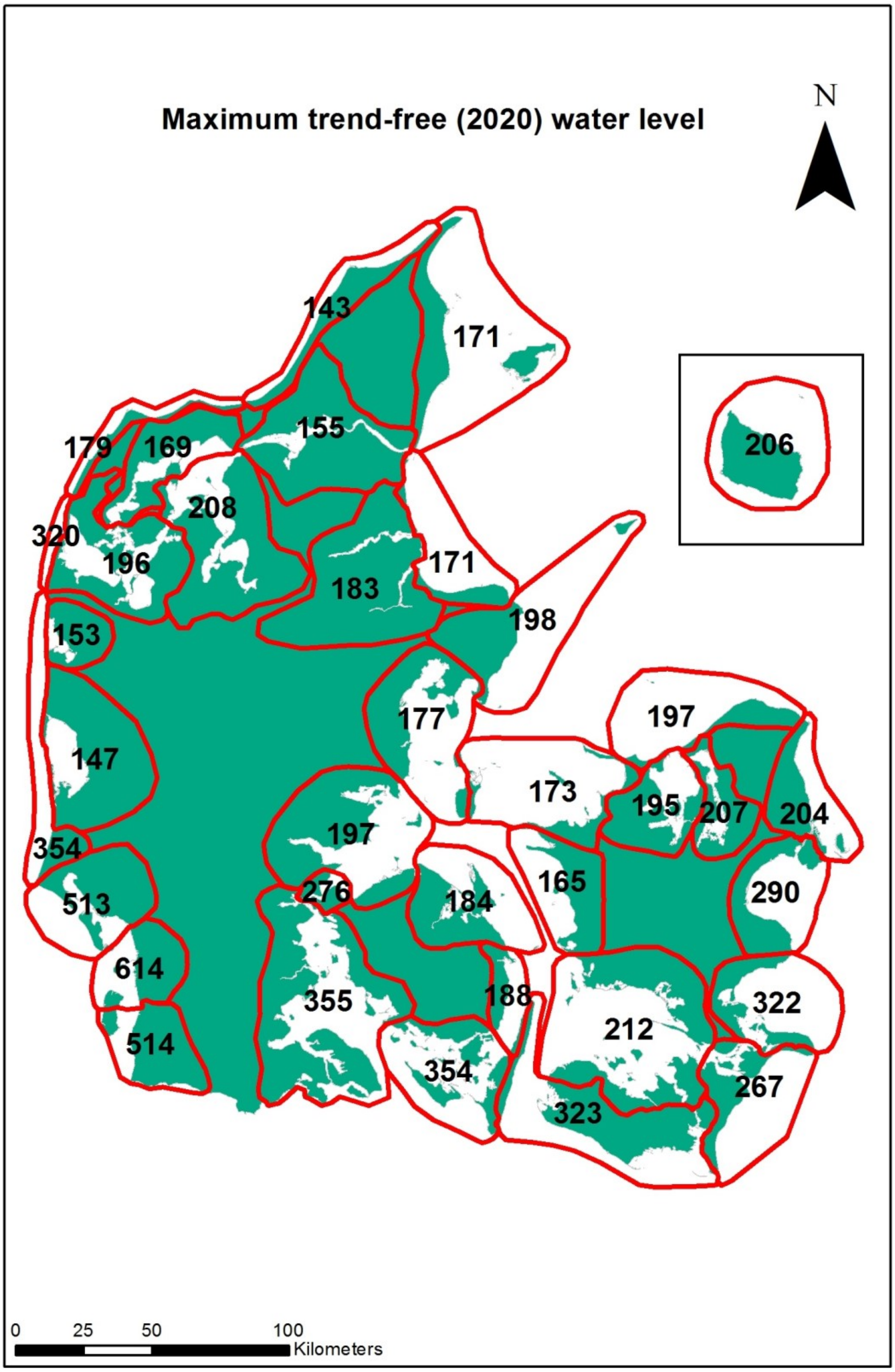

Figure 6: The highest extreme water level (in cm) within each coastal section

Application of models

For a limited number of historical storm surge events the recorded maximum sea level is found to be misrepresented in the data record, either due to malfunction of the TG instrument(s) or inadequate instrumentation. These storm surge events have been modeled as part of DMI's Climate Atlas project, using the DMI operational (2019) storm surge model in combination with the NOAA 20c re-analysis product (1836-2010) version 3 (Slivinski *et al,* 2019), and the UERRA re-analysis product (1960-2018) (Ridal *et al*, 2017). The correlation between observed and modeled sea level is satisfactory, approximating 0.95 for the NOAA runs.

The NOAA forced sea level, however, underestimates the sea level variability during the sea level highs and lows. This is partly due to the coarse resolution of the NOAA surface wind both in space and time, which leads to a systematic under-estimation of sea levels during storm surge events. We applied a simple reconstruction method, *i.e.* re-scaling the surge (unbiased, non-tidal) part of the simulated results forced by NOAA surface wind and air pressure (before 1960). This re-scaling method uses the observation/model surge root mean square deviation (rmsd) ratio during a one-month period including the event as first guess for scaling, but modifying the time window for each event until a satisfactory fit. With this correction, the modeled sea level is used to fill in gaps. Similarly, when the instrumentation is inadequate, the difference in modeled/observed sea level maximum is transferred from neighboring locations to correct the modeled maximum at locations with missing data. The scaling is conducted based on 10-minute model output data, independent of the tide gauge sampling rate.

The modeled storm surge events include (please refer also to Appendix A):

- 31 December 1904 – 1 January 1905. Data gap (8 hours) at and around the time of maximum sea level at Gedser TG and with no other TGs in affected area.
- Autumn and winter 1921/22. Little tide gauge data in the Roskilde/Isefjord system on Zealand, where each of three consecutive storm events in just two months is modeled to have reached their maximum sea level. The water level was recorded at Hornbæk; with the tide gauge breaking down during one of the storms.
- 3 December 1999. December hurricane during which the tide gauge at Ribe in the Wadden Sea broke down around peak level.

When filling-in gaps, the corrected maximum sea level turns out to depend on the width of the data window examined (Figure 7). The time window which was assessed to consistently provide the best results was the '5 days centered', where the scaling-period analyzed stretches from two days prior to the storm maximum till two days after. Model and observed tide is analyzed and calculated using t_tide with the calendar year of data in question as input.

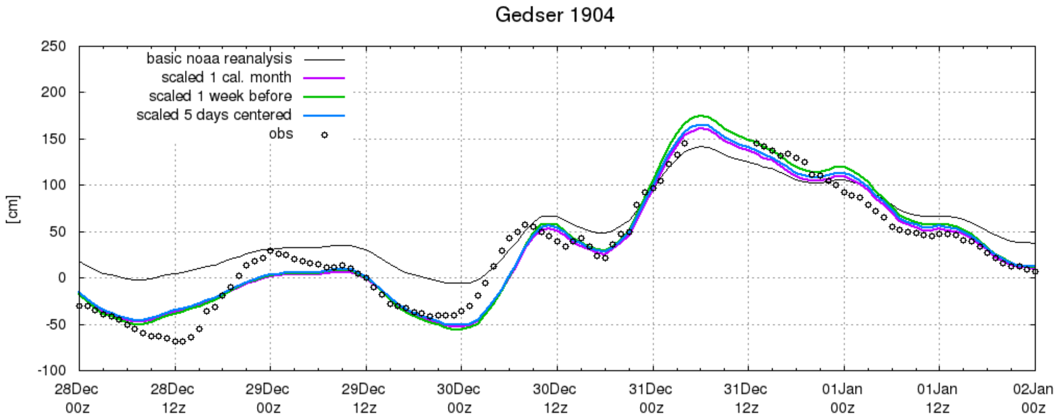

Figure 7: Modeled water levels. Gedser 1904/1905 storm surge: the tide gauge broke down for 8 hours and the water level is therefore reconstructed using the NOAA model. The scaling '5 days centered' (blue) was ultimately selected.

Acknowledgements

This project is carried out in collaboration between the Danish Meteorological Institute (DMI) and the Danish Coastal Authority (DCA). It was co-funded by and carried out under the umbrella of the Danish National Centre for Climate Research (Nationalt Center for Klimaforskning, NCKF) in 2020. NCKF has been a source of funding for the Danish Meteorological Institute (DMI) and collaborators for climate change related research during this year.

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Data Sheets

The results are presented in the provided data sheets, each with a header containing the name of the given Coastal Section. Two initial maps provide an overview of

1) The Coastal Sections
2) The Maximum Trend-free (2020) Water Level within each Coastal Section

The data sheets are sectioned in four main parts:

Description of Coastal Section: A brief description of the coastal section, with relevant information.

Area Map: A figure of the coastal section outlined and the tide gauge systems present within the section.

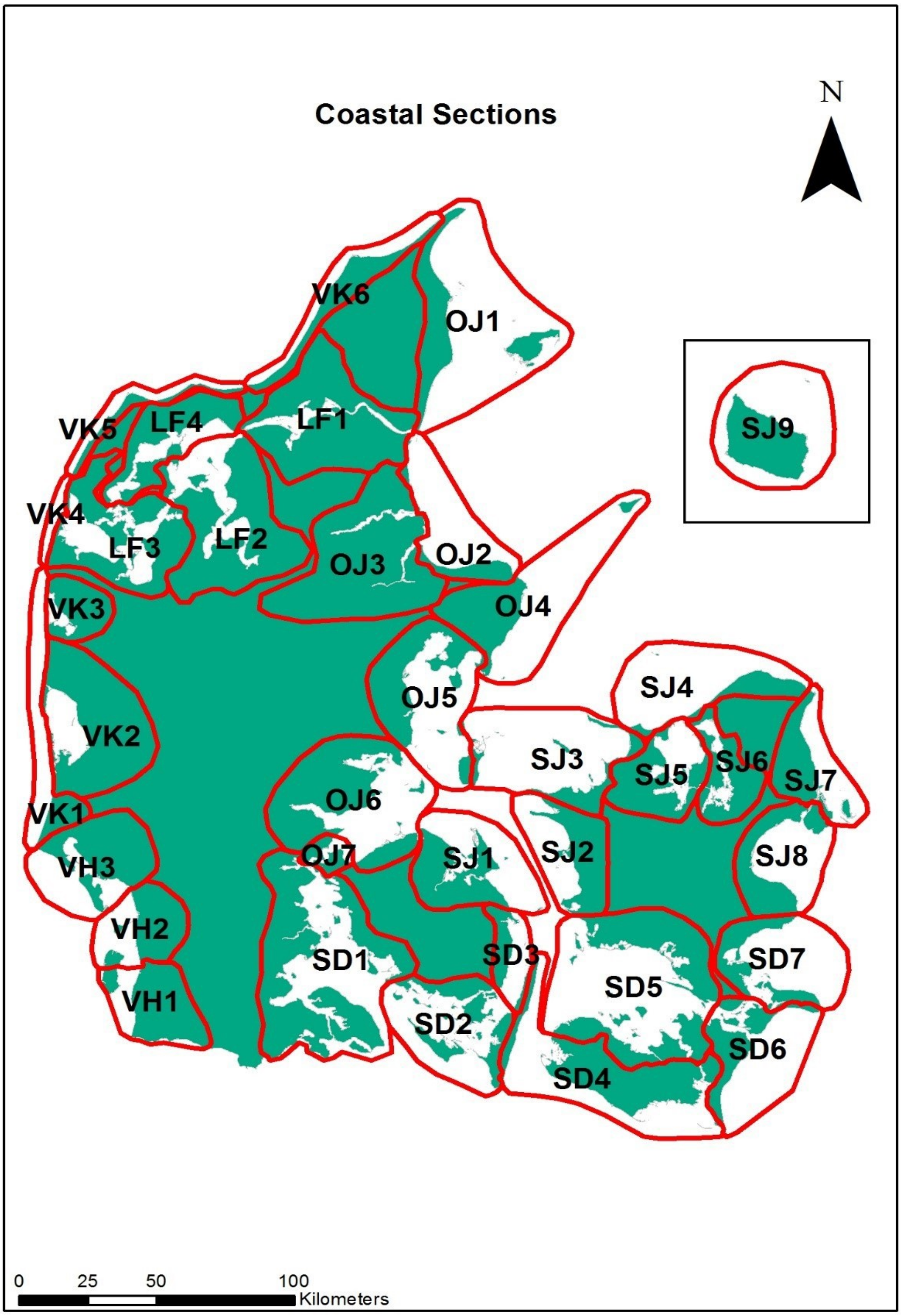
Tide Gauge and Datum Information: Information about the specific tide gauges present within the Coastal Section, and includes: Tide gauge station name, geographic coordinates (ETRS89 32N), height-difference (cm) between the reference planes DVR90 and DNN, and the yearly Relative Sea Level Rise (de-trending) since 1990.

Maximum recorded water levels: Provides a ranked list of the five (confirmed) storm events with the highest trend-free (2020) water levels. The water levels are accompanied by information regarding the location of the measurement, the source, date of occurrence and the water level relative to DVR90.

Sources include: Measured (refers to TG measurements), Modeled, Assessed and *Literary (reported) Sources.*

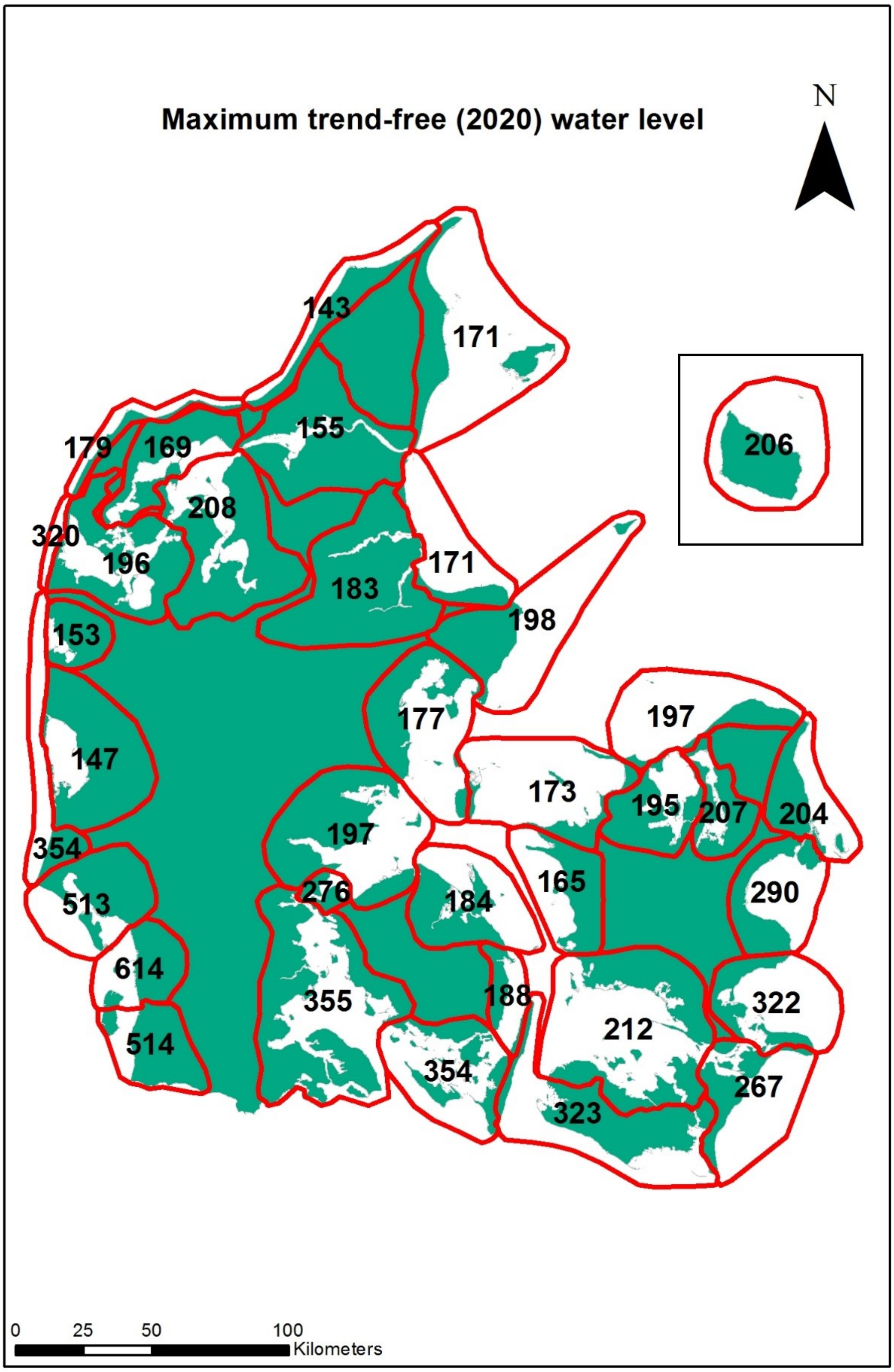
The *literary sources* include
Colding (1881)
Gram-Jensen (1991)
Egedal (1949)
Snabe (2002)
COWI (2015)
Pelt (2012)
Pedersen (1977)

Overview of Coastal Sections



København 2021

Overview of the Maximum Water Level within each section



Description of Coastal Section - Wadden Sea 1

VH1 – Wadden Sea 1. This coastal section is located in the southern part of the Danish Wadden Sea between the Danish/German border and the Rømø Dam (Lister Deep tidal area). The Wadden Sea area is often subjected to high water levels and historically extreme events are generally well documented. There is an east-west water level gradient during storms with lower water levels along the exposed barrier islands and higher water levels along the coastline of the mainland. There are currently three tide gauge stations within this section.

Area map

Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Vidåslusen-Højer I	478346.8	6090692.3	-11	0.28
Havneby Havn	472258.1	6104562.4	-11	0.28
Ballum Sluse	479953.8	6109395.3	-11	0.27

Coordinates:
ETRS89 32N

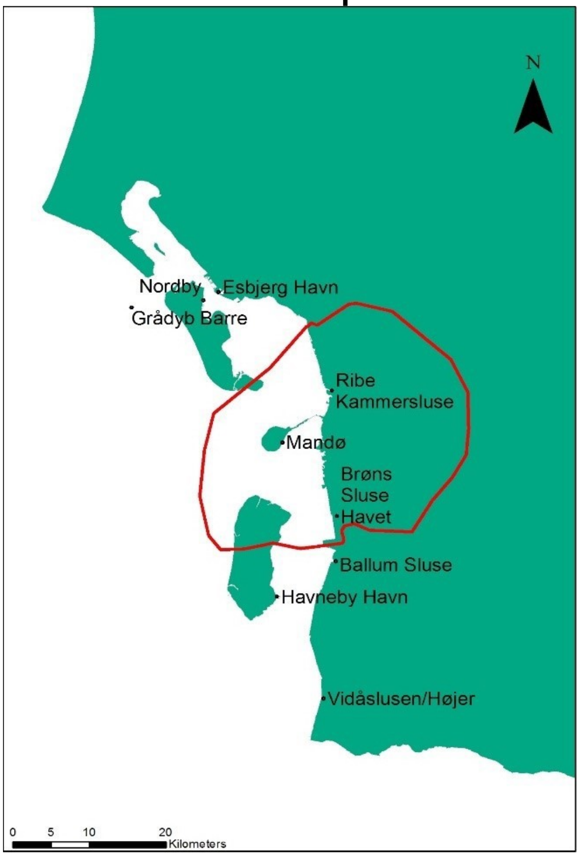
Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Ballum Enge	Storm surge column	12-10-1634	489	**514**
Vidåslusen-Højer I	Measured	03-01-1976	481	**491**
Ballum Sluse	Measured	24-11-1981	462	**471**
Ballum Sluse	Measured	17-02-1962	452	**463**
Vidåslusen-Højer I	Measured	03-12-1999	442	**448**

Description of Coastal Section - Wadden Sea 2

VH2 – Wadden Sea 2. This coastal section is located in the central part of the Danish Wadden Sea between the Rømø Dam and the ebb tidal road to the island of Mandø (Juvre Deep tidal area and parts of the Knudedyb tidal area). The Wadden Sea area is often subjected to high water levels and historically extreme events are generally well documented. There is an east-west water level gradient during storms with lower water levels along the exposed barrier islands and higher water levels along the coastline of the main land. There are currently three tide gauge stations present within this section.

Area map



Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Brøns Sluse	480120.6	6115545.7	-12	0.26
Mandø	472930.1	6125641.3	-12	0.27
Ribe Kammersluse	479449.2	6132678.2	-12	0.26

Coordinates: ETRS89 32N

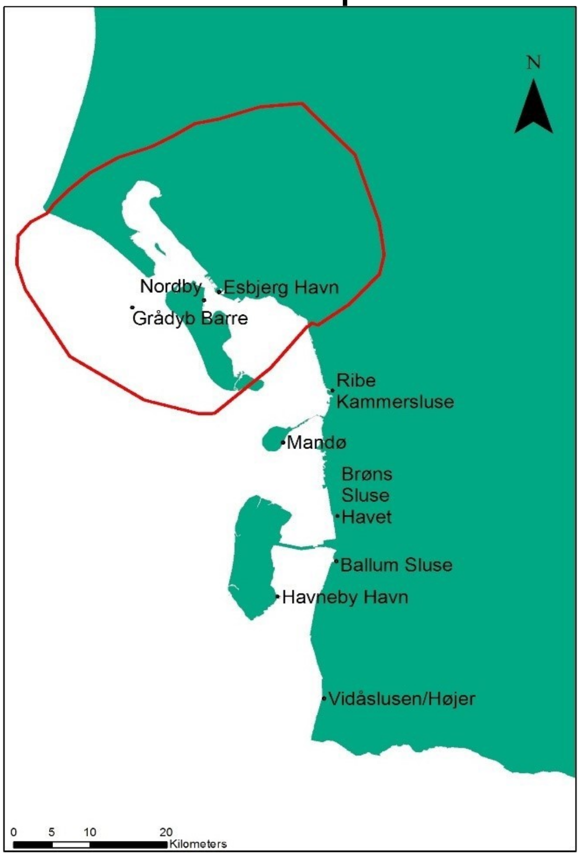
Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Ribe	Storm surge column	12-10-1634	588	**614**
Ribe	Pedersen (1977)	04-02-1825	521	**547**
Ribe	Pedersen (1977)	08-01-1839	521	**547**
Ribe Kammersluse	Measured	03-12-1999	500	**505**
Ribe Kammersluse	Measured	24-11-1981	489	**498**

Description of Coastal Section - Wadden Sea 3

VH3 – Wadden Sea 3. This coastal section covers the northern parts of the Danish Wadden Sea area (Grådyb and parts of Knudedyb tidal areas). The Wadden Sea area is often subjected to high water levels and historically extreme events are well documented. There is an east-west water level gradient during storms with lower water levels along the exposed barrier islands and higher water levels along the coastline of the main land. There are currently three tide gauge stations present within this section. The 1634 AD storm is assessed from the storm surge columns in Ballum Enge and Ribe.

Area map



Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Esbjerg Havn	464569.6	6146143.3	-11	0.26
Grådyb Barre	453194.7	6144013.2	-11	0.26
Nordby	462572.6	6145029.4	-11	0.26

Coordinates:
ETRS89 32N

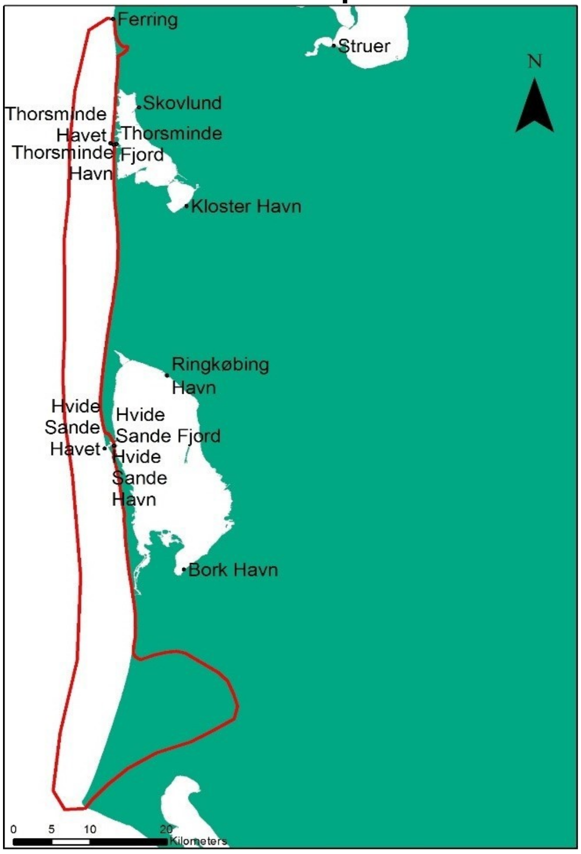
Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Esbjerg	Assessed	12-10-1634	489	**513**
Esbjerg Havn	Measured	24-11-1981	422	**431**
Esbjerg Havn	Measured	26-01-1990	402	**410**
Esbjerg Havn	Measured	24-11-1928	389	**404**
Esbjerg Havn	Measured	03-12-1909	380	**397**

Description of Coastal Section - West Coast 1

VK1 – West Coast 1. This coastal section stretches from Blåvands Huk to Hvide Sande along the North Sea coast. There is a strong southward directed littoral drift, which can be seen from the concave profile of the coastline. The beaches are generally wide and backed by dune systems. During high water events the dunes are suceptible to erosion. There are two tide gauge stations present within this coastal section. Historically, the west coast has experienced numerous storm surge events witnessed by morphological changes but accounts in terms of extreme water levels are scarce before the 1930s.

Area map



Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Hvide Sande Havn	445681.1	6206478.4	-10	0.27
Hvide Sande Havet	444473.7	6206077.8	-10	0.27
Thorsminde Havn	445649.0	6247655.1	-9	0.26
Thorsminde Havet	445253.8	6247860.9	-9	0.26
Ferring	445570.4	6264818.8	-7	0.26

Coordinates: ETRS89 32N

Maximum recorded water levels (cm)

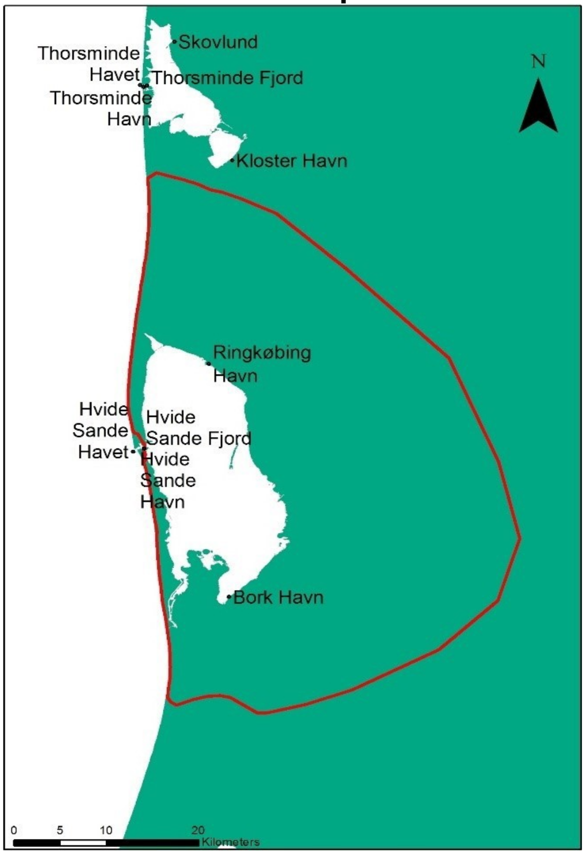
Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Thorsminde Havn	Measured	05-12-2013	352	**354**
Thorsminde Havn	Measured	29-11-2015	330	**331**
Ferring	Measured	08-01-2005	316	**320**
Thorsminde Havn	Measured	24-11-1981	311	**320**
Hvide Sande Havn	Measured	27-10-1936	300	**314**

VK2

Description of Coastal Section - West Coast 2

VK2 – West Coast 2. This coastal section covers the Ringkøbing Fjord. There is a narrow sluice regulated inlet to the Fjord at Hvide Sande Harbour. Maximum water levels in the Fjord are much lower than those observed along the exposed west coast. There are three tide gauge stations present within this coastal section. The practice of sluice regulation has changed over time and past events (before 1972) are not representative of today's conditions.

Area map



Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Bork Havn	454885.4	6189552.8	-11	0.26
Ringkøbing Havn	452686.3	6216071.0	-10	0.26
Hvide Sande Fjord	445730.0	6206431.8	-10	0.27

Coordinates: ETRS89 32N

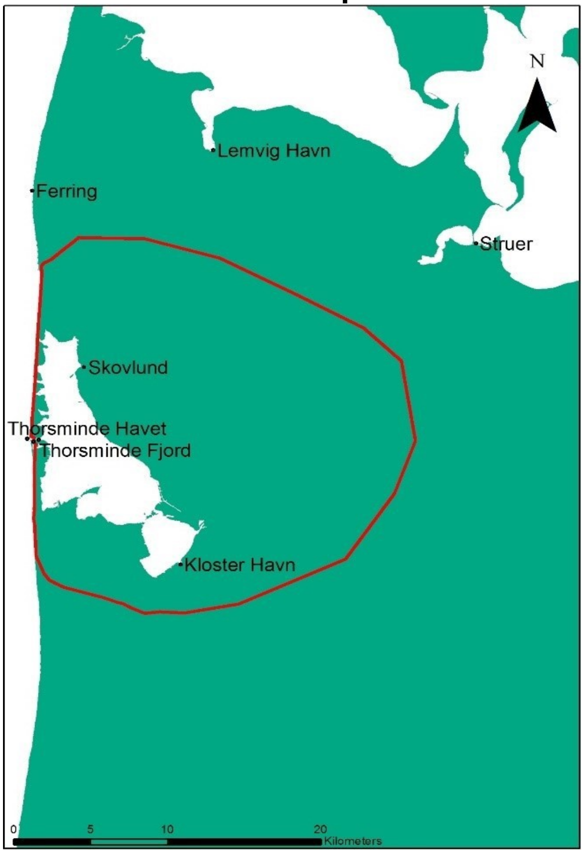
Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Bork Havn	Measured	03-12-1999	142	**147**
Bork Havn	Measured	29-11-2015	133	**134**
Bork Havn	Measured	25-01-1993	120	**127**
Ringkøbing Havn	Measured	08-01-2005	119	**123**
Bork Havn	Measured	18-01-1983	112	**121**

Description of Coastal Section - West Coast 3

VK3 – West Coast 3. This coastal section covers the Nissum Fjord which is connected to the North Sea by a narrow sluice regulated inlet at Thorsminde. There are three tide gauge stations present within this coastal section. The Skovlund tide gauge is located in the river Flynder stream. The practice of sluice regulation has changed over time and past events (before 1972) are not representative of today's conditions.

Area map



Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Kloster Havn	455234.0	6239250.0	-10	0.26
Skovlund	448971.9	6252741.7	-10	0.26
Thorsminde Fjord	446015.5	6247779.0	-9	0.26

Coordinates:
ETRS89 32N

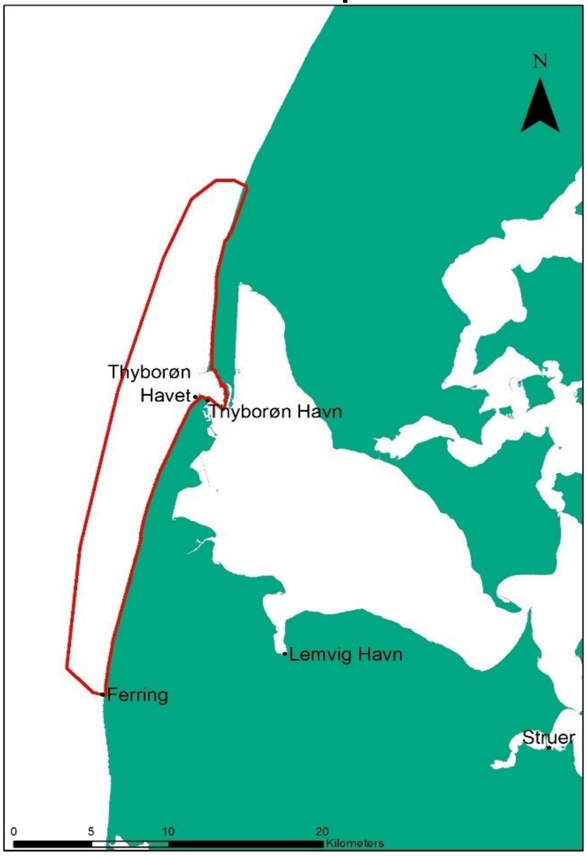
Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Kloster Havn	Measured	18-01-1983	144	**153**
Kloster Havn	Measured	25-01-1993	128	**135**
Kloster Havn	Measured	12-01-2007	131	**134**
Kloster Havn	Measured	28-01-1994	118	**125**
Kloster Havn	Measured	03-12-1999	119	**124**

Description of Coastal Section - West Coast 4

VK4 – West Coast 4. This coastal section covers the North Sea coast from Ferring/Bovbjerg to Lodbjerg in Thy along the Limfjord Barriers. The coastal section includes two tide gauge stations. During surge conditions there is often a steep water level gradient from the tide gauge station Thyborøn Havet (Ocean) to Thyborøn Havn (Harbour) through the Thyborøn Channel connecting to the Limfjord. Despite severe historical storm surge events affecting the area, e.g. in 1825, 1862, and 1868, there is very little information about actual water levels during these events along the sparsely populated coastline.

Area map



Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Ferring	445570.4	6264818.8	-7	0.26
Thyborøn Havet	451571.7	6285111.7	-7	0.24
Thyborøn Havn	452397.4	6284854.8	-7	0.24

Coordinates:
ETRS89 32N

Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Ferring	Measured	08-01-2005	316	**320**
Thyborøn Havet	Measured	29-01-2000	240	**245**
Ferring	Measured	30-10-2000	235	**240**
Thyborøn Havet	Measured	20-12-1991	231	**238**
Thyborøn Havet	Measured	12-01-2007	231	**234**

Danmarks Meteorologiske Institut

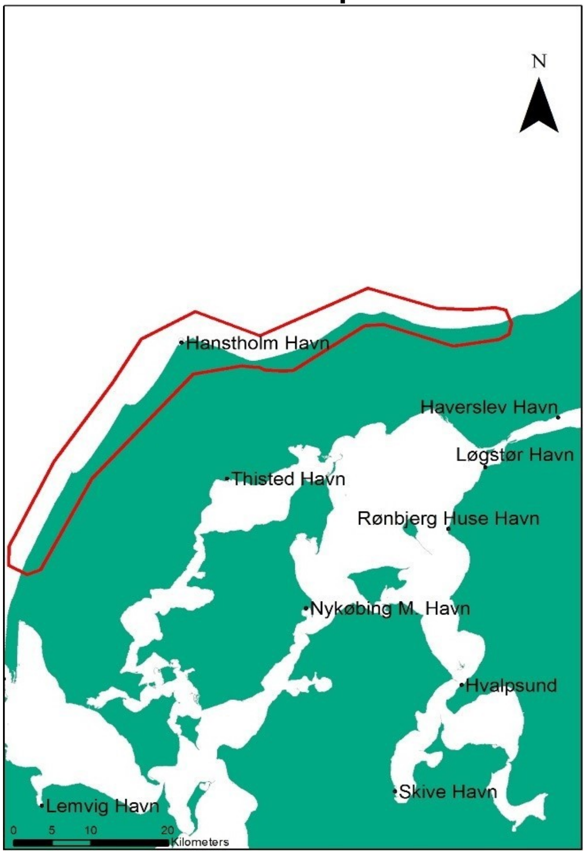
VK5

Ministry of Environment of Denmark
Coastal Authority

Description of Coastal Section - West Coast 5

VK5 – West Coast 5. This coastal section covers the North Sea coast from Lodbjerg to Fjerritslev. The coastal section includes one tide gauge station at Hanstholm. Sparsely populated and/or high coastal cliffs mean that hardly any accounts of extreme high waters have been recorded before the construction of the harbour at Hanstholm in the 1960s. Generally storm surge heights become decrease towards north along the North Sea coast.

Area map



Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Hanstholm Havn	475506.1	6330820.2	-4	0.20

Coordinates:
ETRS89 32N

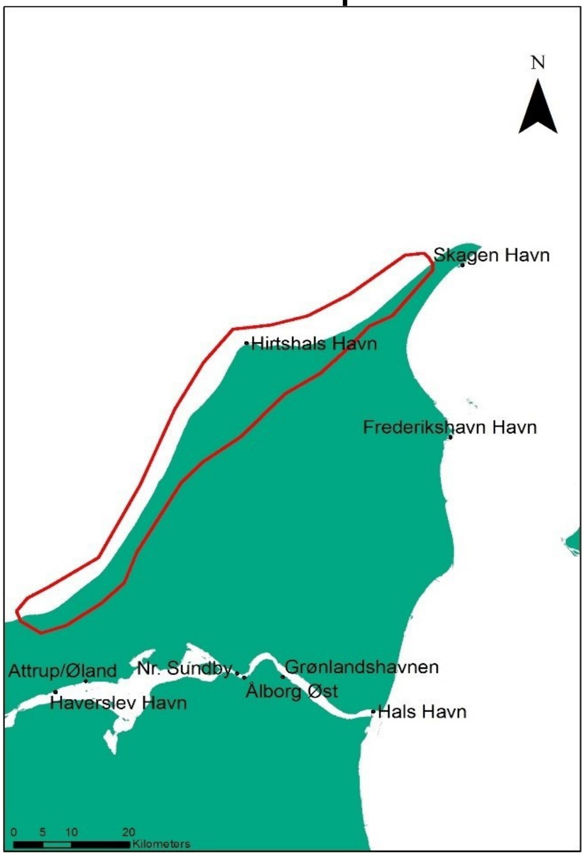
Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Hansthom Havn	Measured	25-11-1981	173	**179**
Hansthom Havn	Measured	06-12-2013	167	**168**
Hansthom Havn	Measured	06-11-1985	162	**168**
Hansthom Havn	Measured	01-03-2008	159	**161**
Hansthom Havn	Measured	19-03-2007	156	**159**

Description of Coastal Section - West Coast 6

VK5 – West Coast 5. This coastal section stretches from Fjerritslev to Skagen and is the northernmost coastal section on the North Sea Coast. The coastal section includes one tide gauge station at Hirtshals. The coast is generally cliffed and/or very sparsely populated. Historical accounts exist but are difficult to evaluate in terms of water levels due to water level and storm wave interactions.

Area map



Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Hirtshals Havn	557533.4	6384040.1	-1	0.10

Coordinates:
ETRS89 32N

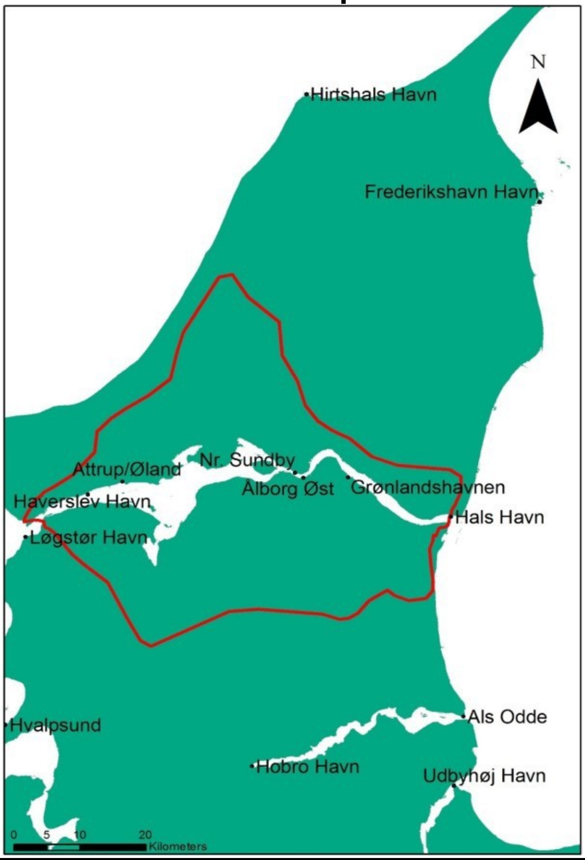
Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Hirtshals Havn	Measured	27-02-1990	140	**143**
Hirtshals Havn	Measured	25-11-1981	139	**142**
Hirtshals Havn	Measured	06-11-1985	139	**142**
Hirtshals Havn	Measured	23-12-1894	138	**142**
Hirtshals Havn	Measured	04-12-1914	134	**138**

Description of Coastal Section - Limfjorden 1

LF1 – Limfjord 1. This coastal section covers the easternmost part of Limfjorden from the inlet at the bay of Aalborg to the inlet at Løgstør Bredning. There are five tide gauge stations located within the section additional to historical records (1950-). Extreme water levels are mainly experienced due to the influx of water from the Kattegat to the east, in some instances high water levels are experienced in both the the east and the west of the area, respectively.

Area map



Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Nørresundby	555869.4	6324029.9	-2	0.16
Attrup/Øland	529656.9	6322590.3	-3	0.17
Nibe/Sebbersund	/////	//////	-3	0.17
Grønlandshavnen	563824.5	6323288.4	-2	0.16
Ålborg øst	557110.6	6323208.5	-2	0.16
Haverslev Havn	524383.7	6320620.1	-3	0.17

Coordinates: ETRS89 32N

Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Nibe/Sebbersund	Measured	25-11-1981	150	**155**
Nørresundby	Measured	07-11-1985	143	**148**
Attrup/Øland	Measured	06-12-2013	144	**145**
Attrup/Øland	Measured	11-01-2015	144	**145**
Nibe/Sebbersund	Measured	14-01-1984	135	**140**

Danmarks Meteorologiske Institut

LF2

Ministry of Environment of Denmark
Coastal Authority

Description of Coastal Section - Limfjorden 2

LF2 – Limfjord 2. This coastal section covers the southern part of Løgstør Bredning and the fjords within the Limfjord south of here. The coastal section includes five tide gauge stations, which are evenly distributed within the section. Extreme water levels are often experienced in situations where influx of water from the North Sea through the Thyborøn Channel has led to a generally raised water level in the Limfjord previous to the actual storm event. Previous to the breaching of the Limfjord Barriers towards the North Sea coast in 1825, the area did not experience significant storm surges as compared to present conditions.

Area map

Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Løgstør Havn	514950.9	6313824.2	-4	0.17
Hvalpsund	511842.8	6284075.6	-5	0.18
Skive Havn	503190.0	6269529.2	-5	0.20
Rønbjerg Huse	510162.9	6305415.7	-4	0.17
Nykøbing Mors Havn	491665.0	6294556.5	-5	0.17

Coordinates:
ETRS89 32N

Maximum recorded water levels (cm)

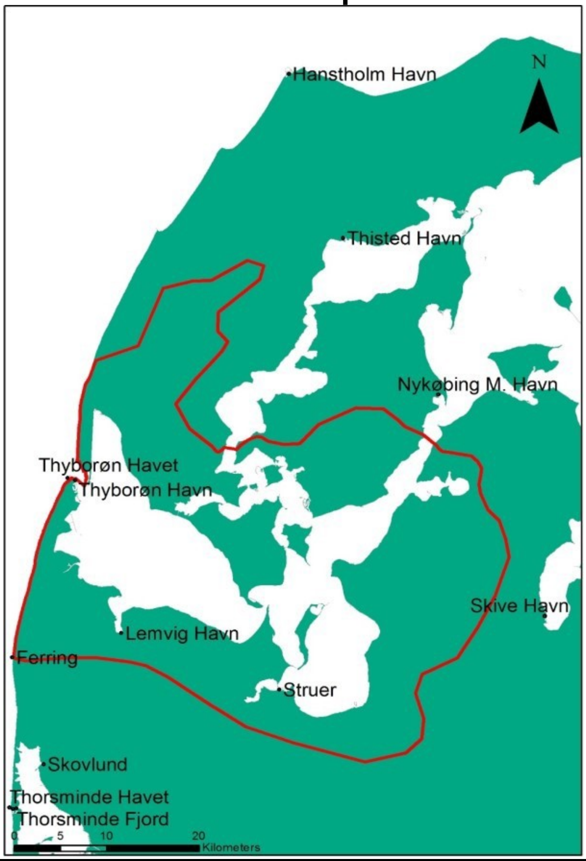
Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Løgstør Havn	Measured	08-01-2005	205	**208**
Løgstør Havn	Measured	25-11-1981	191	**196**
Skive Havn	Measured	11-01-2015	188	**189**
Løgstør Havn	Measured	28-02-1990	178	**183**
Løgstør Havn	Measured	27-11-2011	177	**179**

København 2021

Description of Coastal Section - Limfjorden 3

LF3 – Limfjord 3. This coastal section covers Nissum Bredning, the Bay of Venø and Kås Bredning. The coastal section includes three tide gauge stations, two of which are situated in Nissum Bredning. Extreme water levels are often experienced in situations where influx of water from the North Sea through the Thyborøn Channel has led to a generally raised water level in the Limfjord previous to the actual storm event. Previous to a breaching of the Limfjord Barriers towards the North Sea coast in 1825, the area did not experience significant storm surges as compared to present conditions.

Area map



Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Lemvig Havn	457380.4	6267586.7	-8	0.24
Thyborøn Havn	452397.4	6284854.8	-7	0.24

Coordinates:
ETRS89 32N

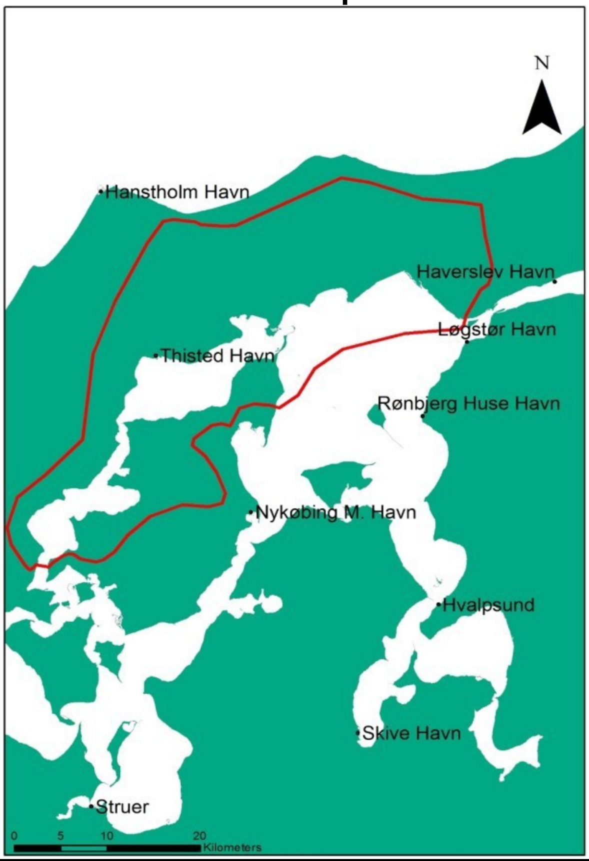
Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Lemvig Havn	Measured	11-01-2015	195	**196**
Thyborøn Havn	Measured	24-11-1981	186	**194**
Thyborøn Havn	Measured	09-12-2011	191	**193**
Thyborøn Havn	Measured	09-01-2005	189	**193**
Lemvig Havn	Measured	06-12-2013	183	**185**

Description of Coastal Section - Limfjorden 4

LF4 – Limfjord 4. This coastal section covers the northern end of Løgstør Bredning as well as Thisted- and Visby Bredning. There is one tide gauge station within this coastal section. Extreme water levels are often experienced in situations where influx of water from the North Sea through the Thyborøn Channel has led to a generally raised water level in the Limfjord previous to the actual storm event. Previous to a breach of the Limfjord Barriers towards the North Sea in 1825, the area did not experience significant storm surges as compared to present conditions. Due to north and westerly winds during storms, water levels are often lower than along the south- and northward facing coastlines.

Area map



Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Thisted Havn	481396.6	6312281.0	-5	0.20

Coordinates: ETRS89 32N

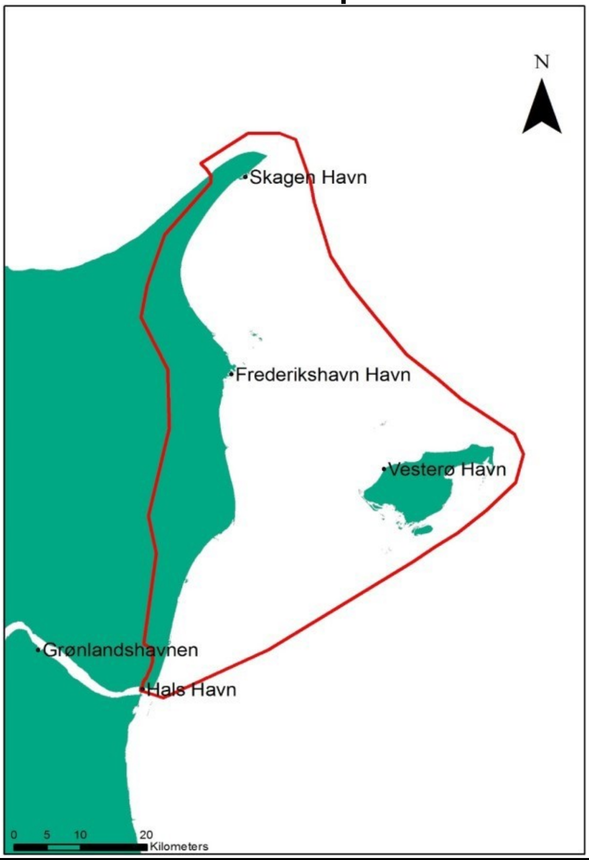
Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Thisted Havn	Measured	09-01-2005	166	**169**
Thisted Havn	Measured	11-01-2015	164	**165**
Thisted Havn	Measured	12-02-2020	157	**157**
Thisted Havn	Measured	10-12-2011	153	**155**
Thisted Havn	Measured	13-01-2007	151	**154**

Description of Coastal Section - Eastern Jutland 1

OJ1 – Jutland 1. This coastal section covers the Kattegat coast from Skagen to the harbour at Hals at the entrance to the Limfjord and includes the island Læsø. There are four tide gauge stations within the coastal section. The tide gauge at Hals harbour is used for both OJ1 and OJ2. High water levels mainly occur when storms force water masses from the North Sea into the Kattegat area. An increase in extreme water levels is generally observed towards south along the coastline.

Area map



Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Skagen Havn	595021.1	6398270.0	1	0.04
Frederikshavn Havn	592922.2	6366949.4	2	0.10
Hals Havn	579506.9	6317045.3	-3	0.15
Vesterø Havn	615943.1	6351983.3	1	0.10

Coordinates:
ETRS89 32N

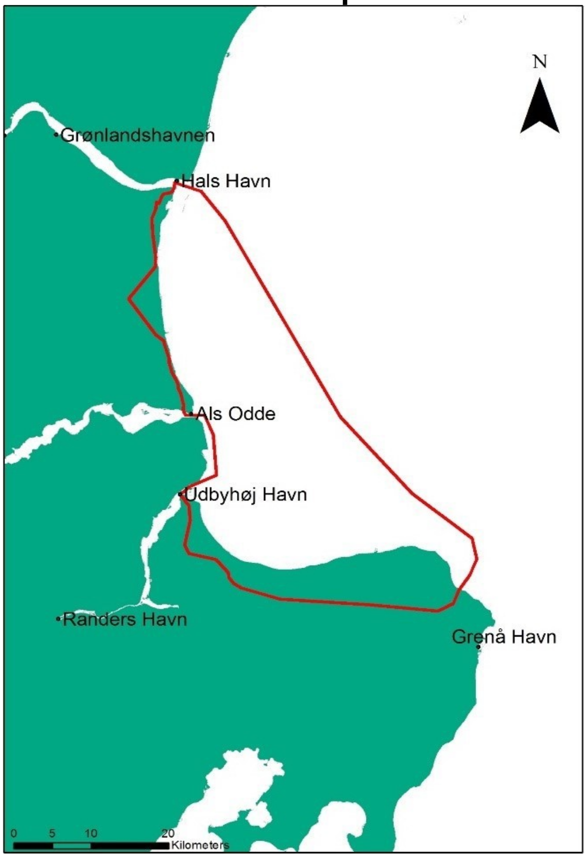
Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Hals Havn	Measured	07-11-1985	166	**171**
Hals Havn	Measured	06-12-2013	162	**163**
Frederikshavn Havn	Measured	23-12-1894	154	**159**
Frederikshavn Havn	Measured	10-10-1926	151	**155**
Frederikshavn Havn	Measured	25-11-1981	150	**153**

Description of Coastal Section - Eastern Jutland 2

OJ2 – Jutland 2. This coastal section stretches from Hals Harbour to the bay of Gjerrild along the Kattegat coast. There are three tide gauge stations within the coastal section. Because of the coastal configuration the highest water levels are experienced along the west – east directed coastline of Norddjurs in the southern part of the coastal section, i.e. there is a north to south increasing gradient in maximum water levels.

Area map



Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Hals Havn	579506.9	6317045.3	-3	0.15
Als Odde	581381.5	6285361.7	-3	0.14
Udbyhøj Havn	579895.6	6274395.9	-3	0.14

Coordinates:
ETRS89 32N

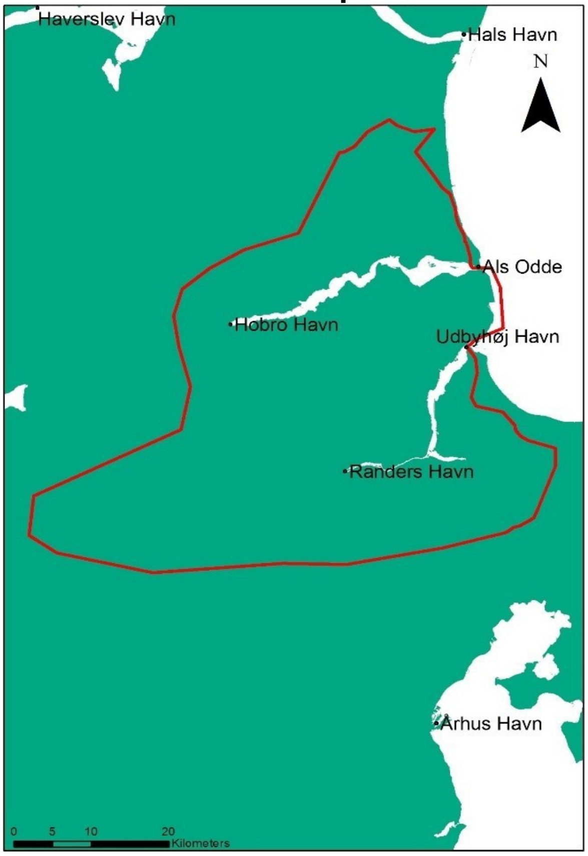
Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Hals Havn	Measured	07-11-1985	166	**171**
Hals Havn	Measured	06-12-2013	162	**163**
Hals Havn	Measured	25-11-1981	147	**152**
Hals Havn	Measured	01-03-2008	138	**140**
Hals Havn	Measured	14-01-1984	135	**140**

Description of Coastal Section - Eastern Jutland 3

OJ3 – Jutland 3. This coastal section covers Mariager Fjord and Randers Fjord. Both fjords are also affected by river discharge. There are four tide gauge stations within the coastal section. Additionally water levels have been measured at Hadsten Harbor in the middle of Mariager Fjord in the past. Generally, Randers Fjord experiences higher extreme water levels than Mariager Fjord. Historically the area has experienced flooding but events that occurred before 1930 lack measurements of actual water levels; for instance the Autumn 1921 floods.

Area map



Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Randers Havn	564154.7	6257432.8	-4	0.17
Hobro	549299.7	6277466.9	-4	0.17
Als Odde	581381.5	6285361.7	-3	0.14
Udbyhøj Havn	579895.6	6274395.9	-3	0.14

Coordinates:
ETRS89 32N

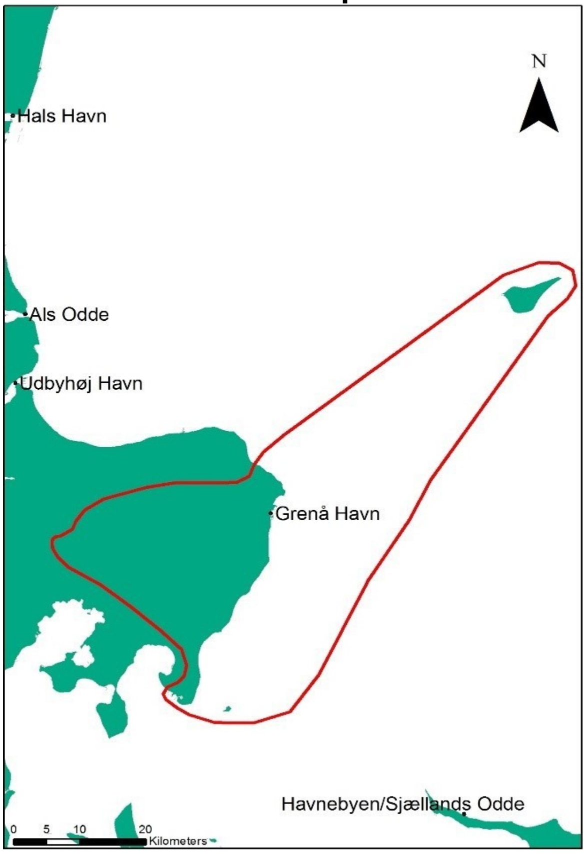
Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Randers Havn	Measured	09-11-1945	176	**183**
Randers Havn	Measured	07-11-1985	173	**178**
Randers Havn	Measured	01-11-2006	172	**174**
Randers Havn	Measured	20-02-2002	168	**171**
Randers Havn	Measured	17-11-1995	163	**167**

Description of Coastal Section - Eastern Jutland 4

OJ4 – Jutland 4. This coastal section stretches from the bay of Gjerrild to Ebeltoft and covers the east coast of Djursland as well as the island of Anholt. There is currently one tide gauge station within this coastal section. Water level readings were performed manually twice a day at Anholt from 1961 to 1994. Local effects at Grenå Harbor seem to lead to abnormally high recordings during some events compared to neighboring tide gauge stations

Area map



Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Grenå Havn	618581.4	6253601.0	-4	0.16
Anholt Havn	/////////	///////////	-5	0.16

Coordinates:
ETRS89 32N

Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Grenå	Egedal (1949)	31-12-1921	190	**198**
Anholt Havn	Measured	06-11-1985	171	**177**
Grenå Havn	Measured	10-01-1995	168	**172**
Grenå Havn	Measured	06-12-2013	165	**166**
Grenå Havn	Measured	14-02-1989	161	**166**

OJ5

Description of Coastal Section - Eastern Jutland 5

OJ5 – Jutland 5. This coastal section stretches from Ebeltoft to Hov and includes the west coast of the island of Samsø in the southern parts of Kattegat. There are two tide gauge stations within the coastal section; at Aarhus (c. 1890-) and Hov (c.2011-).

Area map

Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Aarhus Havn	575957.7	6223077.4	-5	0.18
Hov Havn	578692.8	6197012.4	-5	0.18

Coordinates: ETRS89 32N

Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Ebeltoft	Egedal (1949)	01-01-1922	169	**177**
Hov	Egedal (1949)	24-10-1921	168	**177**
Aarhus Havn	Measured	07-11-1985	162	**168**
Aarhus Havn	Measured	01-11-2006	163	**166**
Aarhus Havn	Measured	22-12-1954	153	**160**

OJ6

Description of Coastal Section - Eastern Jutland 6

OJ6 – Jutland 6. This coastal section covers the Horsens Fjord and Vejle Fjord lying between Hou and the Lillebælt entrance north of Fredericia as well as the northwestern coast of Fyn (Funen) between Båring Vig and Nærå Strand and includes the town of Bogense. There are five operating tide gauge stations within this section. Both the town of Vejle and Horsens have experienced historical floods and have streams running through their town centres. Events at and around Bogense, e.g. in 1921 and 1945, have been documented. As no continuous or overlapping series cover the section there is some uncertainty regarding the order (and potential inclusion) of the most extreme events.

Area map

Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Juelsminde Havn	563850.0	6174894.2	-7	0.22
Bogense Havn	568105.6	6158335.9	-8	0.22
Vejle Havn	534129.2	6173620.6	-8	0.23
Horsens Havn S	553685.9	6190264.2	-6	0.21
Horsens Havn N	554292.0	6190400.2	-6	0.21

Coordinates: ETRS89 32N

Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Vejle	Colding (1881)	14-11-1872	180	**197**
Bogense Havn	Measured	01-11-2006	172	**175**
Bogense	Egedal (1949)	24-10-1921	162	**174**
Horsens Havn N	Measured	06-12-2013	163	**164**
Horsens	Egedal (1949)	01-01-1922	148	**158**

Description of Coastal Section - Eastern Jutland 7

OJ7 – Jutland 7. This coastal section covers the northern part of the narrow Lillebælt (Little Belt) between Jultand and Funen with one long tide gauge time series at the town of Fredericia. Additionally, at periods a tide gauge has been in operation in Middelfart. During the 1872-event the extremity in water levels decreased towards north and the stated water level is thus representative south of the narrowest parts of Lillebælt (Small Belt).

Area map

Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Fredericia Havn	547498.1	6157311.7	-8	0.24

Coordinates: ETRS89 32N

Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Middelfart	Colding (1881)	14-11-1872	259	**276**
Fredericia Havn	Measured	01-11-2006	162	**165**
Fredericia Havn	Measured	31-12-1904	143	**157**
Fredericia Havn	Measured	04-01-1954	135	**145**
Fredericia Havn	Measured	29-10-2017	143	**144**

Description of Coastal Section - Southern Denmark 1

SD1 – Southern Denmark 1. This coastal section covers the entire southern parts of Lillebælt and the southwestern-most part of the Baltic Sea and the corresponding coastlines of Jutland and Funen. The section consists of cliffed coastline and low-lying marine accumulation forms. Several towns and holiday house areas are lowlying. Furthermore, several fjords lead to the Lillebælt and thus large variations in extreme water levels are often observed during individual events within the section. There are six operating tide gauge stations included within this section. In Flensburg just south of SD1 historical events are well documented. See appendix A for information on high water levels i Flensburg

Area map

Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Kolding Havn	530481.2	6149418.6	-10	0.25
Haderslev Havn	532364.2	6122935.6	-12	0.26
Aabenraa Havn	527285.4	6099863.9	-12	0.27
Sønderborg Havn	550351.6	6085131.0	-12	0.27
Fynshav Havn	563057.2	6094612.1	-13	0.26
Assens Havn	556528.1	6125267.2	-7	0.24

Coordinates: ETRS89 32N

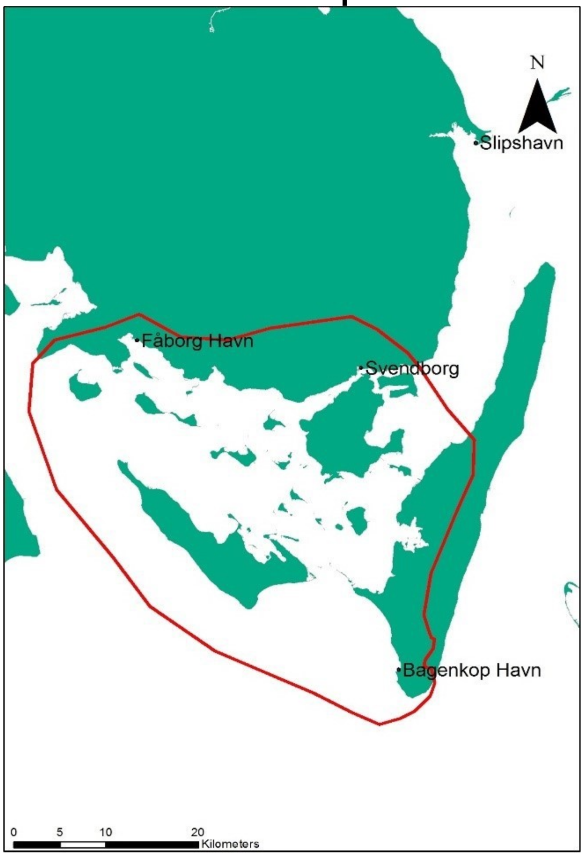
Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Dyvig Havn, Als	Colding (1881)	14-11-1872	333	**355**
Åbenrå	Assessed	31-12-1904	200	**219**
Kolding	Gram-Jensen (1991)	24-11-1890	178	**196**
Fynshav Havn	Measured	04-11-1995	181	**188**
Fynshav Havn	Measured	15-02-1979	178	**187**

Description of Coastal Section - Southern Denmark 2

SD2 – Southern Denmark 2. This coastal section covers the Sydfysnke Øhav (South Funen Archipelago) including the south coast of Funen and the town of Svendborg as well as the southwest coast of Langeland. Some historical accounts/measurements of extreme events exist (e.g. 1872 and 1904), but otherwise there is scarcity in tide gauge records. Currently one (reliable) tide gauge station is in operation at Bagenkop.

Area map



Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Faaborg Havn	579233.3	6105884.4	-8	0.24
Rantzausminde Havn	/////	/////	-8	0.24
Bagenkop Havn	607633.0	6068439.5	-4	0.26
Svendborg Havn	603558.9	6102718.9	-6	0.24

Coordinates:
ETRS89 32N

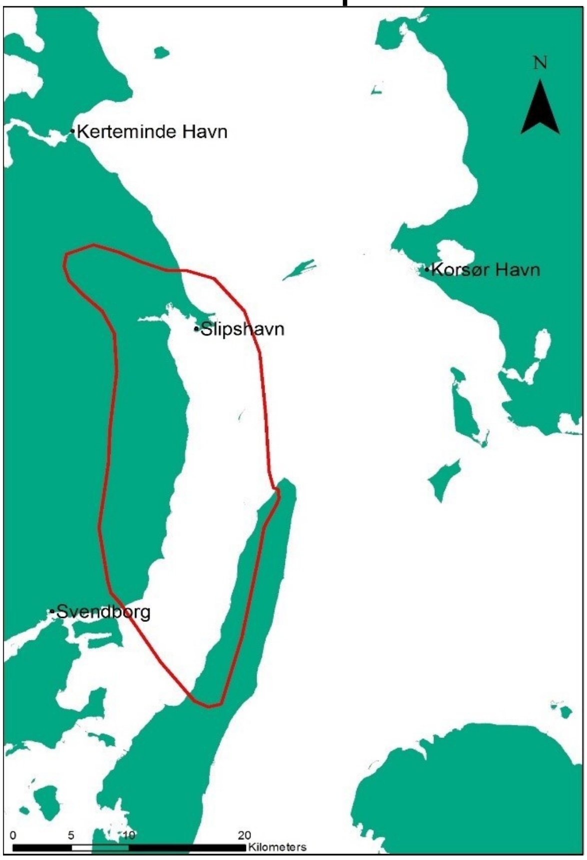
Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Ærøskøbing	Colding (1881)	14-11-1872	337	**354**
Valdemar Slot	Assessed	31-12-1904	220	**232**
Valdemar Slot	Measured/Assessed	01-11-2006	185	**188**
Rantzausminde Havn	Measured	04-11-1995	174	**180**
Bagenkop	Measured	04-01-2017	177	**178**

Description of Coastal Section - Southern Denmark 3

SD3 – Southern Denmark 3. This coastal section covers the Great Belt between Langeland and Funen between the towns of Nyborg and Lundeborg, where extreme events may originate either from the Baltic or the Kattegat areas. There is one operating tide gauge station with a long time series (c. 1890-) at Nyborg/Slipshavn.

Area map



Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Slipshavn	615988.8	6128340.7	-8	0.22

Coordinates: ETRS89 32N

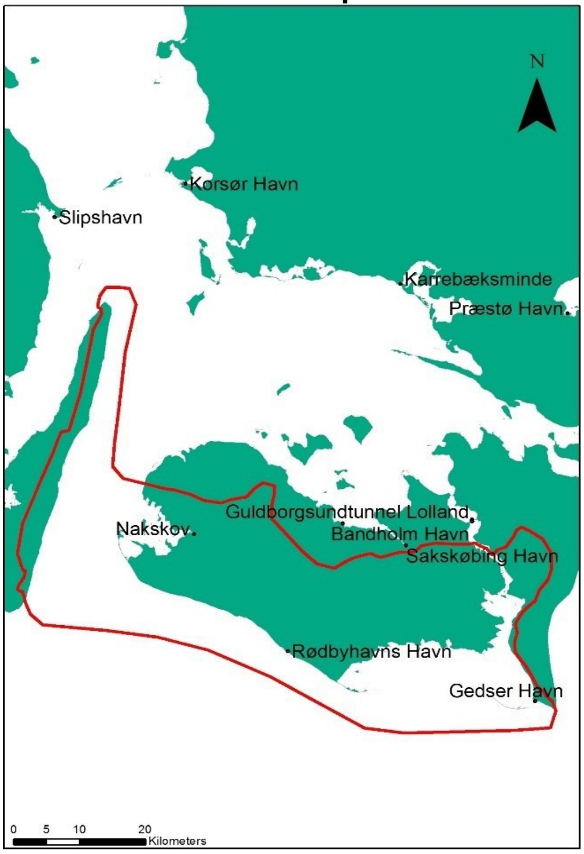
Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Lohals	Colding (1881)	14-11-1872	172	**188**
Slipshavn	Measured	01-11-2006	177	**180**
Slipshavn	Measured	21-02-1993	157	**163**
Slipshavn	Measured	06-12-2013	146	**148**
Slipshavn	Measured	29-10-2017	141	**142**

Description of Coastal Section - Southern Denmark 4

SD4 – Southern Denmark 4. This coastal section at the Baltic Sea Storebælt (Great Belt) transition covers the east coast of Langeland, the southern and western coasts of the island of Lolland and the southwestern coast of the island of Falster. A strong gradient in water level along the coastline in either direction may be experienced during individual events as well as gradients in the Nakskov Fjord at Lolland, and including the town of Nakskov is observed. Two tide gauge stations at Rødby and Gedser hold long series but otherwise data are scarce and scattered in time.

Area map



Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Rødbyhavns Havn	651432.7	6059056.5	-9	0.25
Gedser Havn	689033.5	6051111.6	-8	0.24
Nakskov	637234.8	6077736.8	-6	0.24

Coordinates:
ETRS89 32N

Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Lineslyst pr. Rødby	Colding (1881)	14-11-1872	305	**323**
Gedser Havn	Measured	30-12-1913	185	**198**
Nakskov Havn	Measured/Assessed	01-11-2006	180	**183**
Gedser Havn	Measured	09-01-1914	159	**172**
Gedser	Modelled	31-12-1904	157	**171**

Description of Coastal Section - Southern Denmark 5

SD5 – Southern Denmark 5. This section covers the water body of Smålandsfarvandet and the surrounding coastlines of Lolland and Zealand. There are five tide gauge stations situated inside the area. Additionally the tide gauge station at Korsør Harbour is included.

Area map

Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Karrebæksminde	668572.5	6117644.7	-8	0.21
Korsør Havn	635895.6	6133676.7	-8	0.21
Bandholm Havn	659774.7	6079468.9	-8	0.23
Sakskøbing Havn	669383.5	6075974.2	-8	0.23
Guldborgs. Falster	679459.5	6080027.5	-8	0.23
Guldborgs. Lolland	679459.5	6079828.2	-8	0.23

Coordinates:
ETRS89 32N

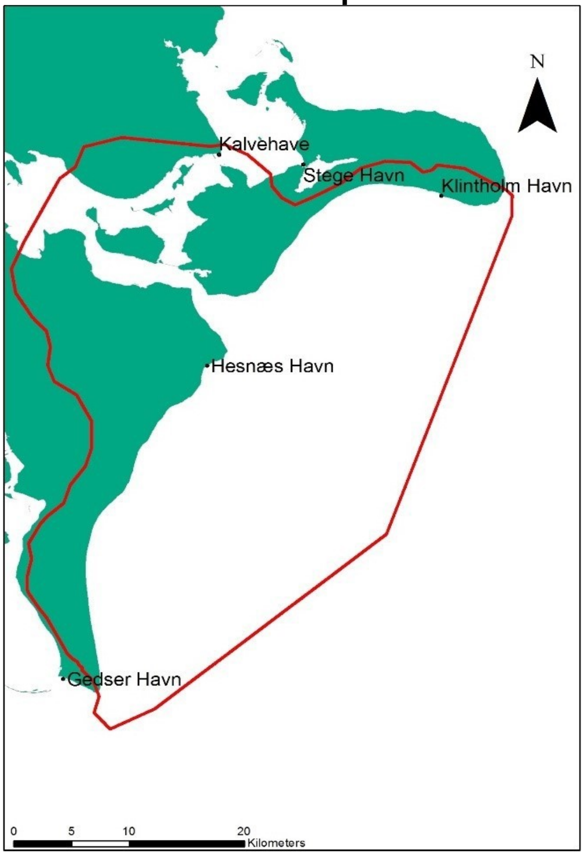
Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Bisserup	Colding (1881)	14-11-1872	196	**212**
Lollands Nordkyst	Gram-Jensen (1991)	24-11-1890	196	**210**
Karrebæksminde	Measured	02-11-2006	165	**168**
Sakskøbing Havn	Measured	02-01-2019	166	**166**
Guldborgsund	Gram-Jensen (1991)	04-12-1883	149	**164**

Description of Coastal Section - Southern Denmark 6

SD6 - Southern Denmark 6. This coastal section covers the south and east facing coastlines of the islands of Falster and Møn towards the Baltic Sea as well as the narrow straits between Falster and Møn and Møn and Sjælland (Zealand). Three operating tide gauge stations are present within this section.

Area map



Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Hesnæs Havn	701535.6	6079615.7	-8	0.22
Kalvehave	702565.7	6098837.2	-8	0.21
Klintholm	721871.5	6095057.9	-8	0.21

Coordinates:
ETRS89 32N

Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Grønsund på Møn	Colding (1881)	14-11-1872	251	**267**
Hesnæs Havn	Measured	04-01-2017	170	**171**
Hesnæs Havn	Measured	02-01-2019	151	**151**
Hesnæs Havn	Measured	02-01-2002	144	**148**
Hesnæs Havn	Measured	21-02-2002	144	**148**

Description of Coastal Section - Southern Denmark 7

SD7 – Southern Denmark 7. This coastal section covers the Faxe Bay area of the western Baltic Sea including the north coast of the island of Møn and the southeast coast of Sjælland (Zealand). There are three tide gauge stations in operation within this coastal section. Additionally the tide gauge at Kalvehave is included.

Area map

Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Rødvig Havn	714443.1	6128279.2	-8	0.20
Kalvehave	702565.7	6098837.2	-8	0.21
Præstø Havn	693984.5	6112941.2	-8	0.21
Stege Havn	709883.3	6097913.8	-8	0.21

Coordinates:
ETRS89 32N

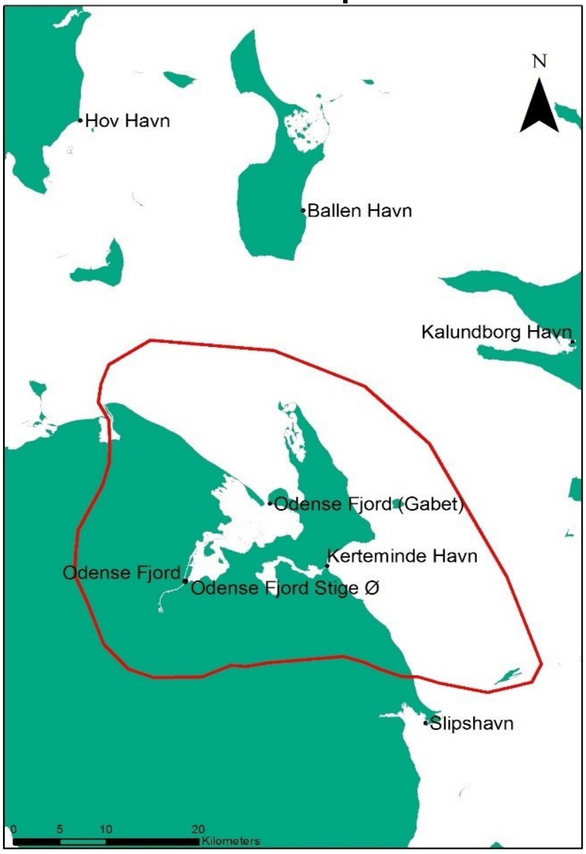
Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Nyord	Colding (1881)	14-11-1872	306	**322**
Rødvig Havn	Measured	04-01-2017	166	**167**
Rødvig	Egedal (1949)	01-01-1922	149	**160**
Kalvehave	Measured	02-01-2019	150	**150**
Kalvehave	Measured	02-11-2006	143	**146**

Description of Coastal Section - Zealand 1

SJ1 – Zealand 1. This coastal section covers (despite its abbreviation) the northwestern coasts of the island of Fyn (Funen) towards Storebælt (Great Belt) and includes the Odense Fjord and Kertinge Nor. The coastal section is susceptible to extreme water levels when north- and westerly winds push water in from the North Sea to the Kattegat. There are tide gauge stations within the Odense Fjord and at the town of Kerteminde – however of a varying quality in data.

Area map



Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Odense Fjord (Gabet)	599139.8	6153335.6	-8	0.21
Odense	//////	//////	-8	0.22
Odense Fjord Stige Ø	590125.8	6144526.6	-8	0.22
Odense Kanal Stige Ø	590003.9	6144412.9	-8	0.22
Kerteminde Havn	605313.1	6146215.6	-8	0.21

Coordinates: ETRS89 32N

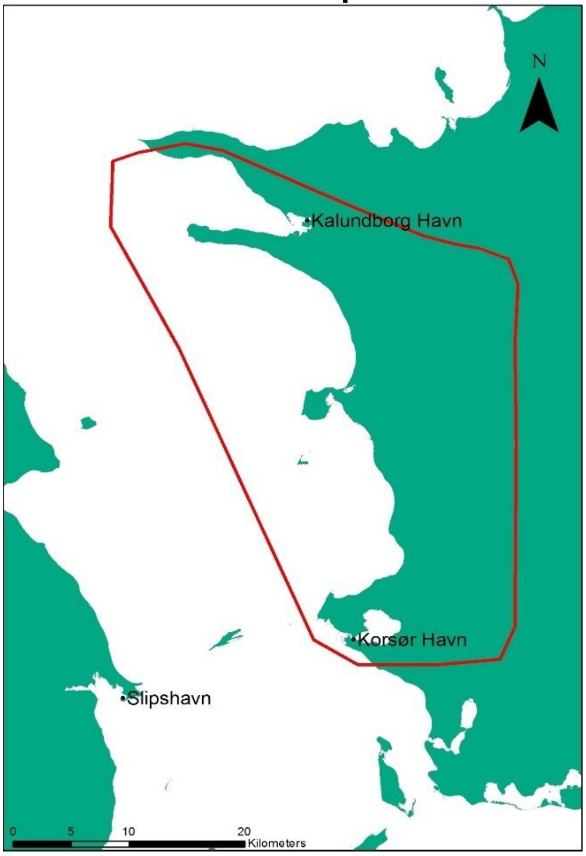
Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Odense	Egedal (1949)	24-10-1921	172	**184**
Sprogø	Colding (1881)	14-11-1872	165	**181**
Odense Fjord (Gabet)	Measured	01-11-2006	174	**177**
Odense	Measured	21-01-1993	164	**170**
Odense Fjord (Gabet)	Measured	29-10-2017	168	**169**

Description of Coastal Section - Zealand 2

SJ2 – Zealand 2 . This coastal section covers the Zealand Coast between the town of Korsør towards south facing the Greaet Belt and the Røsnæs peninsula to the north of the town and fjord of Kalnudborg towards the southern Kattegat. There are two tide gauge stations within this section; one of which has an extensive record (Korsør, c. 1891-). Floods have been experienced at some coastal stretches in the past due to large wind waves but without extremely high water levels: this means that some caution is advocated in the interpretation of past events.

Area map



Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Korsør Havn	635895.6	6133676.7	-8	0.21
Kalundborg Havn	631892.3	6171744.1	-6	0.20

Coordinates:
ETRS89 32N

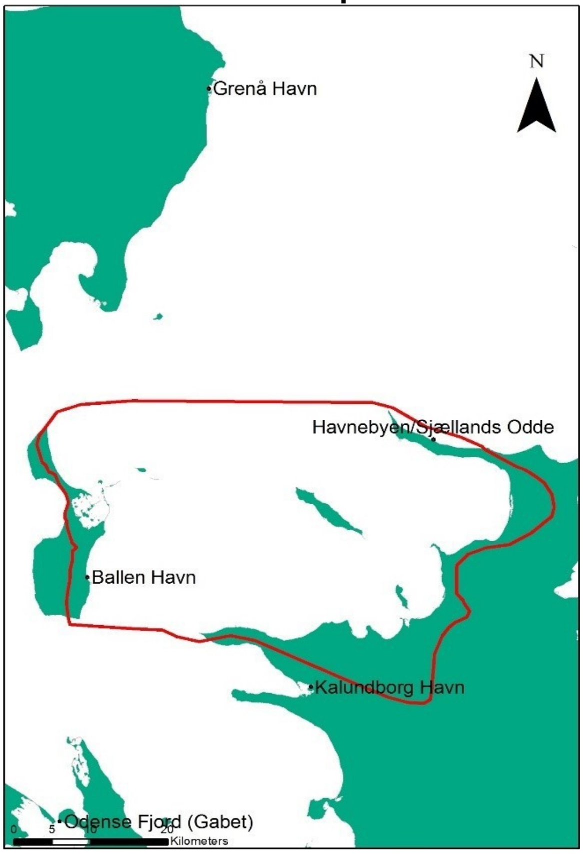
Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Korsør Havn	Measured	01-11-2006	162	**165**
Kalundborg Havn	Measured	21-02-1993	156	**161**
Korsør Havn	Measured	31-12-1904	148	**161**
Kalundborg Havn	Measured	06-12-2013	148	**149**
Kalundborg Havn	Measured	20-11-1973	139	**146**

Description of Coastal Section - Zealand 3

SJ3 – Zealand 3. This coastal section covers the Sejerø Bay area off Zealand and the east coast of the island of Samsø. There are two operating tide gauge stations at Samsø (Ballen) and Zealand (Sjællands Odde). Locally, extreme water levels may be higher along the ungauged coastline of Sejerø Bay.

Area map



Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Ballen Havn	602757.7	6186759.4	-1	0.19
Havnebyen/Sjællands	647862.3	6205581.2	-8	0.18

Coordinates: ETRS89 32N

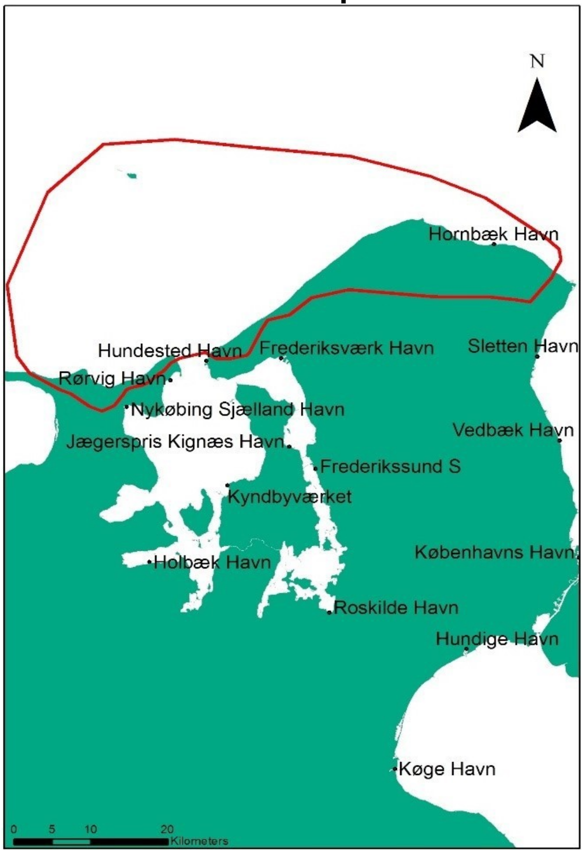
Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Ballen Havn	Measured	01-11-2006	170	**173**
Havnebyen/Sjællands	Measured	06-12-2013	163	**164**
Sejrø	Egedal (1949)	24-10-1921	152	**161**
Havnebyen/Sjællands	Measured	27-12-2016	152	**153**
Havnebyen/Sjællands	Measured	29-10-2017	148	**149**

Description of Coastal Section - Zealand 4

SJ4 – Zealand 4. This coastal section covers the North Coast of Zealand towords the Kattegat. The coast is mainly cliffed east of the entrance to the Roskilde-Isefjord fiord system and thus exteme events in the past have mainly been documented in terms of the erosional impact on the coast. The tide gauge data series at the Hornbæk Harbour have been digitized by the DMI and is one of the most complete series in Denmark dating back to 1891. Previous to tide gauge deployment accounts of actual water levels are scarce/non-existent. Events in 1921 and in 2013 are the most extreme and well-documented.

Area map



Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Hornbæk Havn	715044.7	6221860.9	-6	0.15
Hundested Havn	677554.3	6205894.3	-7	0.17

Coordinates:
ETRS89 32N

Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Hornbæk Havn	Measured	06-12-2013	196	**197**
Gilleleje	Gram-Jensen (1991)	18-12-1921	182	**191**
Kikhavn	Snabe (2002)	01-01-1922	173	**183**
Gilleleje	Gram-Jensen (1991)	02-11-1921	166	**175**
Hornbæk Havn	Measured	27-12-2016	171	**172**

Description of Coastal Section - Zealand 5

SJ5 – Zealand 5. This coastal sections covers the Isefjord area. Strong storms from northerly directions and of long duration may force water into the Roskilde-Isefjord system from Kattegat and cause extreme water levels. Due to the narrowness of the straits inside the system, a long duration is generally needed to attain extreme water levels at the far end at the town of Holbæk. Historical events, e.g. in 1921, have been documented – and further historical events are indirectly evindenced through the lack of old houses (pre- 1900) along the coastlines. There are no long tide gauge records but currently around 6 TG stations within the Roskilde-Isefjord system.

Area map

Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Hundested Havn	677554.3	6205894.3	-7	0.17
Holbæk Havn	670136.2	6178398.7	-7	0.19
Rørvig Havn	672889.2	6203269.6	-7	0.17
Nykøbing Sj. Havn	667198.2	6199669.8	-7	0.18
Kyndbyværket	680293.2	6188865.5	-7	0.18

Coordinates: ETRS89 32N

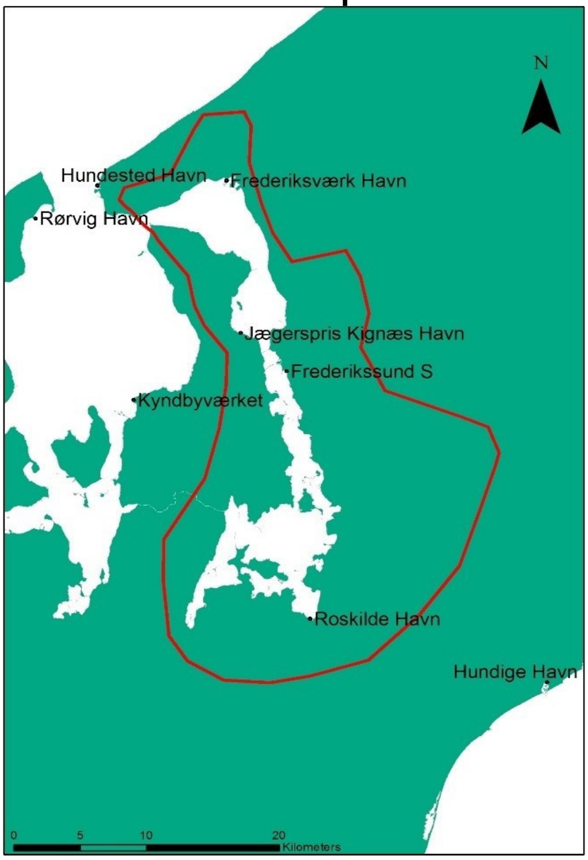
Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Holbæk Havn	Measured	06-12-2013	194	**195**
Holbæk	Egedal (1949)	01-01-1922	183	**194**
Holbæk Havn	Measured	20-11-1973	173	**180**
Holbæk Havn	Measured	07-11-1985	173	**179**
Holbæk	Modelled	02-11-1921	164	**175**

Description of Coastal Section - Zealand 6

SJ6 – Zealand 6. This coastal sections covers the Roskilde Fjord area. Strong storms from northerly directions and of long duration may force water into the Roskilde-Isefjord system from Kattegat and cause extreme water levels. Due to the narrowness of the straits inside the system, a long duration is generally needed to attain extreme water levels at the distal end at the town of Roskilde. Historical events, e.g. in 1921, have been documented – and further historical events are indirectly evindenced through the lack of old houses (pre- 1900) along the coastlines. There are no long tide gauge record but currently around 6 TG stations within the Roskilde-Isefjord system.

Area map



Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Roskilde Havn	693603.3	6171517.9	-7	0.18
Jægerspris Kignæs H.	688333.0	6194175.3	-7	0.17
Frederikssund S	691825.3	6191159.6	-7	0.18

Coordinates:
ETRS89 32N

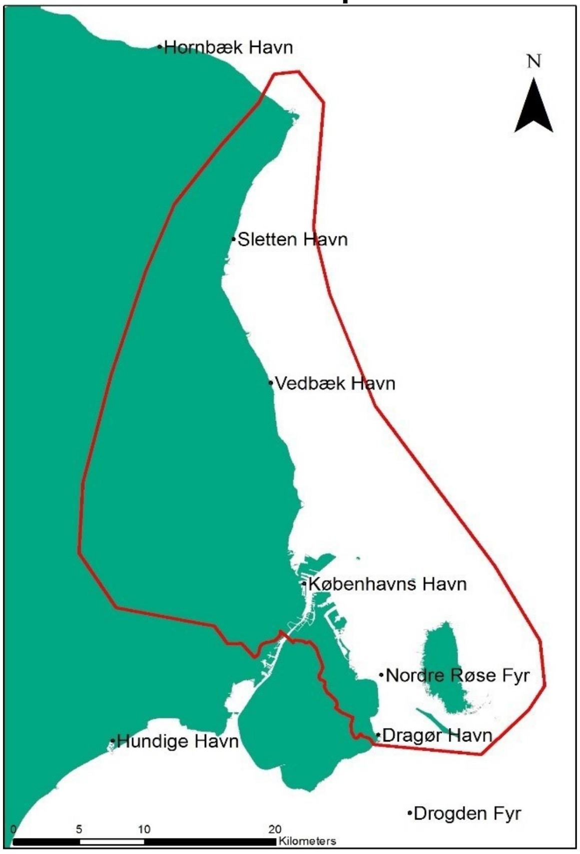
Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Roskilde Havn	Measured	06-12-2013	206	**207**
Roskilde	Modelled	02-11-1921	191	**201**
Frederikssund	Gram-Jensen (1991)	26-12-1862	181	**195**
Roskilde	Modelled	01-01-1922	180	**190**
Roskilde	Modelled	18-12-1921	177	**187**

Description of Coastal Section - Zealand 7

SJ7 – Zealand 7. This coastal section covers the Zealand east coast towards the Sound between the town of Helsingør (Elsinore) and København (Copenhagen). Extreme water levels occur when northerly winds force water masses in from the Kattegat, whereas surges originating in the Baltic Sea rarely affect this section due to a strong gradient in the Sound at the Drogden sill. Copehagen has a long tide gauge series and two additional TGs have recently been deployed. Historically, extreme events have been documented, however rarely with descriptions of water levels. In the past its was mainly fishermen inhabiting the coast. From Copenhagen records date back some period in the early 19th century.

Area map



Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Københavns Havn	726113.4	6179038.8	-7	0.17
Dragør Havn	731764.8	6166979.4	-7	0.17
Drogden Fyr	734171.2	6160738.2	-7	0.17
Vedbæk Havn	723559.1	6195051.5	-7	0.16
Sletten Havn	720701.1	6206532.7	-7	0.15
Nordre Røse Fyr	732016.8	6171741.7	-7	0.17

Coordinates: ETRS89 32N

Maximum recorded water levels (cm)

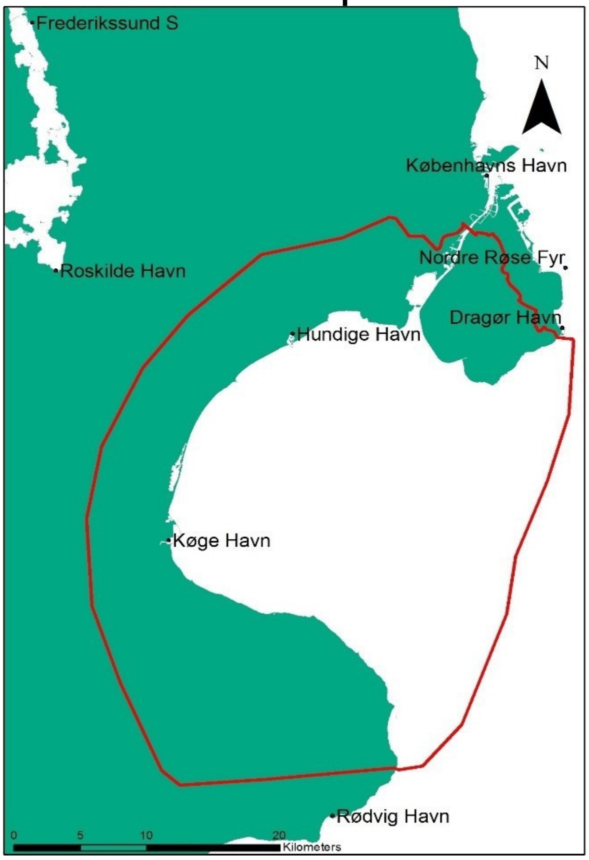
Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
København	Pelt (2012)	26-12-1862	190	**204**
Helsingør	Egedal (1949)	18-12-1921	169	**179**
Københavns Havn	Measured	06-12-2013	172	**173**
Københavns Havn	Measured	31-12-1921	152	**162**
Københavns Havn	Measured	26-12-1902	148	**159**

SJ8

Description of Coastal Section - Zealand 8

SJ8 – Zealand 8. This coastal section covers the Køge Bugt (Køge Bay) area and the southern parts of the low-lying island of Amager towards Copenhagen and faces the Sound and the Baltic Sea. Despite the fact that northerly storm may lead to raised water levels in the area, the most severe storm surges originate in the Baltic as experienced during the 1872 event. Previous investigations have listed a number of surge events and designated water levels to this section, however most of these are speculative as no actual recordings exist. Additional to a recent tide gauge deployment at Dragør on the east coast of the island of Amager, a tide gauge is in operation at the town of Køge.

Area map



Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Køge Havn	702113.5	6150122.6	-8	0.19
Drogden Fyr	734171.2	6160738.2	-7	0.17
Dragør Havn	731764.8	6166979.4	-7	0.17
Hundige Havn	711459.8	6166495.3	-7	0.18

Coordinates:
ETRS89 32N

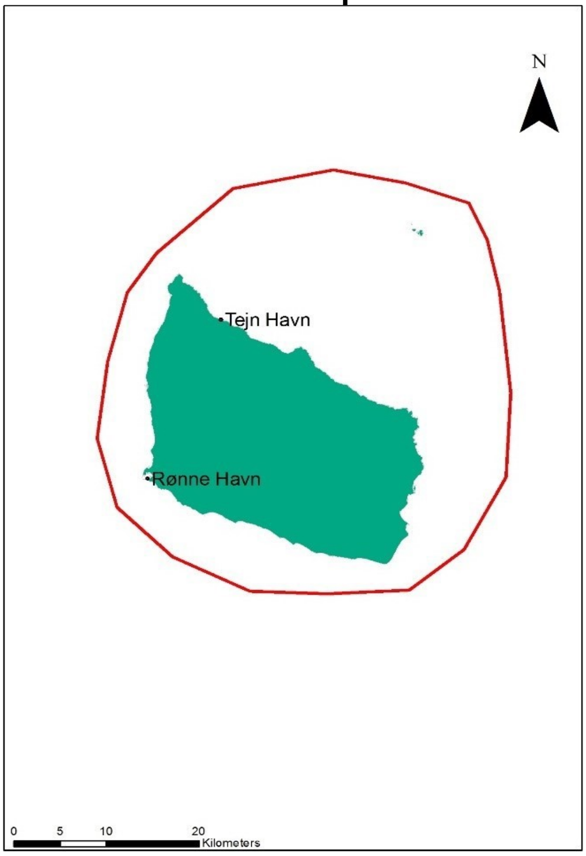
Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Køge	Colding (1881)	14-11-1872	275	**290**
København - Amager	COWI (2015)	10-01-1825	205	**221**
Køge	Pelt (2012)	31-12-1904	192	**205**
Køge Havn	Measured	04-01-2017	157	**158**
Køge Havn	Measured	17-01-1992	151	**156**

Description of Coastal Section - Zealand 9

SJ9 – Zealand 9. This coastal section covers the island of Bornholm, in the Baltic Sea. The island does not, due to its position in open waters, experience as high extreme water levels as, for instance, the coasts of southern Sweden and Zealand. With the severity mainly due to waves, pre-record storm surge levels seems largely undocumented. There are two tide gauge stations in operation at Bornholm at the towns of Tejn and Rønne, respectively.

Area map



Tide gauge and datum information

Tide gauge station	X	Y	DVR90-DNN	Detrending (cm/yr)
Tejn Havn	870827.5	6138041.6	-9	0.01
Rønne Havn	862905.6	6119960.2	-9	0.01

Coordinates:
ETRS89 32N

Maximum recorded water levels (cm)

Tide gauge/location of measurement	Source	Date	DVR90	Trend-free (2020)
Rønne	Colding (1881)	14-11-1872	195	**206**
Bornholm	Assessed	31-12-1904	150	**158**
Tejn Havn	Measured	04-01-2017	121	**121**
Tejn Havn	Measured	02-01-2019	113	**113**

Rønne Havn	Measured	03-11-1995	112	**112**

Appendix B – Tide Gauge Station List

Tide Gauge	WGS84 Lat	WGS84 Long	Data from	In operation
Als Odde	56.7052	10.3292	2012	x
Anholt			1961	-
Assens Havn	55.2706	9.8897	2000	x
Attrup/Øland	57.0458	9.4888	1996	-
Bagenkop Havn	54.7517	10.6724	1976	x
Ballen Havn	55.8155	10.6399	1991	x
Ballum Sluse	55.1308	8.6856	1935	x
Bandholm Havn	54.8368	11.4879	2011	x
Bogense Havn	55.5663	10.0800	2000	x
Bork Havn	55.8494	8.2794	1973	x
Brøns Sluse Havet	55.1861	8.6878	2000	x
Dragør Havn	55.5935	12.6785	2011	x
Drogden Fyr	55.5364	12.7113	1992	x
Esbjerg Havn	55.4602	8.4397	1874	x
Ferring	56.5246	8.1152	1992	x
Fredericia Havn	55.5595	9.7530	1889	x
Frederikshavn Havn	57.4357	10.5479	1893	x
Frederikssund S	55.8278	12.0626	2017	x
Frederiksværk Havn	55.9653	12.0005	2014	x
Fynshav Havn	54.9944	9.9856	1949	x
Fåborg Havn	55.0934	10.2415	2000	x
Gedser Havn	54.5721	11.9245	1892	x
Grenå Havn	56.4121	10.9220	1976	x
Grønlandshavnen	57.0486	10.0520	2007	x
Grådyb Barre	55.4401	8.2602	2000	x
Guldborgsundtunnel Falster	54.8352	11.7944	2017	x
Guldborgsundtunnel Lolland	54.8334	11.7942	2017	x
Haderslev Havn	55.2518	9.5091	2000	x
Hals Havn	56.9901	10.3085	1964	x
Hanstholm Havn	57.1200	8.5955	1890	x
Haverslev Havn	57.0284	9.4017	2017	x
Havneby Havn	55.0870	8.5654	1961	x
Havnebyen/Sjællands Odde	55.9727	11.3694	1991	x
Hesnæs Havn	54.8231	12.1373	1991	x
Hirtshals Havn	57.5951	9.9625	1891	x
Hobro Havn	56.6388	9.8038	2011	x
Holbæk Havn	55.7214	11.7089	1972	x
Hornbæk Havn	56.0934	12.4571	1891	x

Horsens Havn N	55.8561	9.8673	2010	x
Horsens Havn S	55.8549	9.8576	2007	x
Hov Havn	55.9121	10.2589	2011	x
Hundested Havn	55.9655	11.8448	1986	x
Hundige Havn	55.5984	12.3565	2017	x
Hvalpsund	56.7006	9.1934	1995	x
Hvide Sande Fjord	56.0001	8.1298	1990	x
Hvide Sande Havet	55.9968	8.1098	1981	x
Hvide Sande Havn	56.0005	8.1290	1931	x
Juelsminde Havn	55.7156	10.0163	1996	x
Jægerspris Kignæs Havn	55.8563	12.0091	2017	x
Kalundborg Havn	55.6736	11.0973	1971	x
Kalvehave	54.9951	12.1668	2000	x
Karrebæksminde	55.1766	11.6472	2000	x
Kerteminde Havn	55.4508	10.6651	1980	x
Klintholm Havn	54.9530	12.4651	2019	x
Kloster Havn	56.2959	8.2767	1972	x
Kolding Havn	55.4899	9.4824	1986	x
Korsør Havn	55.3306	11.1422	1890	x
Kyndbyværket	55.8117	11.8773	2017	x
Københavns Havn	55.7043	12.5989	1888	x
Køge Havn	55.4555	12.1965	1955	x
Lemvig Havn	56.5507	8.3067	1959	x
Løgstør Havn	56.9678	9.2459	1930	x
Mandø	55.2765	8.5739	2000	x
Nakskov	54.8279	11.1364	2019	x
Nees/Skovlund (Nissum Fjord)	56.4165	8.1729	1972	x
Nibe/Sebbersund			1973	-
Nordby	55.4500	8.4083	2019	x
Nordre Røse Fyr	55.6361	12.6865	2002	x
Nr. Sundby	57.0563	9.9211	1972	x
Nykøbing M. Havn	56.7948	8.8635	2005	x
Nykøbing Sjælland Havn	55.9134	11.6752	2018	x
Odense Fjord (Gabet)	55.5160	10.5701	1978	x
Odense Fjord	55.4388	10.4214	1973	x
Odense Fjord Stige Ø	55.4386	10.4245	2018	x
Odense Kanal Stige Ø	55.4376	10.4226	2018	x
Præstø Havn	55.1251	12.0425	2019	x
Randers Havn	56.4570	10.0410	1909	x
Rantzausminde			1976	-
Ribe Kammersluse	55.3400	8.6760	1919	x
Ringkøbing Havn	56.0874	8.2396	1971	x
Roskilde Havn	55.6509	12.0771	1992	x
Rødbyhavns Havn	54.6561	11.3475	1955	x

Rødvig Havn	55.2543	12.3744	1991	x
Rønbjerg Huse Havn	56.8924	9.1668	2001	x
Rønne Havn	55.0932	14.6896	1987	x
Rørvig Havn	55.9437	11.7685	2018	x
Sakskøbing Havn	54.8023	11.6353	2020	x
Skagen Havn	57.7165	10.5951	1943	x
Skive Havn	56.5701	9.0519	1995	x
Sletten Havn	55.9534	12.5353	2017	x
Slipshavn	55.2878	10.8264	1890	x
Stege Havn	54.9838	12.2803	2019	x
Struer	56.4945	8.5854	2015	x
Svendborg	55.0604	10.6214	2018	x
Sønderborg Havn	54.9106	9.7854	2000	x
Tejn Havn	55.2490	14.8368	1992	x
Thisted Havn	56.9538	8.6941	2001	x
Thorsminde Fjord	56.3716	8.1260	1990	x
Thorsminde Havet	56.3722	8.1137	1979	x
Thorsminde Havn	56.3704	8.1201	1938	x
Thyborøn Havet	56.7075	8.2090	1975	x
Thyborøn Havn	56.7053	8.2225	1935	x
Udbyhøj Havn	56.6070	10.3016	2011	x
Vedbæk Havn	55.8491	12.5715	2011	x
Vejle Havn	55.7071	9.5431	2005	x
Vesterø Havn	57.2961	10.9240	2010	x
Vidåslusen/Højer	54.9628	8.6619	1920	x
Åbenrå Havn	55.0448	9.4270	1980	x
Ålborg Øst	57.0488	9.9414	2002	x
Århus Havn	56.1467	10.2226	1888	x