COASTAL DYNAMICS 2017

Field Excursion Northern Zealand Beaches

Introduction

This field visit will bring you to the coasts of Northern Zealand, branded as "The Riviera of the North". The coast is approximately 60 km long from Hundested in the west to Helsingør in the east (see map on the front page).

There are a few coastal cities in the area, Hundested, Liseleje, Tisvildeleje, Rågeleje, Gilleleje, Hornbæk, Ålsgårde, Hellebæk and Helsingør. The rest of the coast consists of nature areas like Tisvilde hegn, Heatherhill, Hornbæk plantage and Teglstrup hegn, and summerhouse areas. Northern Zealand is the place to be for many of the citizens of Copenhagen, especially during summer.

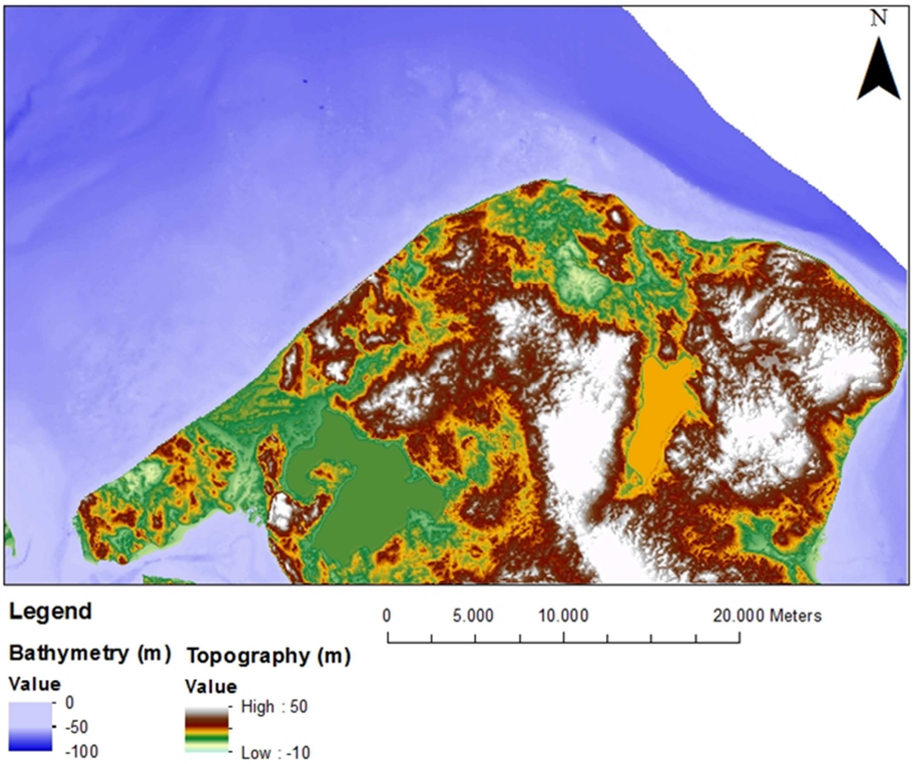

Figure 1 Bathymetry and topography of Northern Zealand and adjacent coastal waters

Geology and geomorphology

Denmark mainly consists of soft sediments in the upper part of the soil. Hardrock is only present at the surface on the island of Bornholm. At a few other places outcrops of chalk can be seen, mainly at Stevns and Møns klint on Zealand, and at Hanstholm in northwestern Jutland.

Denmark is mainly formed by the last two glaciations, Saale and Weichsel. These glaciations have formed a variety of different landscapes like ice pushed moraines and ground moraines with undulating clay. After the last glaciation, some very flat marine landscapes were formed and the relative sea level has fallen since the last transgression in the Holocene (Littorina transgression ca. 7000 y BP). This can also be seen on the North Zealand coast (Figures 1 and 2).

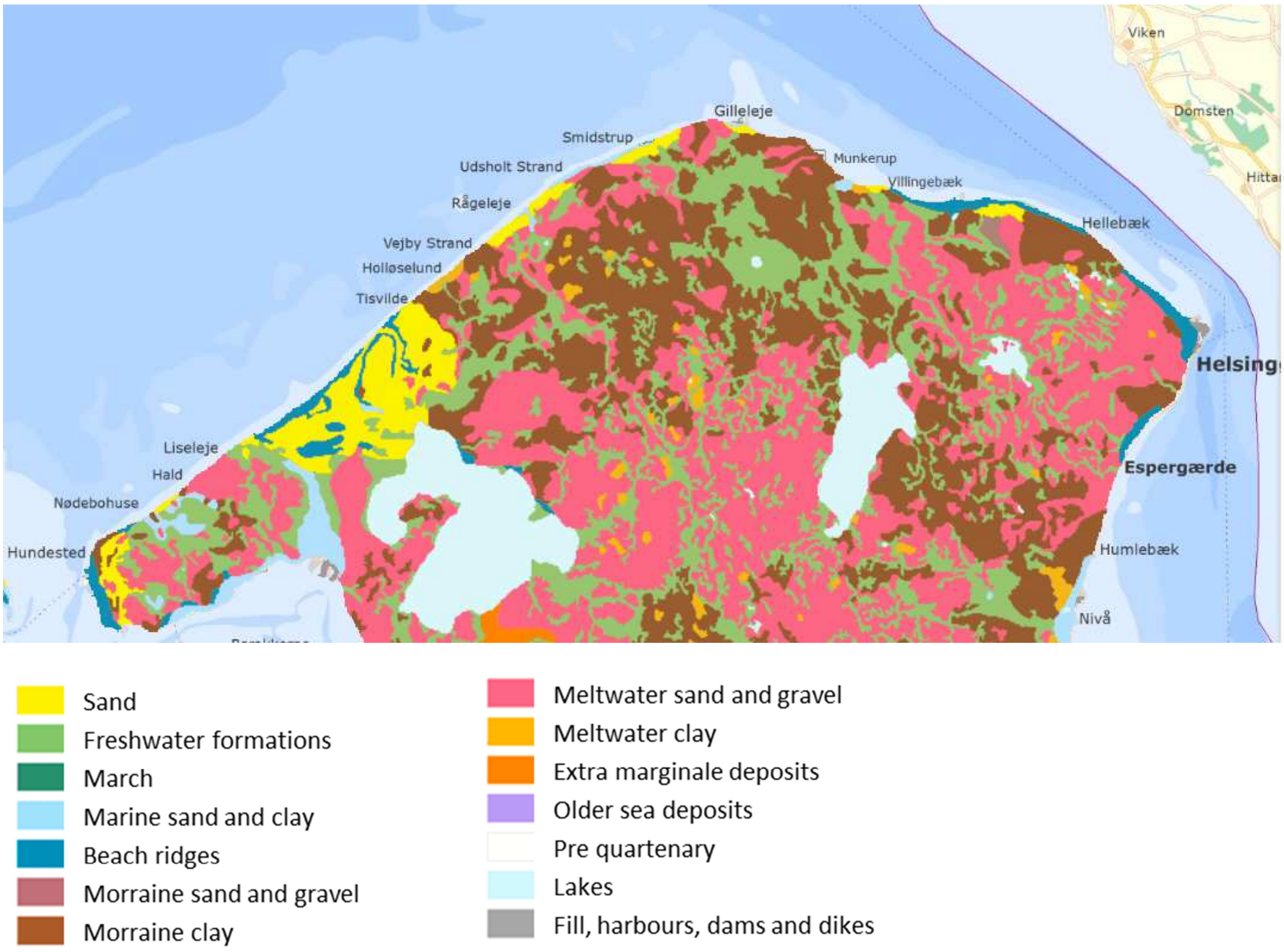

Figure 2 Surface sediments in different geomorphological units

Moraine clay is especially present in coastal cliffs at the central part of the coast. These steep cliffs often have slumps and slides. These slides are caused by geotechnical instability and are triggered by groundwater flow, and wave erosion of the toe of the cliff.

Many houses are located on top of these instable cliffs. For some it is a problem, for some it isn't. The views are great, but the erosion may threaten the existence of the houses. Figure 3 shows a newly build house just above a fresh landslide.

The geology and geomorphology on land is reflected on the seabed. However, the seabed is also influenced by hydrodynamic forcing. Figure 4 shows the sediment characteristics of the upper layer. The underlying data is sparse which results in a quite coarse map. The map shows that the North Zealand coast mainly consists of sand and till.

You will see a larger variation of the geology and geomorphology during field trip.

Figure 3 Houses and slides along a steep coastal cliff with moraine clays

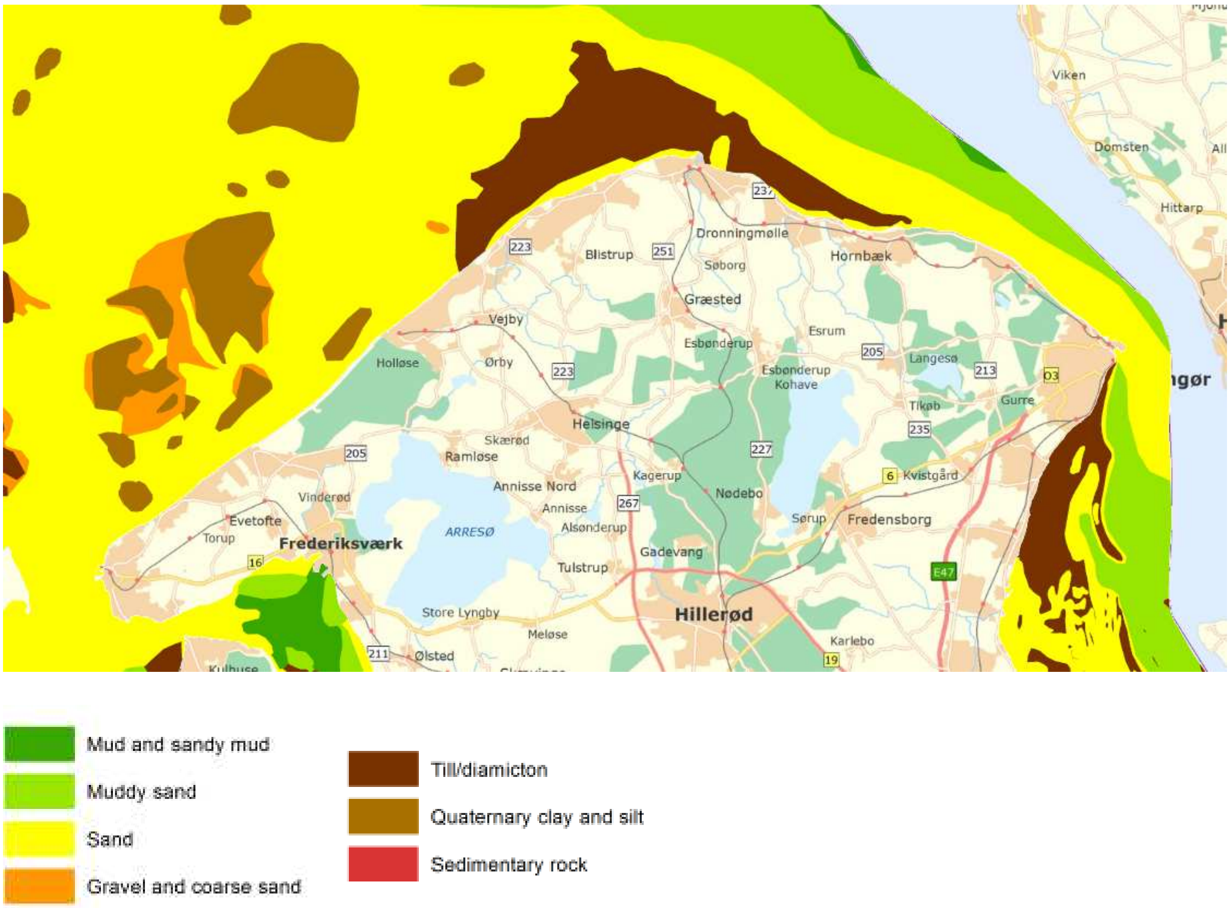

Figure 4 Sediments of the upper seabed in the adjacent waters

Water levels

The tide is semi diurnal and less than 0,5 m. During storm the storm water level can up to nearly 2 meters. The highest waterlevel ever recorded was 1.96 m, recorded on December 5th 2013. It was a more than a 1/1000 year event based on the waterlevel statistics over a 121 year long record (Figure 5).

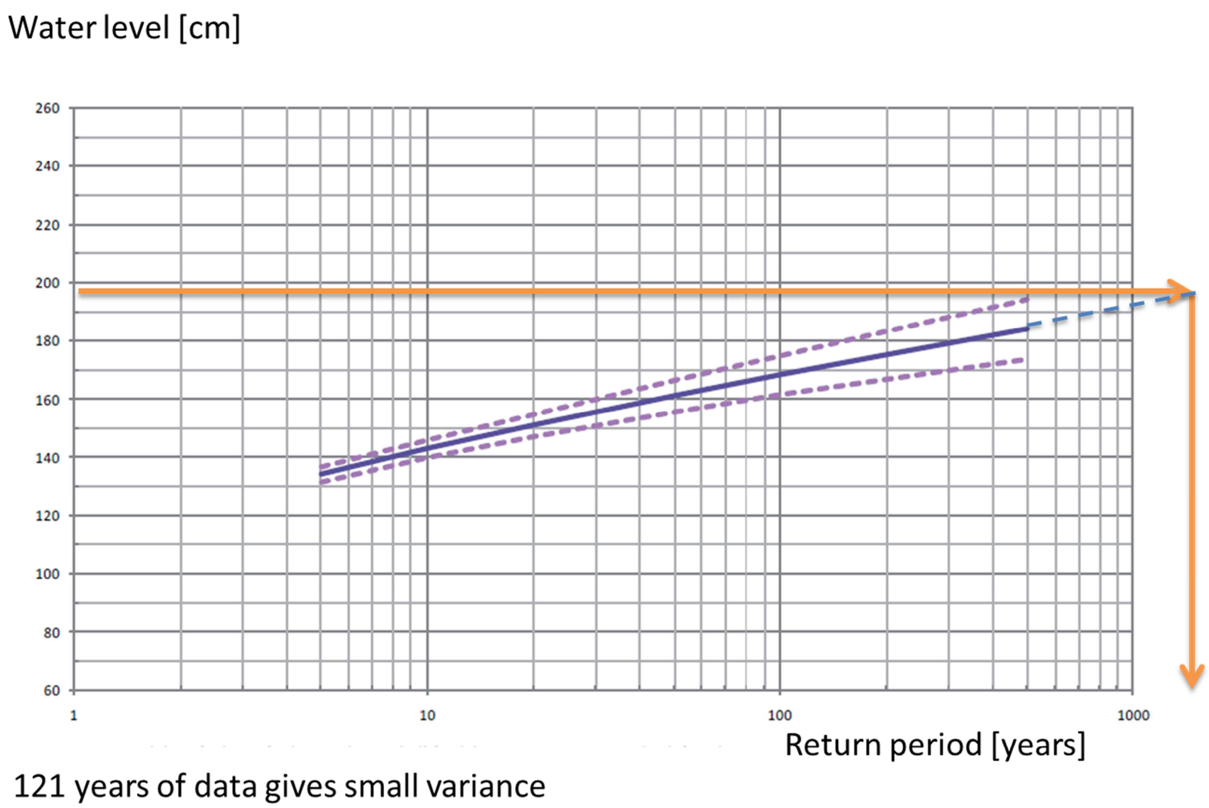

Figure 5 Extreme water level statistics for Hornbæk, based on 121 years of data

Wave climate

The dominant wind direction in Denmark is from the west. Waves are mainly coming from westerly directions where the fetches are relatively long to the west, north-west and north (Figures 6 and 7). A clear sheltering effect of the shift of coastline orientation east of Gilleleje can be seen on the wave roses.

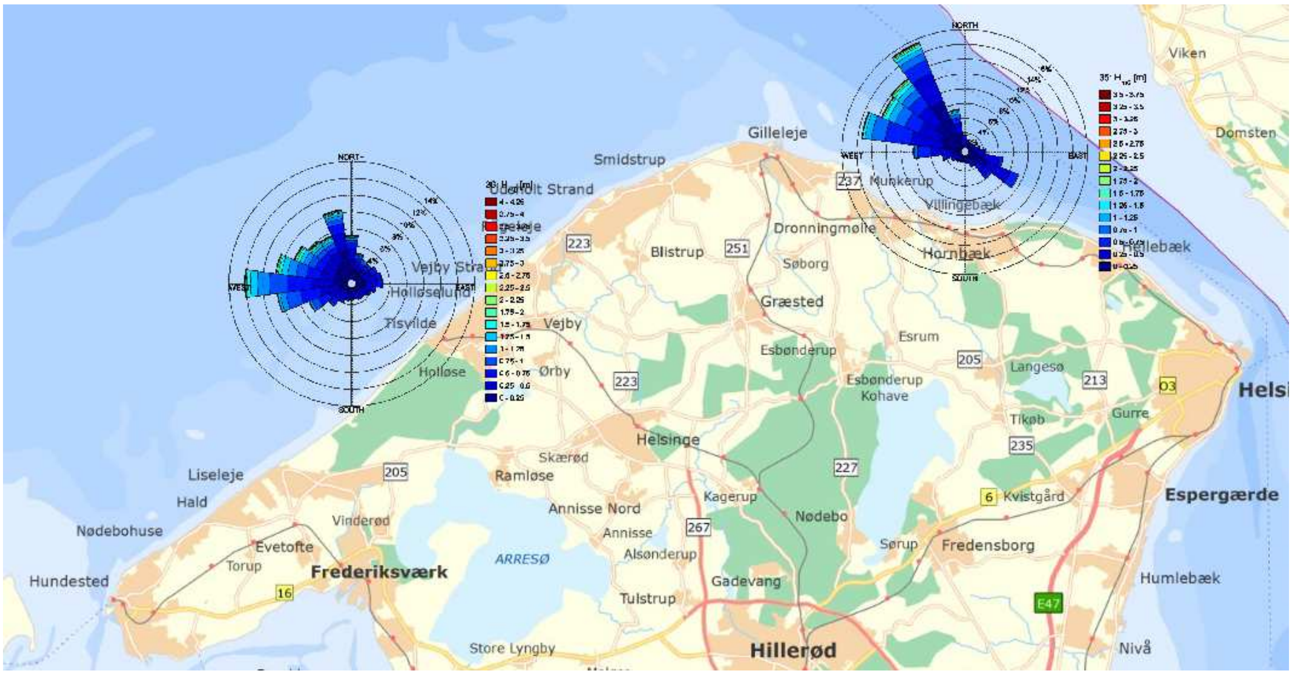

Figure 6 Wave climates at two locations; these are strongly influenced by the coastal orientation

The mean surface elevations of the water levels and the significant wave heights are coorelated for different directions in Figure 8. There is a strong correlation between storm water levels (SWL) and high wave heights (Figure 8). This correlation means that the higher waves are reaching the toe of the cliff during storm events and can they can cause severe cliff erosion.

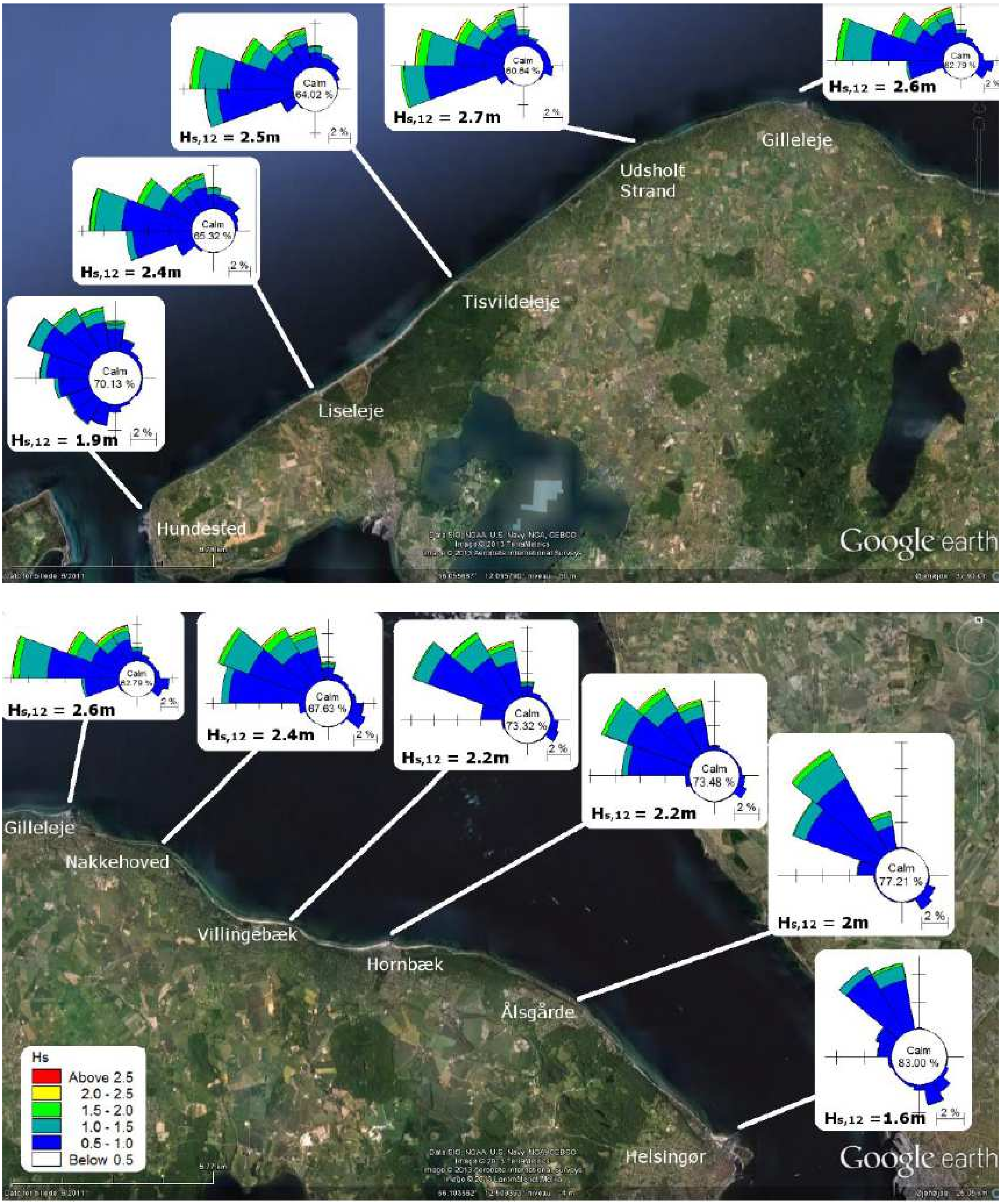

Figure 7 Wave roses for different locations along the coast

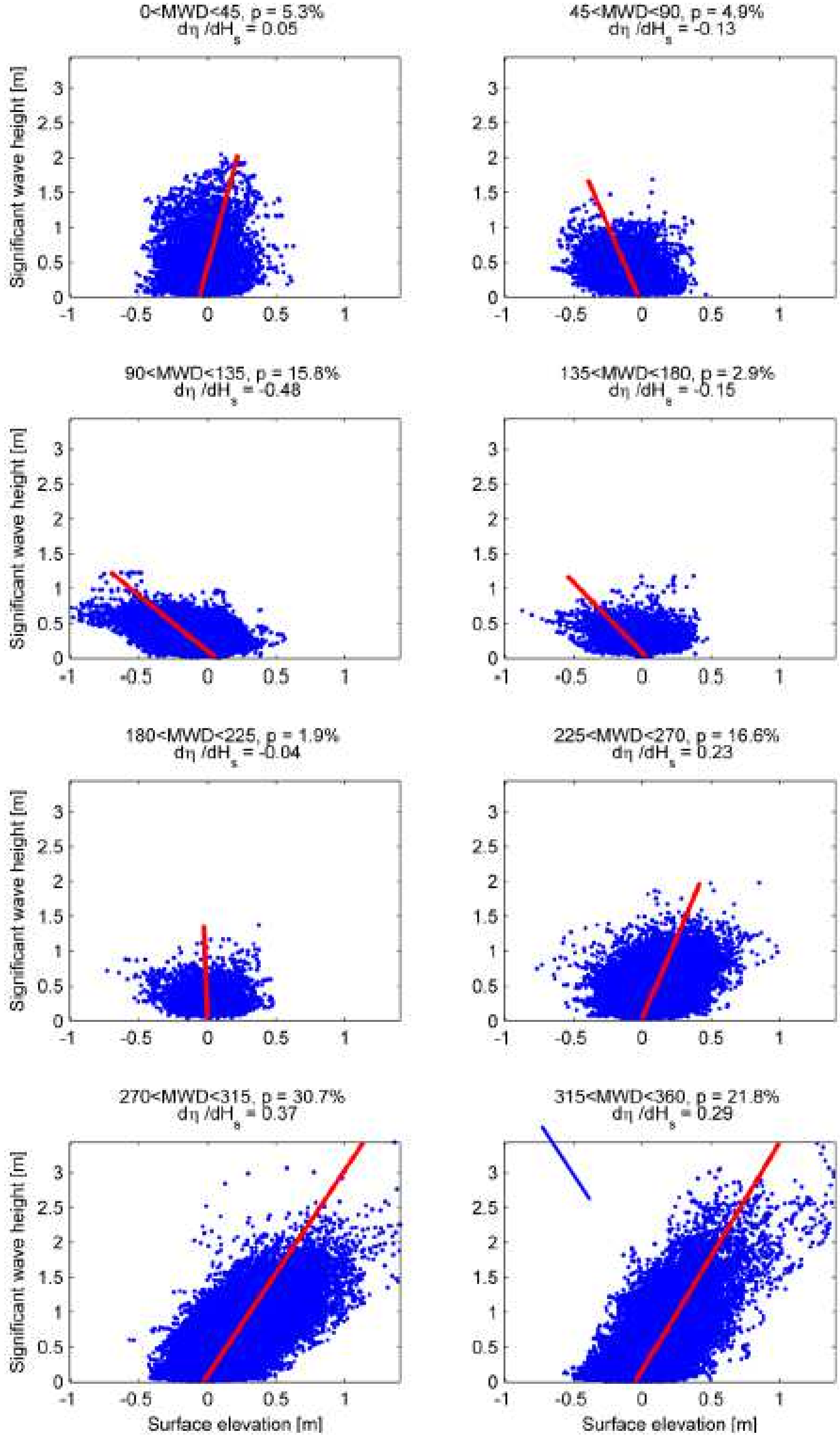

Figure 8 Correlation between surface elevation and wave height at different mean wave directions (MWD)

Sediment transport

Due to the dominant westerly waves, the sediment transport is going from west to east. The sediment budget is unknown due to a lack of measurements. The potential longshore sediment transport is however calculated by using a simple formula for longshore sediment transport. Figure 9 shows the calculated potential longshore sediment transport. The influence of the different coastline orientation can be clearly seen.

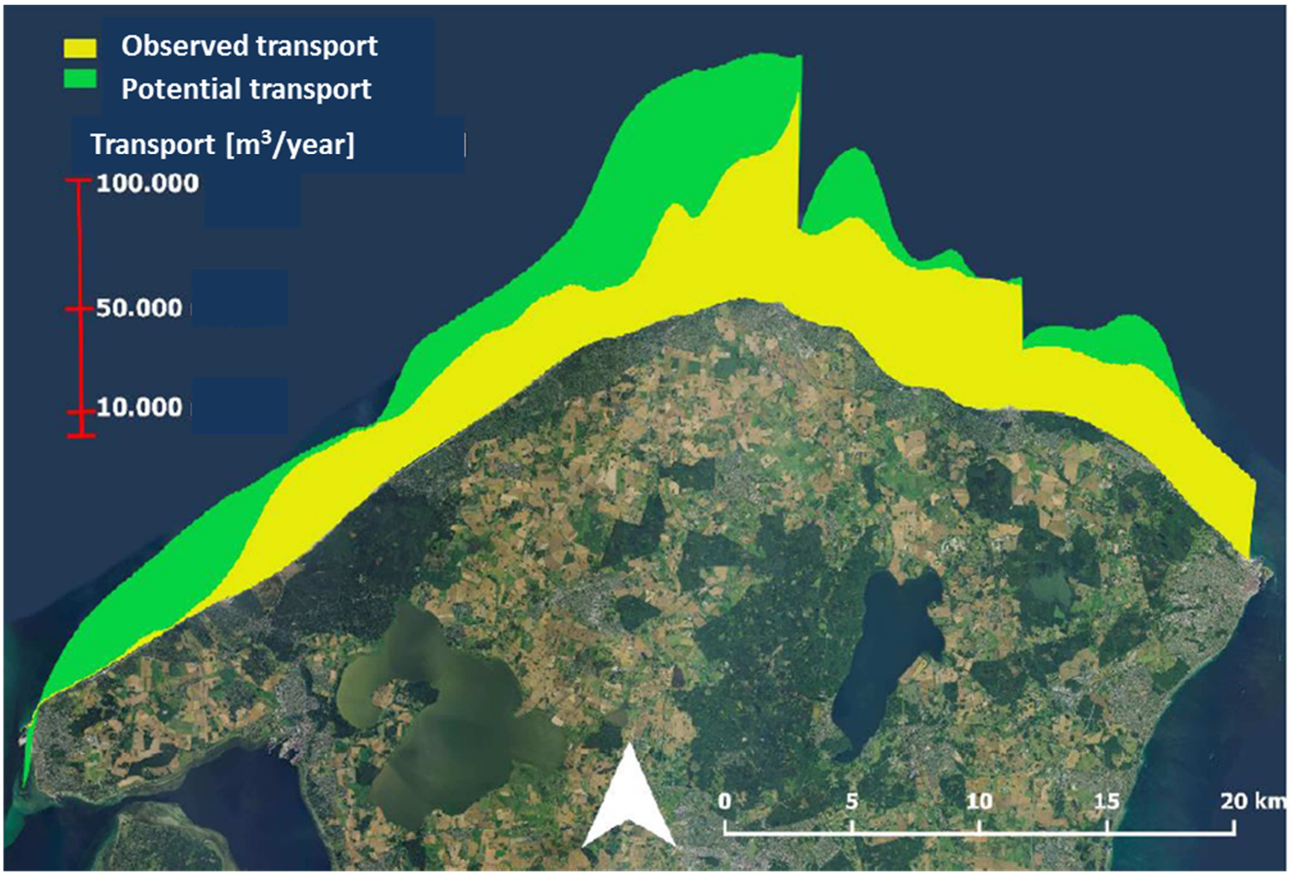

Figure 9 Potential (green) and observed (yellow) longshore sediment transport

Coastal protection

The coast is northern Zealand is one of the most densely protected coastal stretches in Denmark. It is intensively protected by many kinds of passive, hard structures (Figure 10). There is a long tradition of these hard coastal protection structures.

- Construction
- Bypass
- Sand nourishment
- Offshore breakwater
- Groin
- Revetment
- Breakwater
- Dike

Figure 10 Coastal protection

Active coastal protections, defined as focused on solving a deficit in the sediment budget, are not implemented yet. This has resulted in an armored coast (Figure 11), where the coastal profile has steepened during the years, with a significant loss in beach sediments and a change in habitats.

There are huge maintenance costs for the existing coastal protection structures because of this steepening of the profile. Steepening causes larger depths in front of the shoreline and hence bigger waves that hit the coast. The sediment volume of the beach in front of the revetments is gradually reducing and has completely disappeared along some stretches.

Management

In Denmark, each individual landowner is responsible for its own coastal protection. However, he must have a permit from the authorities to build a coastal protection scheme.

The municipalities have the right to enforce coastal protections schemes for longer stretches, either on their own initiative, or based on a contact with a group of landowners. The three municipalities along the northern coast of Zealand, Helnæs, Gribskov and Helsingør, have taken such an initiative. The main objective for them is to start with beach nourishments that compensates for the chronical erosion by the wave-driven longshore sediment transport. The nourishment stretches can be seen on Figure 12.

Figure 11 Armoring of the coast

Figure 12 Proposed beach nourishment stretches

Sites

Site 1: Heatherhill

The coast around Heatherhill shift from a clayish moraine cliff to a sandy cliff (Figure 13 and Figure 14). The cliffs of Heatherhill were stable for many years until the leeside erosion from upstream coastal protection reached the area. The Figures clearly show that a lot of passive coastal protection has been constructed. This has resulted in a sediment starving profile with only one nearshore bar in general.

Recently, three shore-parallel breakwaters have been constructed (Figure 15 and Figure 16). Additional beach nourishments will be done regularly to counteract for the chronical erosion.

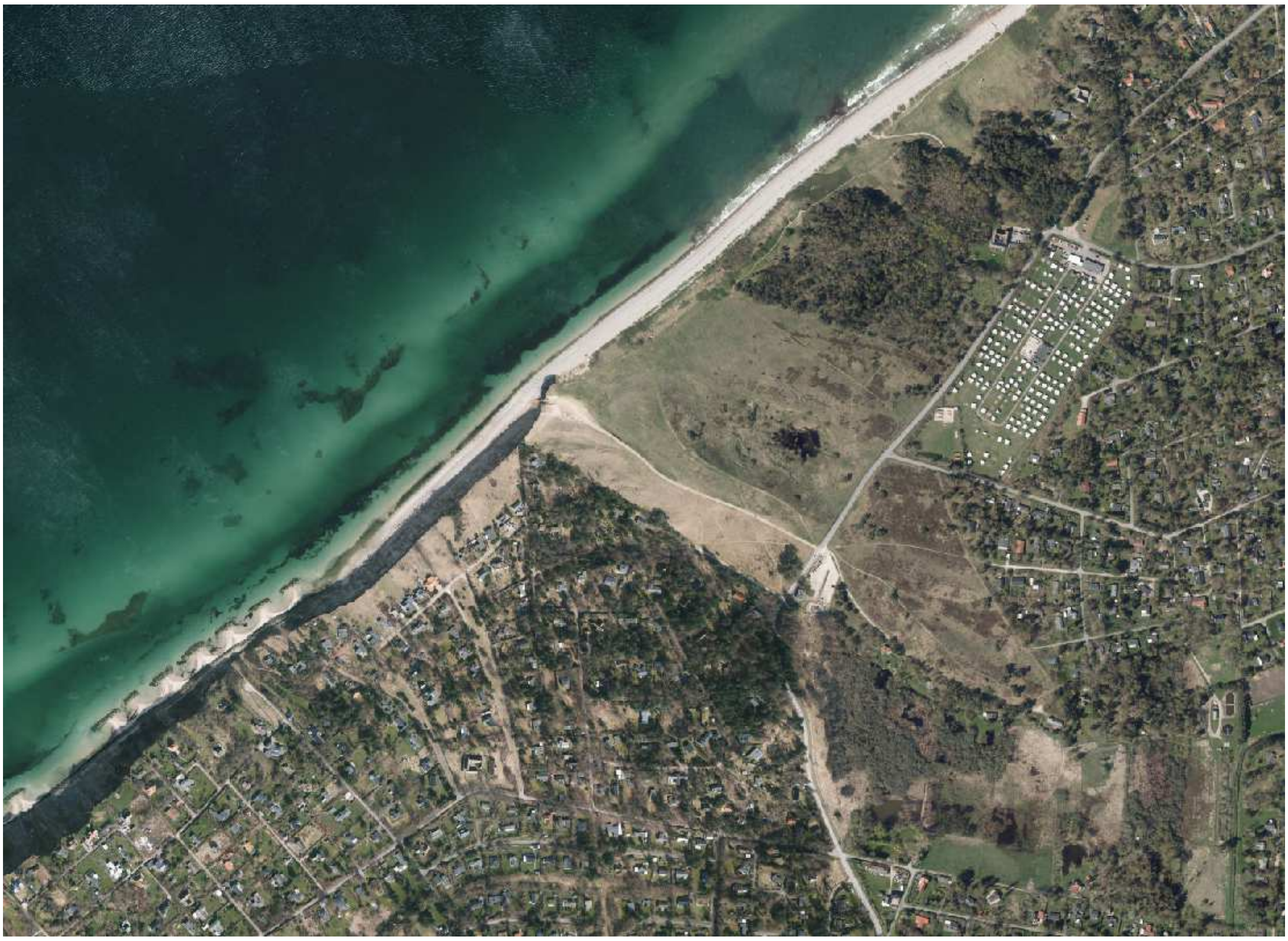

Figure 13 Heatherhill in 2016

Figure 14 Moraine cliffs, coastal protection with Heatherhill in the background

Figure 15 Heatherhill in December 2016 before the construction of the shore parallel breakwaters

Figure 16 Heatherhill in March 2017 after the construction of the shore parallel breakwaters

Normally, the depth of closure was estimated to be around 6 m water depth. However, measurement with an ADCP by the Coastal Authority during the storm Bodil in December 2013 (Figure 17) showed sediment transport at 8 meters water depth (Figure 18).

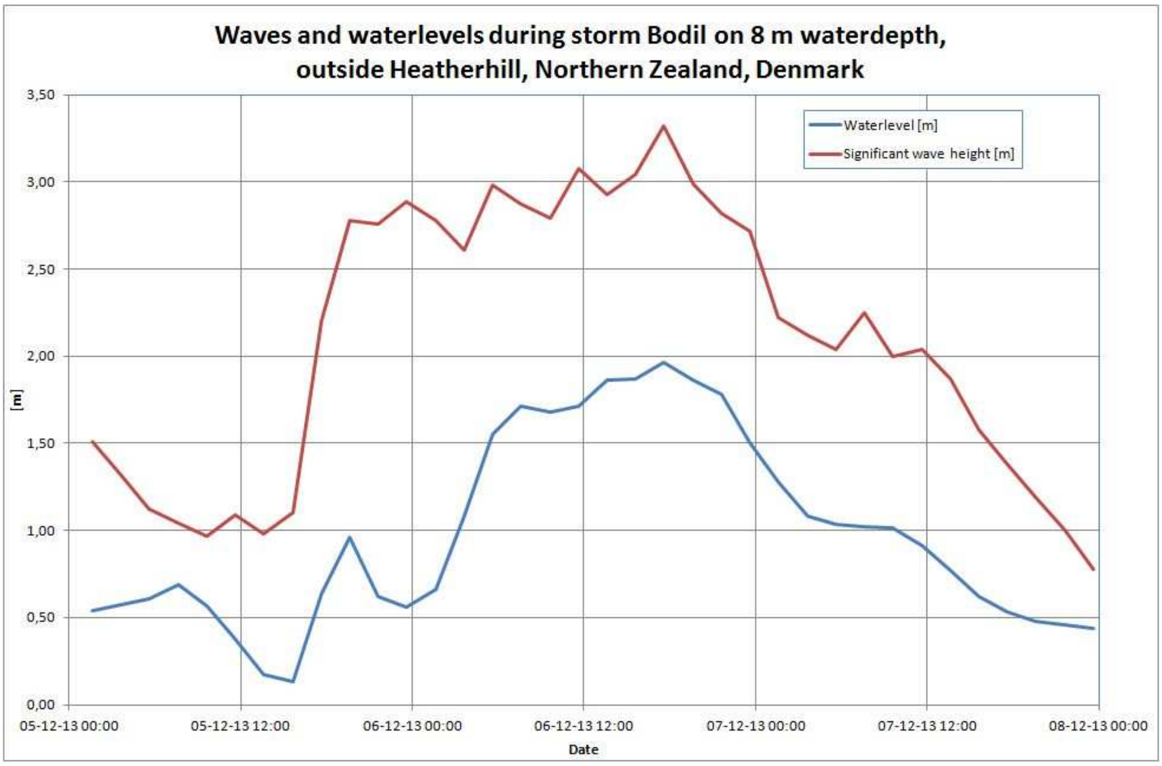

Figure 17 Waves and waterlevels during the storm Bodil in December 2013

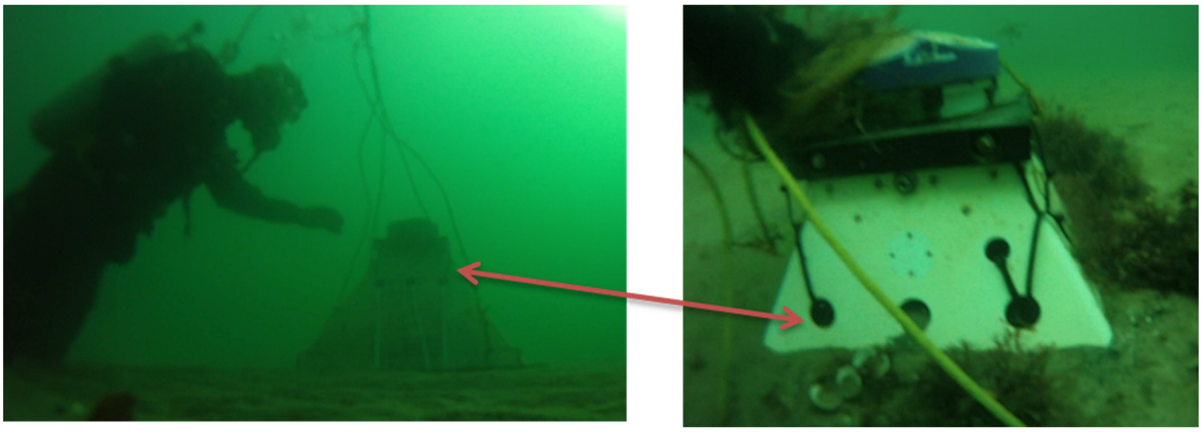

Figure 18 ADCP on the seabed before (left panel) and after (right panel) storm Bodil

Site 2: Rågeleje

Rågeleje is one of the few stretches where there is easy access to the beach and the coastal town has been present for long. Rågeleje used to have a wide nice beach (Figure 20) which gave it a status as an attractive recreational coastal town. However, a breakwater was constructed around 1918 to give shelter for fishing boats. This introduced a clear lee side effect. Erosion of the beach in combination with reflection on the vertical concrete wall resulted in a low gravel beach.

Figure 19 Rågeleje in 2016

Figure 20 Rågeleje in circa 1950

Figure 21 Rågeleje as it is today with less recreational value

Site 3: Smidstrup beach

Smidstrup beach is a natural behaving beach (Figure 22 and Figure 23) which has been quite stable over the last 20 years. The beach protection line as defined in the planning law has prohibited that houses were built close to the coastline. Therefore, there are no coastal protection measures in this area.

The natural wide beach is one of the most visited in the area and has a high recreational value.

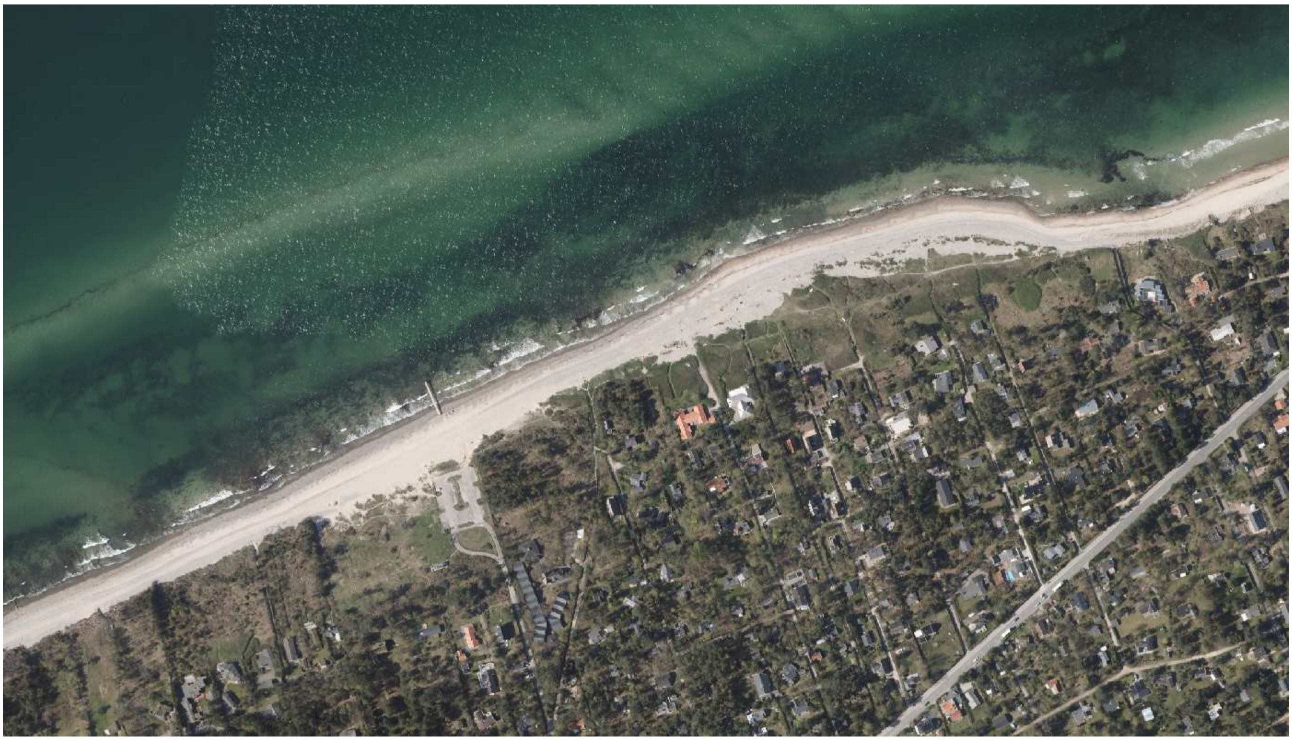

Figure 22 Smidstrup beach in 2016

Figure 23 Smidstrup beach

For many years a coastline undulation has been present in the area. The undulation consists of sand and some gravel. The morphological shoreline development from 1954 to 2016 can be seen in Figure 24. In spring 2017, the undulation was more prominent (Figure 25) and waves were refracting along it.

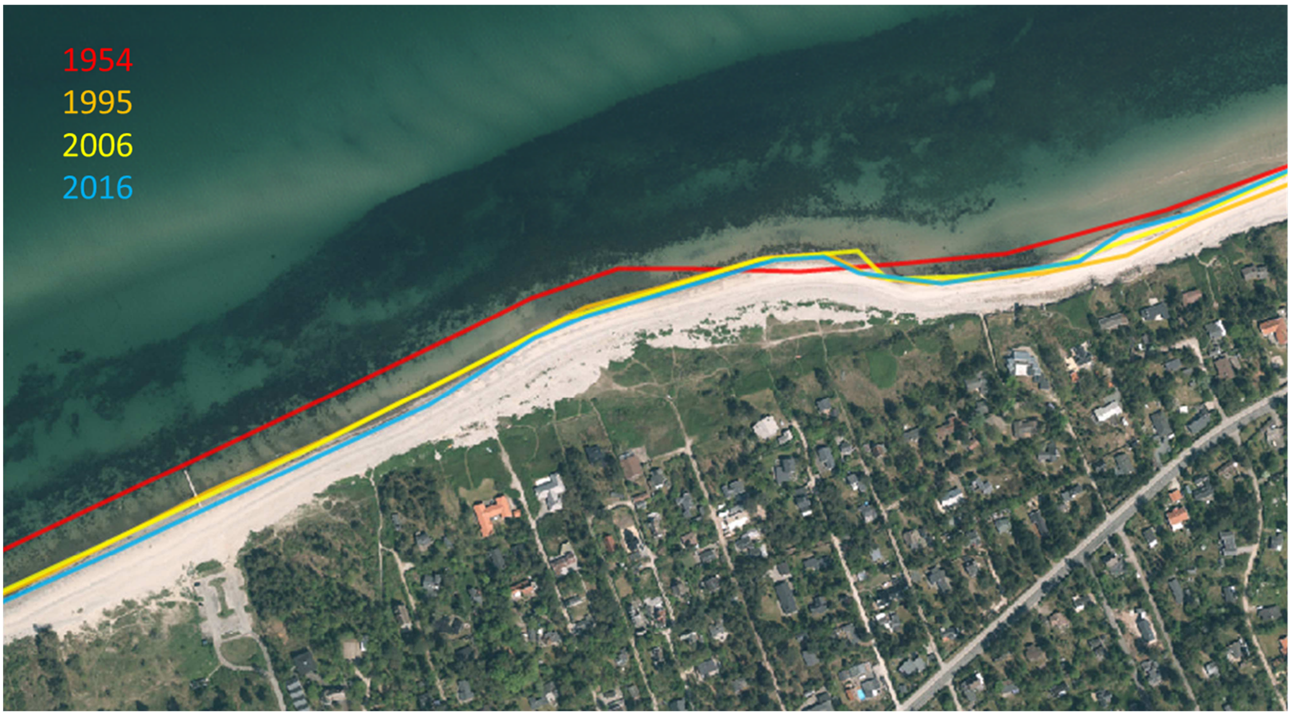

Figure 24 Development of the natural behaving coast at Smidstrup

Figure 25 Waves refracting around beach undulation

Site 4: Gilleleje havn

Gilleleje harbor acts as a huge groin, and the leeside effect is clearly visible (Figure 26).

Figure 26 Gilleleje harbor

A lot of passive protection has been constructed at the leeside of the harbor to compensate for leeside erosion (Figure 27). The municipality initiates frequent beach nourishments for recreational purposes further to the east.

Figure 27 Local coastal protection at the leeside of Gilleleje harbor

Site 5: Hornbæk beach

Hornbæk harbor is placed on a more sheltered stretch of the North Zealand coast (Figure 28). The harbor was completed in 1880 and almost completely financed by people that owned holiday houses, because the felt sorry for the fishermen that had to drag their fishing boats up on the beach. A huge leeward side accumulation of sand can be seen. This has caused aeolian transport from the beach into the harbor basin. Marron grass and brush wood fences are used to stabilize the dunes in order to keep the sand in the area.

Figure 28 Hornbæk harbor

This stabilization has led to unusually high dunes west of the harbor (Figure 29), and constant management of the aeolian transport is necessary. The beach is very attractive to visit and the dunes have a huge recreational value.

Bypass of sediment from the west to the east is regularly done. The bypass volume is approximately 20.000 m^3 and the sediment is placed on the bar at the leeside of the eastern harbor mole.

Figure 29 High dunes and wide beach west of Hormbæk harbor

Field Excursion Organizers

IGN, Copenhagen University has 450 employees and approximately 2000 students. IGN's primary tasks are R&D, education, tasks for authorities, innovation, surveillance, advising, communication and international development program.

The main core R&D is geography, geology, geoinformatics, forest, nature, biomass and landscape architecture and planning. There is a strong coastal community within IGN, represented on CD2017 by Aart Kroon and Troels Aagaard.

DCA, Danish coastal authority has 85 employees and 10 of them in the coastal group. Their primary task is giving advice on coastal matters to the ministers, and the society.

The main research is focused on coastal dynamics, coastal protection measure, climate change adaptation and communication. DCA is represented on CD2017 by Per Sørensen, Anni Lassen and Oliver Ries.

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