Coastal management in Denmark

A UAV approach for coastal monitoring and change detection

Frontpage images:

Top image is a private photo taken on the 14^{th} of May 2018 at Nr. Lyngby beach

Bottom image is showing the final 3D model created for the 14^{th} of May 2018

Title

Coastal management in Denmark
A UAV approach for coastal monitoring and change detection.

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Structural changes to the laws governing the coastal zone in Denmark has led to the possibility of more coastal protection along the Danish coastal. This combined with needs for documentation and monitoring of effects from larger scale erosive protective installations has led to a study on the applications of high resolution models derived from photogrammetric software processing of UAV imagery. It has been the goal to utilize the method for coastal monitoring, change detection and quantification. A DEM and Orthophoto has been produced for the case stretch. Model precision and validity is evaluated to be comparable with national models. The DEM and orthophoto has been applied in a coastal erosion analysis study on the case stretch with good results.

Acknowledgement

The idea and research interest underlying this master thesis has emerged throughout the master and during an internship at the Danish Coastal Authorities. I would therefor like to direct a special thanks to all the people from the Danish Coastal authority for sharing Data, knowledge and know-how with me, both during internship and thesis.

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Nomenclature

Acronyms

AAU	Aalborg University
CSI	Coastal State Indicator
DCA	Danish Coastal Authority
DEM	Digital Elevation Model
DSM	Digital Surface Model
DTM	Digital Terrain Model
dGPS	Differential GPS
GCP	Ground Control Point
GLONASS	Global Navigation Satellite System
GPS	Global Positioning System
GTP	Ground Truth Point
INS	Internal Navigation System
LiDAR	Light Detecting And Ranging
RMSE	Root Mean Square Error
SfM	Structure from Motion
SPM	Sporadic point measurement
UAV	Unmanned Aerial Vehicle
WCL	West Coast Line

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Resume

Den danske kyst zone er foranderlig og ændre sig over sæsoner, år, århundred og årtusinder. Der hersker en stor kompleksitet i det naturlige system som balanceres af de dynamikker som påvirker både havbund, strand og klitter samt klinter. Påvirkninger af disse dynamikker medfører en reaktion og systemet indstiller sig efter påvirkningerne, hvilket stiller store krav til det tekniske design af kystbeskyttelses metoder. I foråret 2018 blev en ny kystbeskyttelses lov vedtaget og større ændringer i formåls paragraffen forventes at give anledning til ændringer ift. hvordan, samt hvornår, der kan gives tilladelse til kystsikring. Ændringer i bl.a. kravene til hvad der kan beskyttes, finansiering af anlæg og behov for beskyttelse er ændret, samtidigt med at der er indført metode frihed på strækninger hvor der er flere anvendelige metoder. Da dokumentation for både store og små kystbeskyttelse projekters udformning eller effekt mm. forventes at være nødvendig, præsenteres en drone baseret monitorerings metode til generering af DEM samt ortofoto som forventeligt kan implementeres i den generelle planlægning og monitorering af de danske kyststrækninger. Den metodiske fremgang baseres på fotogrammetri, altså opmåling i billeder, ved "structure from motion" i det kommercielle software, AgiSoft Photoscan. Ved at benytte drone baserede fotos af kystens overflade som input i det fotogrammetriske software kan genkendelse af objekter vha. programmets algoritmer danne en 3D punktsky der videre kan behandles til endelig fremstilling af DEM samt Ortofoto. Formålet har været at producere veldetaljerede samt præcise modeller i praksis som kan anvendes til observation samt kvantificering af ændringer i kystlandskabet. Sammenligning mellem drone modeller og nationale modeller er blevet implementeret for at vise anvendeligheden af metoden i en relevant case med henblik på at estimere erosionen i et område samt præcisere volumen ændring i den tørre del af kyst profilet. Både DEM og Ortofoto er blevet vurderet til at være tilstrækkeligt nøjagtige, horisontalt og vertikalt, til en analyse af områdets volumen udvikling samt skrænt tilbagerykning. Den horisontale præcision blev bestemt som afstanden fra et veldefineret punkt indmålt med dGPS til placering af samme punkt i ortofotoet. Den vertikale nøjagtighed blev ligeledes bestemt ud fra indmålte dGPS punkter og model, punkter var dog spredt sporadisk, og den vertikale fejl bestemtes som afstanden mellem den indmålte højde og den korresponderende højde fra samme punkt i DEMen. RMSE for modellen d. 19. april 2018 var på 0,064m vertikalt og 0,058m horisontalt. Nøjagtigheden forøges for modellen for d. 14. maj 2018 til RMSE på 0,046m vertikalt og 0,043m horisontalt hvilket betød modellen opnåede samme vertikale nøjagtighed som den nationale model. Nøjagtigheden forhøjedes sandsynligvis grundet en mere detaljeret tilgang til billede optagelserne d. 14. Maj 2018. Metoden finder også ulemper; vejret har stor indflydelse på hvornår en flyvning kan finde sted, nøjagtigheden bør dokumenteres hver gang metoden benyttes, overflade ændringer i form af kraftig sø eller

bevægelige elementer i terrænet kan forstyrre dybdefiltreringen i billederne hvilket introducere støj i objekt genkendelse og i den endelige model. Men metoden viser generelt høj præcision, anvendelighed og flere fordele. Ved drone baseret opmåling er planlægning af opmålings felt-turer mulig på dag til dag basis, få instrumenter er nødvendige for opmålinger og de fylder, samt vejer, ikke meget, metoden fungerer som en relativ lav-budgetløsning til præcisions opmåling af mindre områder i høj opløsning. Både DEM og ortofoto præsentere god anvendelighed i moderne og fremtidig kyst planlægning og vil kunne udnyttes både til myndighedsopgaver, i private virksomheder, til akademisk arbejde, dokumentation af kystens ændring og potentielt som afrapporterings værktøj til kyst udvikling som følge af storm eller kystbeskyttelses foranstaltninger.

Introduction

The coastal landscape presents a diverse and complex system and the relations to it by individuals is dependent on their connection and interest in the areas. It is often related to a variety of values such as recreational, economic, infrastructure etc. depending on how the single area is utilized. The coastal landscape is highly complex, and the hydrodynamic forcing experienced from weather and ocean changes the outline. The system complexity is very dependent on the timescale of which we work with, since changes is governed by the coastal dynamics which can be seen to have impacts over seasons, years, decades, centuries or millennials as the Danish coastline has been developing for thousands of years and the coastline has been moving both back and forth since the last iceage (Weichsel). Various long-term transgressional and regression periods, together with fluvial and Aeolic forcing has shaped the outline seen today. The natural development of the landscape is dependent on the physical factors effecting it and therefore it needs to be incorporated into our planning to ensure the long-term physical quality and resilience e.g.. when installing erosional protective installation. If the coastal landscape did not represent any value for society it would not be regarded as a resource, but it can be difficult to accept changes in the landscape as erosional events can result in loss of some of these values. A conflict exists between utilization and natural development in the coastal landscape and in early 2018 several changes in the Danish law governing coastal protection was made, and it might change the way planning is performed in the coastal zones of Denmark.

A conflict between legislation and citizens exist not only because erosional events, but also because of former restrictions in the design of the protections, including their extension and scale. Questions on financing of protective installations and related responsibility for action contribute overall to a complex situation among the involved parties. The law changes from early 2018 and the possible changes implemented from the 1st of September 2018, means that some responsibilities in the coastal protection law changes hands from centralized at the Danish Coastal Authorities (DCA) to the individual municipalities. A law change giving way for “freedom of method” for coastal protection means that hard structures (such as rubble mound or concrete blocks) as coastal protective installations on erosive coasts is also be allowed, which is expected to lead to more structures of different designs being implemented along the Danish coastline.

As the coastal landscape creates reactions from actions, and with more structures on the beaches, outline changes in the landscape over the next decades are expected if the reactions from installing erosion protection if not countermeasures on the individual stretches are provided. It is therefore the main objective throughout this master thesis to present a remote sensing method for quantification of changes in the beach-, and dune face using unmanned aerial vehicles (UAVs) mounted with high resolution digital cameras. For the model to be relevant, it is also needed to validate the precision of it. The goal has been to create a DSM, from UAV imagery processed in photogrammetric software, which reaches a high enough precision to be valid for comparison with National models. As the method can be thought of as user-friendly, cheap compared to e.g.. LiDAR, relatively fast and, the validation of the model precision is very interesting for future coastal management, as it can be implemented in monitoring for change detection and as an optimization tool for installations in the coastal zone. Impact assessment from storm surges as well as calibration of numerical models could also be future implementation of the tool.

Research design for preliminary study

As in other geographical studies there are a variety of elements that needs to be incorporated to understand the complexities of the world. As the Coastal zone in general is highly complex both in terms of nature and legislation, it is regarded as important to firstly gain an insight in the two via a preliminary study to evaluate the need and possible applications of UAV structure from motion approach. A preliminary research question was used for investigation:

Preliminary problem statement

How will the recent changes of laws governing the coastal zone in Denmark change planning of erosion protective installations and is there a possible usage for UAV monitoring?

Instead of using research questions it has been decided to create a structured preliminary study simply presenting the coastal dynamics and how conventional coastal protection affects the coastal zone, while after the law governing the coastal zone of Denmark together with the resent (to be, or already, implemented in 2018) changes and their effects will be considered with respect to an expert interview. The preliminary study will therefore be structured as follows:

As it is valued necessary to describe the most influencing system features for understanding the dynamics and processes of the coastal zone to understand effects from different erosion protections, chapter one will present a theoretical frame work for understanding coastal dynamics. These coastal dynamics are paired with a presentation of conventional erosive protective installations. The Aeolic dynamics and sediment transport has been left out as the focus are on wave and current induces erosion. Chapter two will shortly introduce the governing laws in the coastal zone, and the most recent and influential changes to the coastal protection law. This is connected to an expert interview on large- and small-scale projects which finally leads to an assessment of the outcomes from the restructuring of the laws. This will lead to summary of the gained knowledge and as it outlines whether a UAV monitoring approach could be influential in coastal management and planning in Denmark, the final problem statement will be presented in chapter 3.

1. Coastal dynamics and processes

The coastal zone in Denmark presents highly dynamic and complex landscapes, and as it will show in chapter 2, high levels of planning exist and varieties of interests are found. To get a grasp on what the changes in the laws governing the coastal zone, will have of influence in the coastal zone, it is important to gain an insight in coastal dynamics and processes. Although this chapter is extensive it is found necessary to present the most relevant details of coastal zone, and the dynamics and processes within the system. This is to gain insight in what effects coastal protection structures have and how it changes the coastal dynamics. It is sought to present a short, theoretic presentation of the most important elements in coastal dynamics and processes, while actual conditions will be presented for the case study in chapter 5 and 7.

1.1 The coastal zone

The coastal zone does not referrer to a defined length but serves as a general term for the shoreface including the beach and the inland limits of the beach and coastal dunes or inland cliffs. The seaward or outer boundary can be set at the outer limit of the lower shoreface since the whole sections is affected under storm, while the landward or inner boundary can be very difficult to define, especially when one encounters coast parallel dune system or coastlines affected by high tidal ranges – It is suggested in (Aargard et.all., 2008) to use the extent to which the coast is under the maximum transgressional phases of the last ice age, but as this would mean that the coastal zone in northern Jutland would extend far inland it is instead set as where dense consistent vegetation cover starts. The outer limit of the coastal zone is set to the outer boundary of the lower shoreface (Aargard et.all., 2008) which is presented under the coastal profile.

1.1.1 The coastal profile

The coastal profile can be divided in different sections, starting from deep water moving to the inland boundary; the shoreface, beach and elements delimiting the seas extent such as dunes or cliff.

The shoreface can be defined as the upper part of the continental shelf, and the extent of the shoreface is therefore very dependent on where in the world we look. The landward boundary is set from the maximal extent of the wave-runup on the beach to the outermost point were sediment is affected by wave energy. The shoreface can be divided into an Upper and the Lower shoreface where the lower shoreface is only significantly affected under stormy conditions, while the upper shoreface is affected more regularly and changes can be measured between seasons.

The outer limit of the lower shoreface is defined as "*to the depth where the mean of the largest waves affects the bottom*" which is very dependent on the variations in the waves (Aargard et.all., 2008, s. 2). It can also be defined as where the largest waves begin to "feel" the bottom – this has been simplified by $d = L/2$ (or $L/4$) where d is the depth and L is the deep-water wave length. (Masselink et. all., 2011)

The upper and lower shorefaces are different, especially as changes occur over different time periods. The lower shoreface is mostly affected in relation to stronger storms and a natural separation between the upper and lower zone could be at the outermost near shore sandbar (Aargard et.all., 2008), or at the "depth of closure" which is seen as a "break in slope" from the bared upper shoreface to the more flat and regular bottom in the lower. The depth of closure can be found from a simplified approximation (Masselink et. all., 2011):

$$h_c = 2\overline{H_s} + 11\sigma$$

Where $\overline{H_s}$ is found as the mean of the annual significant wave height (the annual significant wave height is found as the mean of the daily significant wave height which is the biggest one-third of waves measured) while σ is the standard deviation of $\overline{H_s}$ (Masselink et. all., 2011). A simpler way is to estimate the position is from high resolution transect measurements from longer periods of time (Masselink et. all., 2011) such as the West Coast lines (WCLs), presented in chapter 7.

In the following, a presentation of relevant elements in the upper shoreface and surf zone is given. As there are many in the coastal zone, the relevant is displayed in Figure 1.1 and in the following, the terms are described:

Swash zone is the area where the waves run up and down from the plunging of the waves. It is highly dependent of the water level and wave sizes as it extends inland in high water conditions and seaward in low water conditions. Often the swash is seen to create a beach berm from deposition of sand in calmer conditions.

Sandbars are often encountered on the Danish coasts, but they vary significantly in size and position. They are often seen as parallel to the coast but is also found as crescentic or divided by rip currents (Short & Aagard, 1993).

Breakerbar: The outermost sandbar is not different from the inner bars in the way it is constructed, but it is usually bigger as it is the initial parallel bar the waves meet when they approach the shallower water. The outer breaker bar is also where storm waves are found to shoal and break – it is so to speak the outer limit to the surf zone.

Throughs are found between the sandbars and is often found to have strong shore parallel currents in between as the waves break over the bars and deposits water, strong turbulence is also a factor in moving sediment from the area.

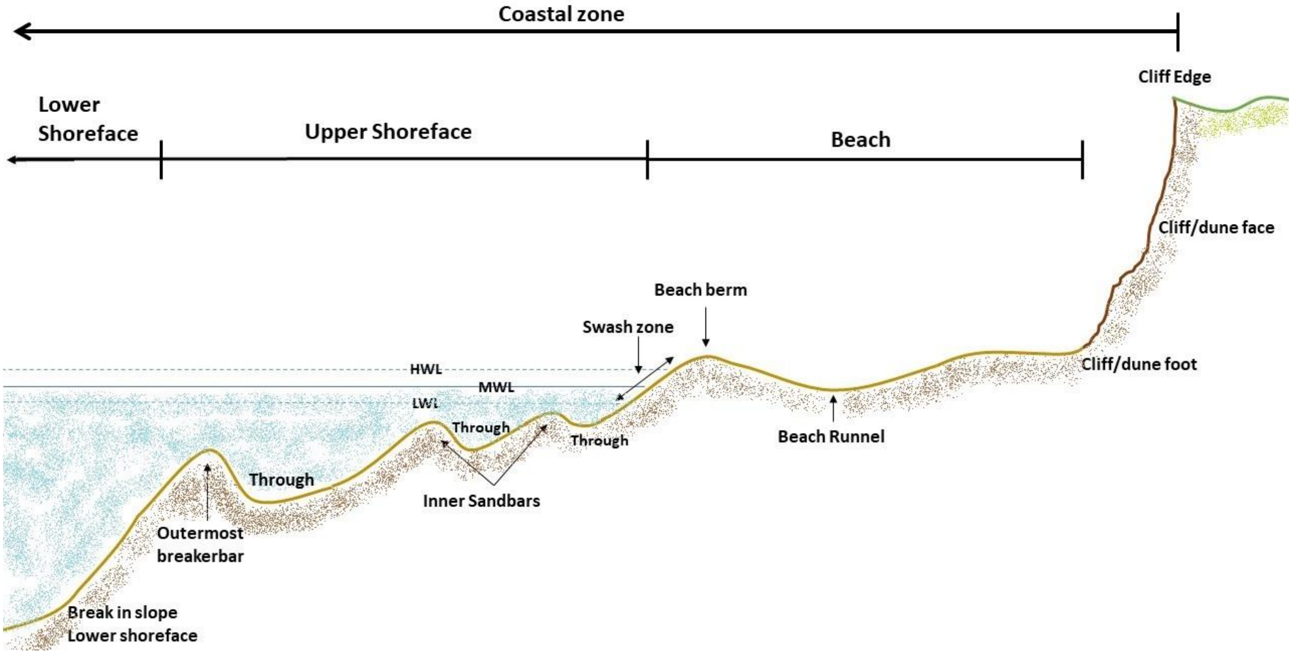


Figure 1.1 Coastal profile and the elements in the beach and upper shoreface. Model made with inspiration from (Aargard et.all., 2008). The different water levels is also included in the figure as HWL (high water level) MWL (Mean water level – DVR90) and LWL (Low water limit).

Beach berm is found as a dry sandbar in the outer part of the beach. The beach berm is created due to wave runup and overflow over the top adding sediment on both sides over the top.

Beach Runnel is found on the landward side of the beach berm as excess water over flowing the berm will be collected here, eventually creating a hole in the berm were the excess water will flow back to sea if the inflow to the water cannot drain into the beach.

Dune- or Cliff foot can often be seen where a significant slope is found between dune/cliff and dry beach – It is though difficult to derive the precise position when looking at, so it will therefore be defined as the height of the 1-year height water return level found to be +0,96m in Hirthals (F, 2012). This is chosen since the water level, at least once pr. year is expected to reach this height which makes this the inner most extend of the beach.

The beach is therefore defined as the area both affected by littoral and Aeolic processes. The seaward limit of the beach is highly dependent on the weather conditions, such as water level and surge.

Cliff face is the slope from the cliff edge to the beach. It is not easily defined as the boundaries again is shifting over the season, but an approach used later, but this will be estimated from a robust measurement approaches, applied in chapter 7.

Cliff edge is described as the very edge of the cliffs facing the beach. If the coastal stretch contained dunes, this position would be much differently defined as the dune systems present very different characteristics. It is also the edge of the hinterland area, often found as the boundary were continuous vegetation cover is found.

1.1.2 Seasonal variations in the profile

The summer period is often calmer with less wave energy than in the winter periods. The changes in weather and forcing also affect the coastal profile. In the summer period smaller swell is often approaching the coast and these will either plunge or surge at low water level, which combined with the landward transport of sand an accretion of sand in near shore or on the beach on the berm, but the upper shoreface also steepens. The bars shrink or stay inactive during these swell periods and they might disappear as a response to the landward sediment transport.

During high intensity waves, often seen in storms during the winter, the sand from the beach will be eroded out in the profile again. Here it again builds up the sandbar system and the profile flatten out again, making it more resistant to waves as they break over the bars and disperse energy in the shoreface. These events are not only season dependent since strong storms also influence the coast during summer periods and calmer periods also is found in the winter periods. More correct terms as Storm-profile and swell-profile could be adapted. (Aargard et.all., 2008)

1.2 Influencing wave dynamics

We now know that the profile is dynamic and changing, but what is causing this dynamic behavior. The dynamics that influences the coastal profile is many, but they are all connected to one another. This section will be related to the forcing that influence the coastal profile. Firstly, a look to the creation of waves will be presented, since the waves on most Danish coasts is derived by the wind, then the waves transport from open ocean to shore will be presented ending up with a presentation of the longshore currents and erosional events.

1.2.1 Deep water waves

As the wind blows over a surface, a negative relationship between the water surface and the wind layers emerge. The speed found in the boundary layer between wind and water surface will be infinitely small, since the friction between the two densities will slow down the wind, but this effect initiates turbulent flow of the wind over the water surface. This shear stress between boundary wind and water creates eddies which initiates capillary waves which, if the wind continues, will increase in size. A "push and pull" effect will assist in dragging the waves in the direction of the wind and the vertical pull in the wave crest will increase the height of the waves. Storm waves are unstructured highly sporadic in length, Height and period, but if the wind continues long enough an equilibrium state is reached (fully arisen sea) where the waves become more organized and regular.

As the open ocean waves has a broad spectrum of waves, the biggest waves will outrun the smaller over time. This is related to the fact that wave speed increase with wave period, which means the waves are sorted (wave dispersion) which forms a more narrow or regular wave spectrum which can also be referred to as swell. (Masselink et. all., 2011)

This is also experienced when the wind decreases or dies out. The waves will continue as before, but slowly they will begin to transform with an increase in length and period, while a decrease is found in the height of the wave. Sorting in the wave spectrum is again seen to create more regular "wave trains" as swell. This is also why waves still is present although the wind system has passed. (Aargard et.all., 2008)

For wind derived waves there are 4 factors in in relations to their size

1. Windspeed
2. Duration of the wind
3. The fetch length of the wind
4. The water depth

If looking over a smaller shallow lake, larger waves won't be experienced not even under storm. Even though the depth was increased the fetch of the wind would still be too short for the waves to reach optimal size. (Aargard et.all., 2008) It is important for the longshore sediment transport to understand waves as they are the initiating factor.

1.2.2 Sediment movement under waves

As the waves are in motion, so are the water particles underneath the waves. In linear wave theory the orbital movement of the water particles is considered closed, meaning that no net transport is taking place. This is not the case for real waves, and because the orbital velocity decreases in relation to water depth, the particles velocity will be slightly higher in the forward movement in the crest of the wave, than in the backwards movement in the through of the wave.

The forward orbital movement of the water particles creates a net drift in the wave direction, which has profound influence on the sedimentary dynamics in the near shore zone. In the movement is depicted and. Deep water the orbital movement in the water particles is seen as round and due to the depth, it will rarely affect the bottom layers, but as the wave approaches intermediate waters, the orbital movement will become more elliptical and the bottom layers will begin to "feel" the wave, while the particle movement on shallow waters will be horizontal. The shear stress on the bed will eventually initiate surface creep, saltation or fully suspend sediments in the water column,

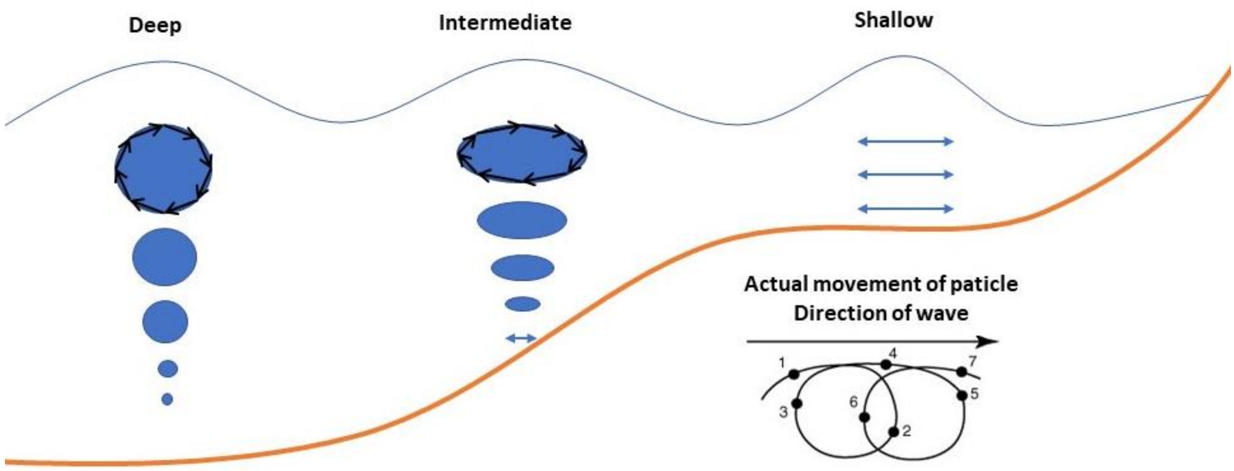


Figure 1.2 – The orbital movement of water particles under a wave in theoretic form over Deep, Intermediate and Shallow waters, with the actuale particle movement shown underneath the bed feature. The figure is constructed with inspiration from (Masselink et. all., 2011).

moving them in the direction of current and waves. (Masselink et. all., 2011) It is not only the orbital movement in the water particles that change, as the waves travels towards the coast. When the waves begin to "feel" the bottom it significantly changes the waves height, speed and length while the period of the waves which remains constant – as the waves move from deep water to intermediate the height will initially decrease and then increase drastically (shoaling). The waves will eventually break, and if the profile is multi-bared the wave can build up again to break over the next sandbar in the landwards direction. (Aargard et.all., 2008) The wave breaking is essential for the next part as the suspension and movement of the sediments is not only in and out but also parallel with the beach.

1.2.3 Refraction of waves and longshore sediment transport.

If the waves are concentrated parallel to shore, the breaking of the waves over the sandbars together with the particle movement of the water creates a surplus of water in the near shore area, which is equalized with an ocean directed bed current. This is also one of the dynamics responsible for creating the sandbars. Another equalization could appear if the water gets "trapped" in the surf or nearshore zone. This excess of water will eventually rip a hole in the sandbars, creating a rip current where the water is transported back into the deeper part of the profile, perpendicular to the coast, and this is seen to replace the bottom currents.

Waves are rarely approaching the coast in a completely parallel motion. The waves might seem to approach the coast parallel, despite it is visible that waves over deeper water is moving along the coast. This phenomenon is called refraction and occurs because of the friction between wave front and the bed contours. As the waves start to feel the bed contours and if the wave approaches with an angle to the bottom contours, the part of the wave closest to shallows will be slowed down, while the wave part on deeper water will propagate in the original speed and direction. This effect gives a rotation on the wave crest traveling over the near shore shallow contours, and the distance between the waves will increase while the wave rotates towards the shore. (Masselink et. all., 2011) Another change in the wave parameters is also that the more the waves feel the bottom the more they will become asymmetrical and as this happens, the landward transport of sand is theoretically much higher the than seaward transport. This is a simplification as gravity and the bed return current will transport sand seaward as well (Aargard et.all., 2008). Is does however have great influence on the sediment transport in the surf zone, as the waves eventually will have a higher velocity in the crest than in the through, together with the steepening of the waves, it results wave breaking. (Masselink et. all., 2011) This is also an excess deposition of water in the surf zone which in combination with the forward motion of the waves, and the incoming wave angle, will create what is referred to as a shore parallel wave induces current. This is the initiating factor to coast parallel sediment transport, as the sediment already is in suspension in the water column, the current can transport it along the coast and not only in and out. The maximum velocity of the longshore current will be found with a $45°$ wave angle to the coast (Aargard et.all., 2008)

When the transport of sediment out of a defined area is larger than the input, a general loss of sediment is experienced, and erosion is taking place. But there are 2 different types of erosional events that are of interest to the coastal studies: Chronic and acute erosion.

1.2.4 Chronic erosion

The chronic erosion can be said to be the general sediment deficit In an area over time. The phenomenon is experienced when more sand is transported out of an area than into it. The chronic erosion will maybe not be experienced the same place every day but will instead spread out overall in the active profile. It is so to speak more permanent over time and the general profile will experience a recession in position and volume. It is often experienced when the longshore sediment increases along the shoreline which mean the water columns ability to carry sediment also increases along the shore. (DHI, 2015) The eroded sediment will at some point settle out from the water column as the current velocity decreases, which leads to an accretion. The can be a factor in creating new land forms or closing of inlets (Aargard et.all., 2008). It is also experienced in the upstream coastal stretches of harbors or groins.

1.2.5 Acute erosion

While Chronic erosion is a longshore phenomenon, acute erosion is seen as a cross shore. It is visible as erosion in the dunes, the cliff or hinterland. The sediment erosion can be experienced in storminess where a surge together with high energy waves and highwater means that the water reaches the dune- or cliff toe. This initiates sediment transport from the beach, dunes or cliffs which will then be dispersed into the wet profile for profile development. It often leads to undercutting of the inland barriers resulting in slumping of sediment to the beach which is then again available for transport. These events are partly irreversible as Moraine cliffs cannot be restored naturally in short time, but it is possible for dune systems to regrow them self again if longer periods with calm weather transports sand back to shore, making it available for Aeolic transport to the dune front again. (DHI, 2015)

1.3 Profile reactions to climate changes

This section is shortly mentioning climate changes, as it is a very relevant topic for the coastal system it will shortly be presented as it is useful for reflection on what types of coastal protection is efficient. As climate changes is a concern in all policy making, it is also necessary to underline the possible effects it could have on the coastal profile. As there is already seen higher mean water levels and the expectations is that it raises even more it will have influences on the coast. (Martin Olesen, 2014)

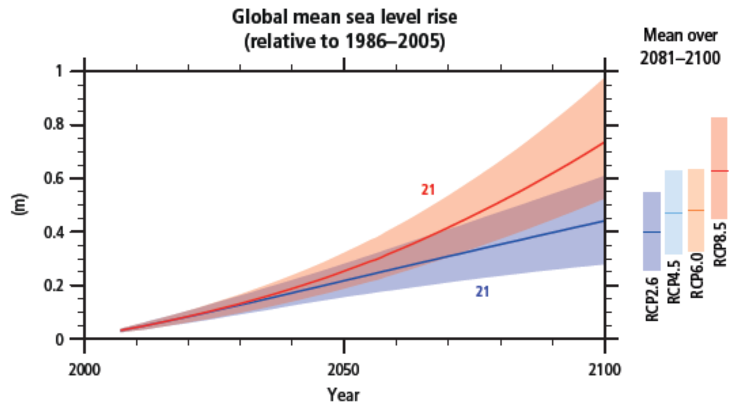


Figure 1.3 RCP2.6 – RCP4.5 – RCP6.0 – RCP8.5 stands for "representative Concentration Pathways" and describes different climate scenarios with RCP2,5 being the minimum and RCP8,5 is maximum. (IPCC, 2014)

The global mean sea water level is expected to raise between 0,26 and 0,82 meters – this is of course seen on a global scale, while local variations might be higher (IPCC, 2014). The estimated values from the Danish meteorological institute ranges between 0,34m and 0,61m respectively for RCP2,6 and RCP8,5. The maximum estimation is though set to 1,2 meters. This is combined with an expectation of more frequent extreme events with stronger outcomes. (Martin Olesen, 2014)

The coastal profile will need to find a new equilibrium state or profile with a raising water level. A simple rule for the expected events in the profile seen from a raise in the mean water level, also known as Bruun's rules.

$$\delta y = -S * \frac{w_*}{h_* + B}$$

Where S is the rise in sea level, $w_*$is the width of the shoreface, h_* is the depth of the shoreface (using e.g.. d=L/2) and B is the height of the dry beach. There are though several considerations to take regarding the formulation as it is not a perfect fit (Masselink et. all., 2011), but it is an easy to use estimation, also included in the Danish coastal analysis by the DCA and DHI (DHI, 2015).

1.4 Coastal protection installations

Now that a general understanding of the dynamics and the processes that govern the sediment transport is understood, the ways to protect to coast from eroding will now be presented. As there are many elements effecting the coast there are also many coastal Protective installation designs, which have been implemented. The design of, and effects from, different installations will here be shortly presented. It should be mentioned that "soft" coastal protection refers to the use of adding sediment to the erosion area, while "hard" coastal protection refers to more permanent structures which is fixed in its position and made form stones, concrete, wood, etc.

1.4.1 Groins

A groin is a hard structure often placed perpendicular to the coastline. The construction material varies between different installations, but they can be built with stones, wood, concrete blocks etc.

Figure 1.4 – Private photo of the Groin named P on the Danish westcoast near Fjaltring.

The principle of the installation is to hinder the longshore transport. This is accomplished when the structures reach into the wet part of the profile as it is seen in Figure 1.4 – Private photo of the Groin named P on the Danish westcoast near Fjaltring.. The sand is trapped in the upstream side of the groin, but it also allows for an escalated erosion downstream, and it does not protect against erosion in the cliffs or dunes. Additionally, the chronical erosion in the outer profile will continue and steepening of the wet part of the profile is experienced. (Aargard et.all., 2008) and (DHI, 2015)

1.4.2 Breakwaters

When breakwaters are placed it is with the purpose of breaking the waves before they reach the beach and disperse the energy over the rocks. This gives a lower wave energy level on the beach making deposition of sediment possible, while the cliffs and dunes can stabilize. But as diffraction of the waves around the breakwater is taking place, and tombolo formations will eventually close of the longshore sediment drift between breakwaters and the beach.

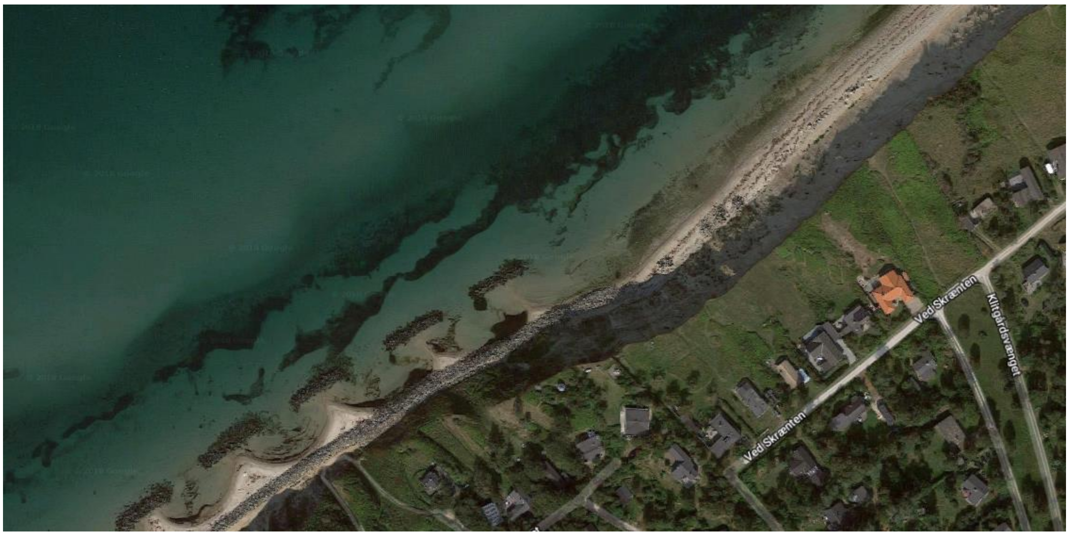


Figure 1.5 – This stretch known as heather hill just west of Raageleje in the northern part of Zealand is showing multiple breakwaters and increased erosion in the eastern side of the end section of the breakwaters.

The downstream stretch will suffer from sediment deficit and increased erosion is experienced. The surf zone will continue the chronic erosion and the wet profile will steepen on the outside of the breakwaters. Currents between the breakwaters will also decrease the safety of swimmers. (Aargard et.all., 2008) and (DHI, 2015) From Figure 1.5 – This stretch known as heather hill just west of Raageleje in the northern part of Zealand is showing multiple breakwaters and increased erosion in the eastern side of the end section of the breakwaters. which is from the northern Zealand just west of Raageleje there is a longer installation of breakwaters, additional revetment is installed behind it. On the eastern side, the cliffs shows little to no signs of vegetation on the cliff face which indicates the cliff is active additionally the dense vegetation cover is further inland on the un protected stretch than on the protected which could indicate a heightened erosion on the downstream side of the breakwaters.

1.4.3 Revetments

The revetment construction is installed to hinder the ocean in eroding in the cliff of dunes, and an extreme example is seen from Figure 1.6. Installations of stones or concrete blocks in the dune or cliff toe protects the cliff and dune face from waves, so acute erosion is hindered. In extreme conditions the water from the waves will percolate through the stones in the swash and some wave energy will be reflected. This does of course also imply that the sediment that should have gained in the water column from the dunes/cliff will now be eroded from the beach. In time the beach will be eroded away and free passage along the beach won't be possible. (Aargard et.all., 2008) and (DHI, 2015)

Figure 1.6 – The revetment in the picture is placed between the angled groin known as Q and the perpendicular groin known as P on the westcoast of Denmark near Fjaltring. Private photo.

1.4.4 Sand nourishment

In general sand nourishment is the process of compensating the eroded sediment by applying compensating amounts of sediment of the same granular size or larger to the beach, shoreface or in-between. The way sand is added or deposited is different but can be described in 3 general forms.

Beach nourishment can either be performed from a ship or from dumpers. When it is performed from a ship, as in Figure 1.7 – Nourishment types. 1. is beach nourishment from ship. 2. Is nearshore nourishment from ship canon. 3. Is Shoreface nourishment. The images is reproduced from the DCA educational material on their webpage. , the hull is filled with excavated or pumped sediment, which is pumped into the beach in a pipeline. It is hereby deposited all over the beach as the sand is pumped in with water, and the pipe is moved when necessary. When it is performed with dumpers, the sediment is excavated inland and driven to the beach to be offloaded and redistributed by heavy machinery.

Near coast nourishment is performed from ship, Figure 1.7 – Nourishment types. 1. is beach nourishment from ship. 2. Is nearshore nourishment from ship canon. 3. Is Shoreface nourishment. The images is reproduced from the DCA educational material on their webpage. , but instead of pumping it via pipe to the beach, it is pumped out from onboard canon which disperses the sediment and water in a rainbow shape from the ship into the water. The sediment then settles out on the bottom and is redistributed by current, waves and wind.

Shoreface nourishment is performed from split-hull ship where the hull is capable of either splitting or opening shuts in the bottom of the hull. This releases the sediment into the water over the barred area which in theory then distributes itself from the shoreface to the surf zone and bar system. This method needs to be repeated if the nourishment need to be stretched. (Aargard et.all., 2008) and (DHI, 2015) In general, the sediment is set as an erosional buffer and building block for the shoreface and beach. The sediment deposited is redistributed via sedimentary transport and will in theory build up the profile. It can be seen as a buffer for the chronical erosion found in the profile and a storm buffer if placed in addition to the existing dune or cliff face. Beach nourishments can also be installed as sand buffers on in front of hard structures, creating a combined protection.

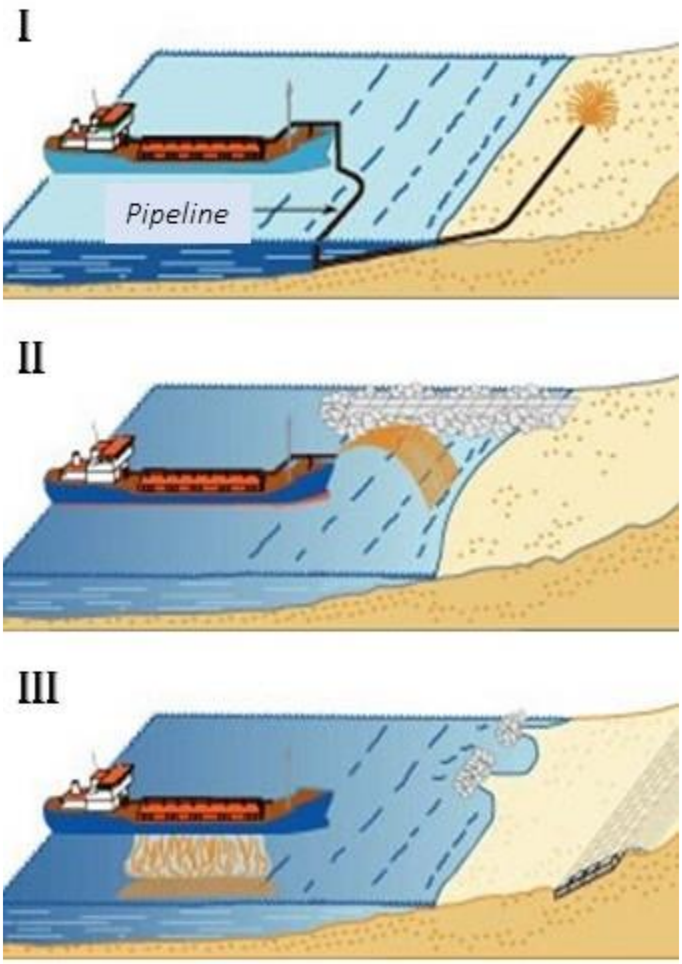


Figure 1.7 – Nourishment types. 1. is beach nourishment from ship. 2. Is nearshore nourishment from ship canon. 3. Is Shoreface nourishment. The images is reproduced from the DCA educational material on their webpage. (Kystdirektoratet E, 2018)

1.4.5 Combined protection methods

In general, all the hard structures can be combined with nourishment of relevant sediment. It is e.g.. seen in Noerlev which is presented in Figure 1.8 – A drone photo acquired in Noerlev beach, showing the newly installed sleeping defense. The black line is showing the extent of the revetment bellow. This installation combines a revetment in the dunetoe and duneface with additional nourishment. (Kystdirektoratet C, 2016). The sand buffer installed is working as an initial buffer protection for acute erosion of the dunes. The revetment ensures a last defense and protection of the dune face position in heavy storm and under extreme events.

As the changes in the laws governing the coastal zone of Denmark, so that freedom of methods (with restrictions) it implies that there will be some changes to the future of coastal planning and to what types of installations that can be allowed. In the following a comparison between the elements together with an expert interview will investigate the need for future monitoring of coastal protection, effects and impacts.

Figure 1.8 – A drone photo acquired in Noerlev beach, showing the newly installed sleeping defense. The black line is showing the extent of the revetment.

2. Management and planning in the coastal zone of Denmark

It is a complex matter when planning is undertaken within the Danish coastal zone, but as there is a long tradition for managing the landscape, both for usage and commercialization, a homogeneous planning with several restrictions has served to protect areas of natural interest. This chapter will focus on shortly presenting the laws governing areas of the coastal zone in Denmark and the element of these laws relevant in coastal planning. As several changes to the coastal protection law was introduced in early 2018, and a new law change is expected to be implemented from the 1st of September 2018 these will also be introduced. The chapter is finished with a summary of an expert interview, which had the purpose of knowledge insight in actual planning, challenges facing the municipalities in large scale project and how a UAV monitoring approach could be interesting for in future work.

In June 2016 an agreement between the Danish government and 3 other Danish political parties, was constructed named “Denmark in better balance – better framework for municipalities, citizens and corporations in all of Denmark”. In this agreement, there was a general focus on a renewal of the planlaw (presented in chapter 2.1), to create new possibilities for economic growth in the rural (and outside of the cities in general) Denmark. New initiatives was needed to lift the planlaw and the nature protection law, into a modern planning and development paradigm (Regeringen, 2016). The former planlaw restrictions and regulations was said to make development projects difficult, and processing of cases was referred to as bureaucratic and slow. Especially the physical planning in the near coast zone and in the smaller cities located on the coast obstructed local and regional development. (Regeringen, 2016) In the agreement, 6 major points for promoting economic development (especially in the near coast zone and rural areas) were agreed upon (Regeringen, 2016) and implemented on the 15th of June 2017 when the planlaw and the nature protection law went through several restructurings (Folketinget, 2017). The law changes also implemented that the coastal protection law should be updated.

2.1 The planlaw

The law on planning – from here on referred to as the planlaw is currently placed under the ministry of trade, and is the basis of ensuring a coherent planning throughout all of Denmark, whether it is in the cities, the Capital, the rural area, etc. The planlaw makes up an overall planning structure to ensure a cohesive and predictable quality planning in all of Denmark, while both undertaking the interest of the nature and environment, human living standards as well as the possibilities for economic development in all of Denmark. (Erhvervsstyrelsen, 2018)

The near coastal zone – This administrative zone is regulated by the planlaw and defined from the shoreline (Land/water boundary) and 3 kilometers inland. Only specified areas can be utilized for buildings, terrain change, recreation, etc. by municipalities if a "developmental area" is created within the zone. Building within this zone is forbidden except for planned areas such as City/habour zones and development zones. It is not allowed to plan anything else within the 3km range unless it has a necessary connection to the coast, and this does not include laying down new summer house areas. (Erhvervsstyrelsen, 2018) The changes of the planlaw also created a possibility to apply for a relocation of unexploited summerhouse areas within the near coast zone, and existing summerhouse areas can also be transferred to "cities" which opens up a whole new planning aspect since the refence in the planlaw then changes to city planning. (Erhvervsministeriet, 2017)

2.2 Nature Protection law

The Nature protection law is instated to ensure preservation of nature and environment, so that the development of society is happening in a sustainable way with respect to the conditions of life, and to preservation of plant- and wildlife. (Miljø- og fødevarerministeriet C, 2017)

Areas under §3

The nature protection law preserves different nature areas an specifically protects 7 threatened nature types: lakes, bogs, insipid meadow, beach meadows, heaths, pasture and streams/creeks. These preservations are not to be mistaken with conservation areas since a preservation area under the §3 act can be altered if permission is given from the municipality and a land owner can even get permission to build on it if he/she designates another area of the same size as the original §3 area or if the state of the area is not negatively affected. (Miljøstyrelsen, 2018)

Beach protection line

This line is regulated from the nature protection law and is a prohibition zone located 300 meters from the beginning of cohesive vegetation (see §69a stk. 3 in the law on nature protection (Miljø- og fødevarerministeriet C, 2017)), though only 100meters in summerhouse areas and is comparable with the dune preservation line.

Dune preservation line"

This line is regulates a prohibition zone, and is 300 meters from the shoreline, though only 100 meters in summer house areas. It is often extended into preservation areas as there are inland dunes in Denmark which is also preserved under this prohibition zone.

An international conservation area is also protected. Natura2000 areas, has special restriction and nature management requirements in place to ensure a correct handling and conservation of the natural state. Rubjerg Knude and Lønstrup cliffs (Natura2000 area number 7 in Denmark (Hjoerring Kommune A, 2016) are one example and is only few kilometers north of the case area for the UAV flight. This international conservation act refers to bird habitats, nature areas and wetland (RAMSAR) areas, and it is a national obligation to ensure that NATURA2000 areas are preserved with a strategic plan of action in the distinct areas. (Miljøstyrelsen, 2018)

2.3 Coastal Protection Law

The coastal protection law is in place to ensure that the physical state of the coastal stretches is not changed without permission – This is e.g. installation of structures, changing the natural state, bypass of sand, installations in near coast sea-territories, etc. (Miljø- og fødevareministeriet B, 2017) The coastal protection law is regulating beaches and coastal stretches without continuous vegetation as well as areas up to 100 meters inland from where the vegetation cover starts – this is c.f. §16 in (Miljø- og fødevareministeriet B, 2017). The coastal protection law handles changes within the regulated zone, such as landscape changes, dredging and especially coastal protection installations, which needs to be approved before it can be installed. As it is the law mostly in focus in this report a more detailed description is required:

The first law on coastal restriction was already set in 1922 in the law "Coastal protection installations" (law nr. 235 from 12th of June 1922) and in 1937 a 100m nature "preservation zone" was set in the law about nature preservations (law 140 of the 7th of may 1937) to ensure that there were no unregulated changes made which could disturb the natural state of the landscape and also to ensure that no installations would obstruct the free and open beach. In 1969 a 100 meters preservation zone from the beach and inland was passed which prohibited any kind of terrain altering and/or buildings within this zone. (Kystdirektoratet A, 2018)

The coastal protection law was instated in 1988, and has been changed 4 times since then:

1. In 1994 it was added that considerations regarding nature protection was included in the coastal protection law when installations referred to several estates
2. In 2006 a purpose regulation was installed in the form of different balanced considerations needed before a coastal installation could be permitted. A clarification of the law conditions and regulations was also made.
3. In 2016 a simplification of the municipality processing in coastal matters was instated.
4. In January 2018, the purpose of the law, and the general processing of cases have been changed. The changes will be presented in chapter 1.3.1
5. An additional law change is expected to be implemented on the 1st of September 2018 which is presented in chapter 1.3.2

2.3.1 Law change January 2018

On the 23th of January 2018, changes were made in the coastal protection law. They presented a different approach to what type of coastal protection can be permitted and what requirements is needed for getting a permission. (Miljø- og fødevareministeriet A, 2018). The main changes from the law change in January 2018 is presented in the following.

The purpose of the law has been changed slightly, but it is basically the same statement, so no big changes there. Larger changes are though seen in the considerations under the purpose. The numbered elements underneath is describing the 6 considerations that needs to be undertaken when handling an application for coastal protection. They have been narrowed from 8 points to 6 in the law change from January 2018 (Miljø- og fødevareministeriet A, 2018). The main changes will be described here and will be described from the new teaching resource (Miljø- og fødevareministeriet E, 2018) published for the municipalities by the DCA, and the remarks from the law proposal (Miljø- og fødevareministeriet F, 2017). In the following the numbering present the titles of the actual considerations and underneath a description on what has changed.

1. **The need for coastal protection**

Before the law change it was a requirement for getting a permission that there, within a foreseeable future (20-25years) could be expected negative consequences for structures or humans. This requirement is no longer in affect so if negative consequence can be expected, no regards to when is needed for getting a permission. And "what" can be protected then? Before it was mainly humans and structures, while the new law focuses on both, gardens, football pitches, sheds, infrastructure, etc. Therefore the "protection of property" is now a very wide definition. If an approval is given, it was a requirement before that the structure should be able to withstand and protect against a 50-years event – This Is no longer a requirement, but it is though advised.

2. **Economic considerations in projects under chapter 1a**

Before the law change, the expense from protecting needed to be counterbalanced by the value of the protected. This is no longer a requirement, so private applicants can pay as much as they want for as much protection as they like. This is not the case for chapter 1a cases which is "municipal common projects of coastal protection" – the changes in the consideration now implies that economic considerations is needed for these larger projects with the municipalities as entrepreneurs. This is connected to the municipalities abilities to impose payment for the installations from the landowners that are protected or in other way are drawing advantage from the installation cf. §9a in the coastal protection law. Therefor the common projects are not allowed to "over protect" or pay unreasonable amounts for low value installations.

3. **The coastal protections technical as well as nature and environmental quality**

This 3rd considerations incorporate the old sections 3, 4 and 5 in one (Miljø- og fødevareministeriet F, 2017). Before the natural system was not allowed to be obstructed and the coastal landscapes preservation and reestablishment was in focus. It still is, to some extent at least. Before the use of hard structures such as groins, revetments, breakers etc. was mainly prohibited, the new law opens for "freedom of method". It is though implied that the installation must be relevant and functioning in the coastal landscape in which It is install, but when multiple choices are available, the landowners have freedom to pick their desired solution. It is a requirement that it is not causing negative effects at the neighbors stretch and there can be set a requirement of additional nourishment. And it is also a requirement to evaluate the natural quality of the structures, as the coastal landscape presents valuable nature interest – it is also valued that the structures are tidy and that the beach keeps being nice. (Miljø- og fødevareministeriet E, 2018)

4. **Recreational utilization of the coast**

This section touches on the possibility to establish new beaches and preservation of existing. The coastal protections installations impact on the beach stretches must therefore also be evaluated. (Miljø- og fødevareministeriet E, 2018)

5. **Protection of the existing access too and along the coast**

As the beaches is common grounds for Danes, the access cannot be obstructed according to §22 section 4. (Miljø- og fødevareministeriet C, 2017) it is therefore required that free passage on the beach is not obstructed, nor over time. Access was cannot either be blocked. This must be a part of the technical design.

6. **Other things**

This is simply referring to the implementation of other laws.

Another interesting change from the beginning of 2018 is the new undersections to §16 where stk. 4 and stk. 5 have been added. These sections gives mentions new and experimental coastal protection which can be allowed in test periods to investigate influence and effect in real coastal conditions. The permit can be given from the Environment – and food minister if the projects are supposed to hinder flooding's or coastal erosion. (Miljø- og fødevareministeriet A, 2018)

As already presented there is an additional, law change in hearing in the parliament, and it is expected to be implemented from the 1st of September 2018.

2.3.2 Law Change from 1st of September 2018

This is where the main changes to the coastal protection law shall be found and one major change will be the change of hands over responsibility for applications of coastal protection cases. The possible law change presents a comprehensive change of the whole law on coastal protection. If the law proposal is voted through the authority on coastal protection matters will be decentralized from the DCA to the municipalities. The DCA will no longer be linked to the process of giving permits regarding private coastal protection, their role will solely be to give a technical statement on the project within 4 weeks. This statement on the installation quality can though be disregarded by the municipality. This is with the exceptions: when the "state" is entrepreneur and in the case of the common agreement on the central part of the west coast. (Miljø- og fødevarerministeriet D, 2018)

This law proposal is a general conceptual change made to ensure a shorter and less bureaucratic process when applying for permission to install coastal protections. The new law will also ensure that when a permission is given, it also means that dispensations from other laws will been included in that permission. The ministry has named it a "one-stop-shop" as it is stated in the remarks to the new law proposal. (Miljø- og fødevarerministeriet D, 2018) This law change will most likely be implemented since it has already been agreed upon from different parties in the parliament from the "Denmark in a better balance" agreement, and the DCA has already established a mobile coastal unit to assist the municipalities, initiated a course on coastal administration for the municipality planners and made documents on how the handling of cases referring to the new "Coastal protection law" (Kystdirektoratet A, 2018).

2.4 Summary of Interview with Lise Holm

To get firsthand knowledge on how the municipalities construct their coastal protection, an expert interview with Lise Holm – "Project manager" on "The future of the north shore" – from Gribskov Municipality was conducted on the 08th of May 2018 at 14:30. The interview was constructed as a semi-structured interview where the interviewer follows a preexisting interview guideline with specified questions, but still is able to ask "to depth" questions during the interview (Longhurst, 2010). As the Zealand north shore project is a large-scale project planned for a 60km stretch with 3 municipalities as developers, it was especially interesting to gain knowledge on which administrative-, stake holder- and design challenges there has been during the project and what solutions have been used. Additionally, it was also of interest to gain insight in how the law changes will affect the project and how (if any), monitoring of coastal installations have been conducted until now and if there is a possible use for it in the future. The following will be a short sum up of the interview while the interview guide and a full transcription in Danish can be found in appendix F.

The North shore project.

The project on the northern coast of Zealand is planned to be done for a 60km stretch, where 7 to 9 beach stretches will be nourished with a total of 10 million m3 of sand for a complete protection of the north shore. No hard structures are to be implemented, but the project suggest places where hard structures can be implemented, but it will be the responsibility of the ground owners to initiate application, plan, design and finance for these structures.

An authority challenge has been that it in general is a new form of application to the environmental administration as it is rare to have multiple developers and even more rare that they are municipalities. The coastal protection law is an upcoming challenge as it is under strong reconstruction and an administration change from DCA to municipality is excepted. These challenges have been met with close dialogue trying to avoid mistakes in the various application processes, ensuring correct procedures and less wasted time.

A challenge is also found with the multiple stake holders in the project, namely the ground owners that is included in the project stretch and will be obligated to pay. There is general interest in the project, but it is both found as negative and positive interests. Some are not convinced that beach nourishment is a correct method as they simply don't believe in it. Others believe beach nourishment is fine, but the payment should be coming from the state or municipalities. It is a continuous process to keep a very close dialogue with the stake holders, so they are not surprised by newly instated elements – especially when implementation of a payment plans for the near coast ground owners is started. This is expected to create a lot of complaints and frustration among the ground owners.

The new law and future administration

Even though Lise Holm is not directly in contact with the handling of cases her impression is that many ground owners are excited about the shift of competencies from DCA to the municipality and some has already applied for their applications to be handled by the municipality even though it is not implemented yet. A qualified guess from Lise Holm to why this has been received positively, is that the DCA is very far away, and with the new law the competencies moves much closer while a more flexible law with the prospect of allowance for installation of coastal protection has been eased. The law changes is according to Lise Holm not necessarily making their project easier as are thought to be confirming doubters in their beliefs on coastal protection, as they now can protect with just stones, while the supports will most likely like that both stones and sand can be implemented. But the law changes will not change the coastal technical design of the North shore project, so it will still only implement the nourishment.

Currently monitoring of coastal installations are only applied for stretches where the municipality is the ground owner or if an illegal circumstance is reported. But Lise Holm expresses interest in coastal monitoring and modelling using UAV based methods as it is an interesting aspect, also for the North shore project. The timespan for the project is 50 years and it is a requirement to document when the nourishments are made, how they develop and ensuring an optimized nourishment effect by applying additional nourishments in the right time. Currently they are also trying to develop a less expensive (compared to e.g.. costly LiDAR scans) method for monitoring and optimization of nourishments and maintenance.

3. Considerations of preliminary study

The new and expected law changes to the coastal protection law, with freedom of method and a simplified application and permission process, could lead to several new structures being implemented on the beaches and in the shallow waters. Even though hard coastal protection structures are to be allowed under the coastal protection law §1 sect. 3 (also without additional nourishment) but with Leeside, beach and wet profile erosion being known responses to implementation of hard costal structures it must be difficult to get the permission without additional nourishments, since no negative effects can take place at the neighbor stretch. This is not the case for stretches where multiple hard structures is already present, as new can be allowed without compensating initiatives:

"The purpose of the coastal protection law is changed so hard coastal protection installations without compensating sand nourishment on stretches that already is intensively protected by hard structures is enhanced" Directly translated from (MVFM, 2017)

As a rule of thumb, it is the ground owner themselves who is obligated to pay for the protection of their own property. The municipality or state cannot be held responsible in money issues on the small-scale projects unless the state is the developer of the project making them responsible for financing. The role of payment in erosion protection is mentioned by Lise Holm during the interview as a future challenge for the project on the Zealand north shore, and the reason for this is that the large-scale projects stretching beyond the small scale private installations into common projects, can provide protection of economic advantages for the ground owners and can be imposed payment from the municipality. The municipalities are obligated to pay for the initial consultant bills and planning (Miljø- og fødevarerministeriet D, 2018).

More installations like the sleeping defenses seen in both Noerlev (Kystdirektoratet C, 2016) and Loekken (Kystdirektoratet B, 2015) could possibly be expected in the near future since there seems to be interest in adding hard coastal protection privately in addition to the common large-scale nourishment project on the north shore of Zealand. If this is the case it is interesting to take note of the requirements for the allowance of installations in Loekken and Noerlev as they are required to report the quantities of the nourishment volumes added according to the permits (Kystdirektoratet B, 2015); (Kystdirektoratet C, 2016). High resolution transect have also been made for every 25m along the sleeping defenses from top of the old dune to -0,5 meters in the profile, on 3 to 4 occasions which has been used for quantification of volumes and estimation of volume changes over time.

As reporting of the nourished quantities, reporting of development and possible side effects are all elements that would be possible to measure with high temporal and spatial resolution using UAVs, there seems to be grounds for a test of the method in coastal monitoring for change detection.

3.1 Problem statement and research design

Continuous monitoring with differential GPS and reporting of nourishment quantities is implemented for the 2 test sites with transect measurement, and reporting of effects of future large-scale new coastal protections are necessary. This combined with the possibilities of more coastal erosion protection in Denmark there could be a need for cost-effective monitoring tool for future coastal management. And even though it is not required for the municipalities to inspect private installation, they are still required to act if a complaint is handed in. As the UAV based monitoring approach present a possible cost-efficient and detailed method for deriving both DEMs and orthophotos with high temporal and spatial resolution, which, as it will show, has also been implemented in other studies with satisfying and high-quality results, it is considered a possible monitoring approach for implementation in the Danish coastal zone management.

All together this builds the base for moving forward with the UAV approach for coastal monitoring and therefor the problem statement is as follows:

How can the use of Orthophotos and DEMs derived from UAV imagery be useful in coastal management and what model requirements should be fulfilled?

Instead of using research question a presentation of the desired research design is presented here:

Firstly, it is necessary to gain insight in the technicalities of traditional Orthophoto mapping and DEM creations on a national level as this will be the only available source for comparison between periods. The usages of a UAV photogrammetric approach and methods from other studies is also presented from a short literary study. The field trip campaign is presented together with an area description and the workflow for creation of an Orthophoto and DEM from automated photogrammetry software AgiSoft. The results are presented and evaluated from statistical test validating the model to desired precision set to be at least the same as for the national models and improvements of the models are discussed. The Derived DEM and Orthophoto is then applied to a real case study in a coastal analysis of the case area together with traditional geographical methods, to determine the retreat or advance in a coastal stretch, and for comparison between methods. It is finally summarized in a discussion on the advantages and disadvantages of the UAV approach, model quality and possible coastal monitoring applications. All necessary equipment, software and considerations and methodological approach is presented in the chapters.

4. National DEMs and orthophotos

The national Digital Elevation Model (DEM) is a digital surface layer build from true 3D point measurement which describes the surface in real world conditions. Light detection and ranging (LiDAR) is a well-known and highly precise way to construct the dense point cloud measurements that is needed for the construction of DEM models for surface terrains. The individual points are constructed by reflecting light waves from a mirror in a laser scanner towards an object, which reflects the light wave back again. The laser scanner detects the time used for the light wave to travel to the surface and back to the scanner. Using both time, position and angling of mirror makes it possible to define a 3D position for the point. This is done thousands of times pr. second and the scanner can be mounted on an airplane. As the airplane and scanner are both equipped with internal registration of both position, yaw and tilt the georeferenced position of the 3d points are measured with high accuracy. (Balstrøm, Jacobi, & Bodum, 2013) The 3D point cloud is then used for interpolation in a grid with specified cell sizes. The National Danish DEM at least 4 points are used in each grid or cell for height definition (KMS / Geografisk Infrastruktur, 2012).

In Denmark, National DEM models have been constructed for the whole country in both 2007 and 2014. Several bi-products such as DSM (Digital Surface Model), DTM (Digital Terrain Model) and climate change adaptive models are types of DEMs available free of use from www.Kortforsyningen.dk. These DEMs have been constructed from point clouds measured with LiDAR. They are used for investigation of climate adaption, volume calculation, military defense etc. the DSM is also used for Coastal protection and monitoring (SDFE, 2016). There are many different processing tools used for correction of the DEM models such as smoothening, creation terrain models, removal of unwanted elements, point cloud compares etc. which can be used for optimization of models or production of different types of DEMs.

The precision requirements for the original DEM is seen in the table below, and it is estimated that the accuracy of the DEM derived from UAV imagery must fulfill the same criterions.

Year\quality control	Vertical precision **Required**	Vertical precision **Measured**	Horizontal Precision **Required**	Horizontal Precision **Measured**	Resolution (Grid Size)
DEM2014	0,05 m	0,05 m	0,15 m	0,15 m	0,4 m
DEM2007	0,1 m	0,06 m	1,0 m	0,67 m	1,6 m

(KMS / Geografisk Infrastruktur, 2012) og (SDFE, 2016)

The method for creating an orthophoto has been specified in the publication "Specifications for ortophotos" (Geoforum, 2011). The Ortophotos made today is constructed from aerial photography, georeferenced and orthorectified. To account for the distortion in the cameras, the images is taken with a lengthwise overlap of 60% and a sidewise overlap of 20% making point recognition possible from stereo view. The national orthophotos are created by following these 6 steps

1. Flight photography
2. Aero triangulation
3. Establishment of a DEM (or use an existing)
4. Produces orthophoto from central projection flight photos
5. Collecting all orthophotos into one or more mosaics
6. Colour adjustment – Since the images of the whole country is not made on the same day.

When a photo is taken from a camera the image is perspective and central projected. The center point in the image is the precise point where the view from above is perpendicular on the image, while everything around the center point is seen slightly from an angle. A correction of the perspective photo to an orthogonal projection is possible if it is georeferenced in a coordinate projection from well-defined positions. Steep terrain presents challenges to traditional stereo view created orthophotos. The flying height is often constant there will be a ground sampling mismatch between low lying areas and higher grounds. Therefore, a DEM model is used for correction of the orthorectified photos, so terrain slopes is correlated for the final mosaics (Balstrøm, Jacobi, & Bodum, 2013). Knowledge on the outer orientation of the aircraft and camera is used for efficient positioning and angling of camera. The orientation and position are necessary to interpret the relationship in the photos when connecting them. In a manual process of aero triangulation at least 1 point must be found in 3 or more photos, and at least 3 Ground Sampling point must exist in each photo – the point position is found from the "least square method" based on the knowledge on the position 4 other points which is then used to determine the position of another point. (Balstrøm, Jacobi, & Bodum, 2013)

4.1 Implementation of UAV monitoring in coastal studies

Monitoring coastal environments from UAVs is considered to be a relatively new approach to the authors knowledge. But is already being implemented in various types of studies. Photogrammetry (the science of measuring in photos) based on Structure from motion (SfM) in several highly detailed environments have been performed in studies such as (M.J. Westoby et. all, 2012) where only terrestrial photos are used, while others implement the use of UAVs in highly detailed and remote areas as in (Jaud & Passot et. all, 2016) and (Cook, 2016). The usages of DEMs and orthophotos derived from UAV imagery has also been found in coastal studies (Gonçalves & Henriques, 2015); (Brunier et. all., 2016) and in coastal dune studies (Gonçalves, Pérez, & João, 2018); (Ruessink, Arens, Kuipers, & Donker, 2017). All detailed studies applies the use of computational SfM photogrammetric software's for construction of DEMs and Orthophotos to illustrate how UAV imagery can be utilized in various landscapes analysis. They also include to detail described precision measures for the models derived. Vertical precision of models made in dunes was estimated with RMSE 0,04m for the Ground control points (GCP) used for model orientation while individual RTK-GPS measurements reveald RMSE up to 0,1m in (Ruessink, Arens, Kuipers, & Donker, 2017). Vertical precisson inside the reference in (Gonçalves & Henriques, 2015) was found to have RMSE from 0,035m to 0,05cm for what they referee to as ICP (Independent Control Points) and planimetric RMSE was found to be 0,025m. Both (Ruessink, Arens, Kuipers, & Donker, 2017) and (Gonçalves & Henriques, 2015) used AgiSoft Photoscan which revealed high quality and precision. Other freely available software can be implemented to compare results with results from the commercial photogrammetry software such as it is made between MicMac and AgiSoft in (Jaud & Passot et. all, 2016). As there exist many open source software's (Cook, 2016) the assessment of quality difference is of course interesting but not further described as this has been left out of the present report. A disadvantage regarding the software is post fieldtrip processing time as it is heavy and evaluated to be between 7 and 56 hours depending on the data quality and area size in (M.J. Westoby et. all, 2012) but it is also proven to be a low-coast efficient tool for change detection in coastal environments (Ruessink, Arens, Kuipers, & Donker, 2017). There are very different quality assessments within the different studies, but the RMSE is generally used to describe both horizontal and vertical errors while (Höhle & Höhle, 2009) presents more extensive statistical measures to ensure the model quality is satisfying and statistically strong. Various approaches are used and (Ruessink, Arens, Kuipers, & Donker, 2017) base their DEM quality on the AgiSoft statistical report together with testing the model quality with several other sporadic dGPS point measurements made for evaluation of elevation difference found from dGPS and DEM elevations. In (Jaud & Passot et. all, 2016) the horizontal and vertical accuracy is evaluated from the RMSE from the statistical report on the GCPs but also from Ground Truth reference Points measured with dGPS in a well-defined point on a blue target plate. The horizontal error is found as a distance between Ground truth and the corresponding target plate position in the DEM/orthomosaic model, but the vertical difference is found as the elevation difference between: height found in the ground truth reference point in the model and the height found from the dGPS measurement in the same point – so even though there is slight horizontal distortion in the model, the height is still evaluated in the exact same point (Jaud & Passot et. all, 2016). The RMSE as evaluated as a good measure for the general errors found in the models, but is it also assessed that further statistical analysis should be supporting the models (Höhle & Höhle, 2009). Accuracy assessment of DEMs should bear the "fit for purpose" approach in mind as well as the pixel size and GSD which limits the precision of measurements. Instruments made for ground truth RTK-GPS position also has an error of up to 2cm. In (Gonçalves & Henriques, 2015) it is argued that since it is smaller than the photogrammetric model accuracy the error of the RTK-GPS contributes to the overall error of the model. As there are several studies implementing the UAV and photogrammetric approach to highly detailed, coastal and inland areas, it is difficult to evaluate which is better. The approach used for image acquisition, modelling results and statistical tests are presented in chapter 5 and 6. Most of the studies also include a section on how to optimize the photogrammetric process and thereby also the model quality. Photogrammetric software uses an automated bundle adjustment algorithm (Brunier et. all., 2016) which identifies tie-points and object recognition throughout the images and when several images are taken with certain overlaps, these tie-point can be re-identified and positioned in a sparse 3D point cloud. As the model depends solely on unique feature detection in the images the quality and focus must be insured (James, Robsonb, & et. all., 2016) while it is recommended to use as low ISO as possible for the images (Agisoft, 2018). It is recommended in general to document the precision of the models produced, both using Automated software report on the RMSE (James, Robsonb, & et. all., 2016) and in general, also from independent test measurements (Brunier et. all., 2016) and (Gonçalves & Henriques, 2015). For optimization of the photogrammetric process, knowledge on the camera sensor and orientation of sensor used for acquiring photos is of great influence on the process. Image size, Focal length and the height above surface must be considered as factors affecting both the image quality and the Ground sampling distance (GSD). It might seem obvious that the higher up the lower detail will be found in the photos – but by applying GSD formula makes it is possible to specify the average size of the image pixel on the ground in relation to the flying height. One way to estimate the average GSD is

$$GSD = \frac{H(m)}{f(m)} * \frac{Sensor\ Height\ (m)}{image\ Height\ (pix)}$$

Where H is averaged Flight height (mm), f is Focal length (mm) (Gonçalves & Henriques, 2015). While the technical descriptions for orthophotos in Denmark uses the same formula, it is presented differently:

$$GSD = (pel') * h/c$$

Where h is flying height above terrain, c is the focal Length and (pel') is the pixel size in the CCD chip found as $sensor\ height\ (mm)/image\ height(pixel)$ (Geoforum, 2011).

The GSD is a factor when estimating the accuracy of measurements in the orthophotos. As a general rule, the pixel size in the finished orthophoto should not be smaller than the GSD, and the measurement accuracy cannot be expected to be higher than GSD (GeoDanmark, 2014).

5. Data acquisition and Workflow

Using orthophots and DEMs for change detection in terrain and volume for investigation on the coastal development of the dry part of an erosive coast can possibly be utilized for future monitoring effect and development of Coastal protection programs. A focus on describing model quality and implementations in coastal erosion studies is applied but the case area needs to be presented before the methodological approach can be presented.

5.1 Noerre lyngby

Nr Lyngby is a smaller village, mostly consistent of summer house, on the northwestern part of the Danish west coast, presented in Figure 4.1. An application for biological revetment in combination with additional sand nourishment is currently being processed at the DCA. The installation is supposed to be in extension of a hard revetment structure which is initialized by the municipality on the northern side of the access road to the beach.

Figure 4.1 – The area of interest is presented and the position of it is depicted in the underlying topographic map for northern Jutland. The map is produced by the author in ArcMap under license of Aalborg university.

It is an interesting area to use for a 3D modelling approach as it presents a relatively wide sandy beach with a highly detailed active clay cliff facing the ocean. The complexity is interesting as the feature recognition in the software needs to be highly precise to detect these details. It therefore presents an ideal area for testing the UAV measurement approach. There is also the fact that the coastal protection project is expected to be realized, therefor the measurements can serve as a baseline study of the stretch before installation for future studies in the area.

5.2 Geological description

The need for protection of property is clearly seen in Nr. Lyngby as the distance between the cliff edge and the houses lying in the hinterland is narrowing. Several houses are close to the cliff edge and some houses, as well as a part of the old cemetery, has already fallen onto the beach.

The soft moraine cliffs are highly consistent of clay. It is though interesting that the beach is sandy, but a couple of meters out into the wet profile the bottom consists of clay. Although there might be sand in some of the cliff layers, a hypothesis is that most of the sand on the beach is washed up here from the longshore transport.

The Danish landscape is primarily made up of soft unconsolidated sedimentary material, accumulated on old sea bottom that has been pushed around, up and down and eroded by the ice sheets in the iceage Saale and Weichsel. The coastal stretches have in the time after the last iceage been affected by fluvial and aeolich dynamics as well as regression and transgression which has shaped the coasts we see today. (Sand-Jensen et. all., 2012)

In Noerre Lyngby the composition of the layers in the cliff is well known, especially from the "Skærumhede series" which consist of clay 100 meters of marine deposited layers, deposited over 100.000 years (Sand-Jensen et. all., 2012) and is laying just on top of the chalk layers, which is approx. 80 meters beneath the surface in nr. Lyngby (Pedersen et. all., 2016). The skærumhede series is also found in Nr Lyngby, where only the approx. 16m of the top is seen as the cliff face – the layers are mostly consistent of clayey muddy layers, and sandy muddy layers (Pedersen et. all., 2016). All layers are not easily detected since there are landslides covering the bottom of the slopes, but some of the top layers is visible as seen in Figure 5.2.

The layers seen are still found in a horizontal position, but just a couple of kilometers north of the stretch many of the layers are found to be almost vertically layered. The last iceage "Weichsel" begun around 117.000 years ago and ended in 11.700 years ago - Throughout that time, large sections of ice sheets crossed this area while pushing up the bottom layers below creating deformation of the soil layers. Due to climatic changes the ice sheets retracted and shifts between heat- and cold periods have changed the outline of the dry land many times due to rising and falling sea levels. As the ice sheets applied high pressure on the layers beneath it, a rebound process (glacio-isostatic rebound) has meant that the landmass formerly pushed down is raising. (Pedersen et. all., 2016)

During the period of the Yoldia ocean, 15.000 years ago, a transgression (relative waterlevel raise) meant most of northern Jutland was covered by arctic sea and there were only few islets present in the area – the top 10 meters of the skærumhede series was deposited in this period and consists of

Figure 5.2 – Private photo taken on the northern side of the access road to Nr. Lyngby beach. Notice the vertical layers in the cliff sides.

muddy clay with sand. As the eustatic water level raise was overhauled by the isostatic rebound in the landscape, a regression (relative land raise) approx. 11.000 years ago made most of northern Jutland dray land. (Pedersen et. all., 2016). But as the sea level rose once again a transgression meant that some areas were flooded by an ocean referred to as the Littorina ocean. A large fjord from just north of Loekken and inland was created in this period. The following regression is seen today as the northern Jutland is again dry land, but the position of the shoreline and cliff edge position has been retreating in this period (Pedersen et. all., 2016). When the area at Nr. Lyngby erodes it is an irreversible positional change as the sedimentary layers cannot be reestablished within a few seasons.

5.3 Field Trips to Nr. Lyngby

The coastal stretch in Nr. Lyngby was visited 4 times during the thesis period.

- The 24th of February

A meeting with the ground owners whom applied for the erosive coastal protection, was setup so an initial idea of the project could be established. It was also to gain insight in who was responsible for the application, and how they had come to an agreement on financing. The meeting has not been documented as it was an initial meeting. But a concern from the ground owners was that there are only a handful ground owners involved and the project while the once in the near hinterland was not interested in participating in the project. The main ground owners association were at that time debating the possibility to extend the initial application for 150m of protection with an additional kilometer, covering the whole area with houses close to the sea. It was regarded as very difficult to come to an agreement in the association as payment structure seemed impossible to agree upon, doubt on the protective effect and some refused to even participate.

- The 14th of march a second field trip was conducted to acquire images for 3D modeling.

The field trip was conducted together with the project supervisor and co-supervisor with the purpose of acquiring imagery for an initial modelling attempt. The UAV flight was conducted with a DJI Phantom 3 drone carrying a Go Pro hero 3 black edition ultra-wide-angle camera. The results of the modelling process were of such low quality that it has not been included in the report – this is not due to the equipment, but to the quality of the images acquired. This did though lead to an extra check of imagery acquired before leaving the study site, which was implemented for the next 2 field trips.

5.3.1 Methodological approach for reference points and Image acquisition

The software used for 3D reconstruction, DEM and Orthophoto production is the commercial software Agisoft Photoscan licensed under AAU. As it is a requirement to use at least 10 Ground Control points (GCP) for scene reconstruction and most optimized georeferencing in agisoft (Agisoft, 2018) It was decided to use 11 Ground Control Points (GCP) for the area made as white plastic squares with a black cross made from duct tape.

Additionally, 9 Ground Truth Points (GTP) made as blue plastic squares with a black cross made from duct tape, was added within the survey area, which was not used for georeferencing but for horizontal precision estimation of orthophoto and DEM.

Additionally, Sporadic point measurements (SPM) of the beach and the cliff was conducted with dGPS to estimate the elevation precision

The GCPs and GTPs was distributed over the area and the dGPS positions was measured with differential GPS (dGPS) with a vertical and horizontal accuracy set to 0,02m. As soon as they were placed the drone flight was initiated first flying in strips along the cliff to collect plan view overlapping images. After the flight acquiring plan view photos were ended, another flight was initiated to collect 45◦ angled photos along the beach and cliff. As the field trip on the 14th of march revealed such low-quality results, it was decided to self-invest in a DJI Mavic Pro for image acquisition. The DJI Mavic pro uses a 1/2,3 CMOS sensor with the following dimensions:

Focal length	4,73mm
Sensor size (1/2,3 CMOS) (W x H)	6.17 mm x 4.55 mm
Image quality	12 MP with 4000 X 3000 pixels

The overall workload is estimated to 3 hours from survey start to end. This is with a single person approach and includes flight planning before dGPS measurement start.

Two field trips with the DJI mavic Pro was conducted, first time on the 19th of April and second time on the 14th of May. All requirements according to the “drone law” (Transport-, 2017) was meet and permission to fly above houses was provided prior to flight from the ground owners in Nr. Lyngby. The image acquisition was slightly different between the two field trips, described in the following:

5.3.2 The 19th of April 2018 - Field trip, approach and Image acquisition

The drone was flown manually with an approximated altitude of 30 meters above terrain. Lengthwise and sidewise overlaps of images is uncertain since flight speed was not constant trough out the flight. The camera was set to time lapse of 5 seconds with 12MP JPEG images. The finished flight provided 123 high quality RAW images used for processing in AgiSoft. Sporadic point measurements of the beach were conducted in the end of the flight and 123 dGPS measurements was made.

With a flying height of 30m the GSD is found to be

$$GSD = \frac{30m}{0{,}00473m} * \frac{0{,}00617m}{4000\ pix} = 0{,}009m$$

As the drone ran low on battery, before the 45◦ angled photos where taken, battery charging was necessary which resulted in tampering with at least on GCP, which can have interfered with the result. It was not noted in the final result but it can have set the model slightly of.

5.3.3 The 14th of may 2018 - Field trip, approach and Image acquisition

The second field trip was made with a more constructive approach. This time a flight plan was made using the “DJI mavic pros” intelligent flight mode “waypoint mission” and the altitude was set to 75m above the beach. The side overlap cannot be automatically set so at least 20% was visually estimated when setting the end-waypoints. After the flight plan was finished the drone returned to the gear station and the targets squares was placed.

This time the photos was acquired in RAW+JPEG so the minimal time lapse sequence was only possible at every 10th second. It has already been decided that the flight overlaps must be 20% sidewise, and the lengthwise must be 60%. To ensure the lengthwise 60% overlap, the GSD was used to estimate the flying speed so that the photos was acquired with a 60% overlap lengthwise.

With a flying height of 75m the GSD is found to be

$$GSD = \frac{75m}{0{,}00473m} * \frac{0{,}00617m}{4000\ pix} = 0{,}025m$$

Knowing that every pixel is approx. 2,5cm X 2,5cm makes it possible to estimate the length of one photo on the ground as the height of the image multiplied by the GSD:

$$3000 \text{ pixels X } 0{,}025\text{cm} = 75\text{m}$$

Acquiring a 60% overlap would mean that the drone were not allowed to fly more than 40% of the image length meaning 40% of 75m = 30m. Knowing that 10 seconds is required between the images, it means that the speed must be set no higher then 3m/s. to ensure the 60% overlap. The flying speed was set to 2m/s, which should provide more than the minimum requirement of 60% overlap of images lengthwise – an illustration of the flight path is seen in Figure 5.3. Again, 45degree photos was acquired of the beach and cliffs. Two flight strips with waypoint mission was set with an altitude of 75 meters. 92 images were acquired in total for processing.

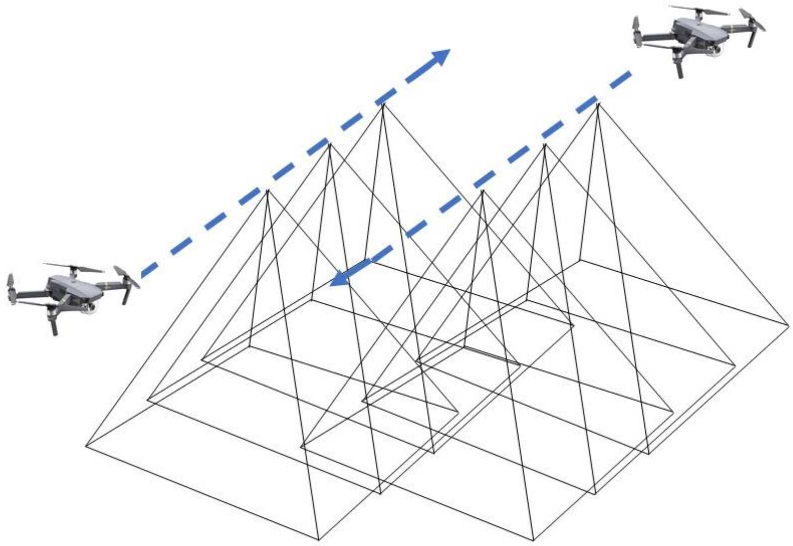


Figure 5.3 – illustration of timelaps photo acquisition along pre-determined flightplan. The model is not to scale, and is produced with inspiration from (Balstrøm, Jacobi, & Bodum, 2013)

Sporadic point measurements of the beach were conducted in the end of the flight and 60 dGPS measurements was made before the GPS broke down – this was just enough to cover the beach and cliffs, and as it will be mentioned in the statistical tests, additional sporadic measurements from the 19th of April was added to this data set.

5.4 Photogrammetry Workflow

In the following the commercial software agisoft is used for construction of a 3D model, DEM and Orthomosaic. There are several other softwares which are open source, on the market which can be used for producing the same products, (VisualSfM, Bundler, MicMac, MeshLAB etc.). As Agisoft already is licensed for AAU, while proved to produce high quality model while is an easy to handle and semi-automated tool (Brunier et. all., 2016); (Gonçalves & Henriques, 2015); (Ruessink, Arens, Kuipers, & Donker, 2017) it has been preferred. The workflow for creation of 3D model, DEM and Orthophoto is shown in the process seen in Figure 5.4. The steps, when using other software is almost identical, but further processing is though needed.

The processing of the models has been conducted on the Authors computer which uses an Intel Core i3-3217U CPU 1,80 GHz with internal 6GB RAM while the GPU could not be used in AgiSoft.

The processing in agisoft is highly automated and very well described in (Brunier et. all., 2016), but the model still needs to be optimized via manually deleting of unwanted elements such as spikes or noise from the depth filtering. As the surface of the swash zone is wet and changing in reflection and surface during the flight it will create noise in the depth tie-point creation in the images, as is the same for the water surface (Brunier et. all., 2016). The automated agisoft smoothening tool was applied for beach and swash zone as the general characteristics is not deleted, while the resulting surface is much more representative and much easier for production of contour line estimation in later GIS processing.

When the photos have been aligned, tie points have been detected for all images added to the workspace. These tie points indicate major elements that can be recognized in other images. These tie points result in a sparse point cloud creation and the camera position in space will be estimated in a network optimization (bundle adjustment). (James, Robsonb, & et. all., 2016) Camera calibration is advised and the correct values from the camera must be checked to ensure correct optimization of the model. Agisoft self-calibrates the camera information from the image files and as DJI Mavic pro both recognizes camera alignment, flight orientation and position this calibration is highly effective although the internal positioning and INS is made for navigational purposes of the drone. When using a fisheye lens, manual update of the camera type is needed in the camera calibration tool. The tie points will after the alignment, represent an initial surface of point (sparse point cloud).

Since DJI mavic carries GLONASS for 3D position of drone, the sparse point cloud will be referenced from that to the coordinate system chosen in AgiSoft, but images still needs correction to the GCP positions and coordinate system. A CSV file for the Ground control points can be imported under the reference menu. Using the newly build sparse point cloud model for identification of GCPs can be difficult but is recommended - right click on the model and choose “Filter photos by point”. Looking to Figure 5.5 the sparse point cloud for the 14th of May is shown during the process of setting GCPs to the model and underlying photos so that referencing is made to the real datum with the GCPs ensuring the correct elevation for further processing.

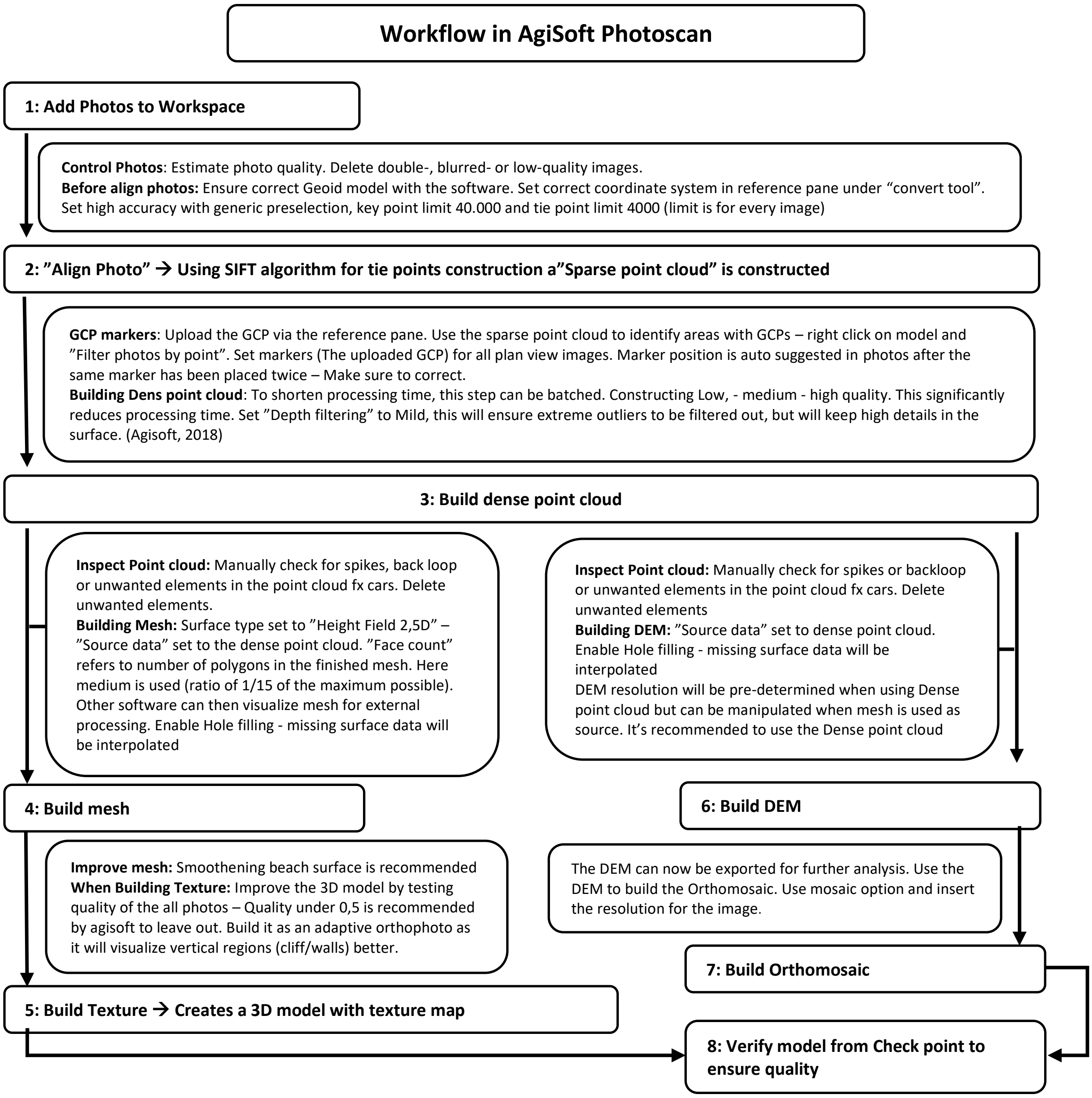


Figure 5.4 – The figure describes the steps of the photogrammetric process from start to end. The numbered boxes illustrate the different tools utilized in agisoft. The textboxes underneath describe which concerns and precautions is necessary before and after a step I order to get the most correct interpretation of the images to the model.

When placing markers (imported GCPs), it is important to place them with as sub-pixel precision as possible for the following modelling (Gonçalves & Henriques, 2015). Agisoft automatically suggests marker targets after they have been placed twice, but they need to be correct for all planview images.

When Building the dense point cloud, the settings used are important for the outcome of the model. "Depth filtering" is set to MILD, because this ensures outliers of extreme character is identified and left out, but steep faces such as the cliffs and structures is not filtered out. (Agisoft, 2018) During

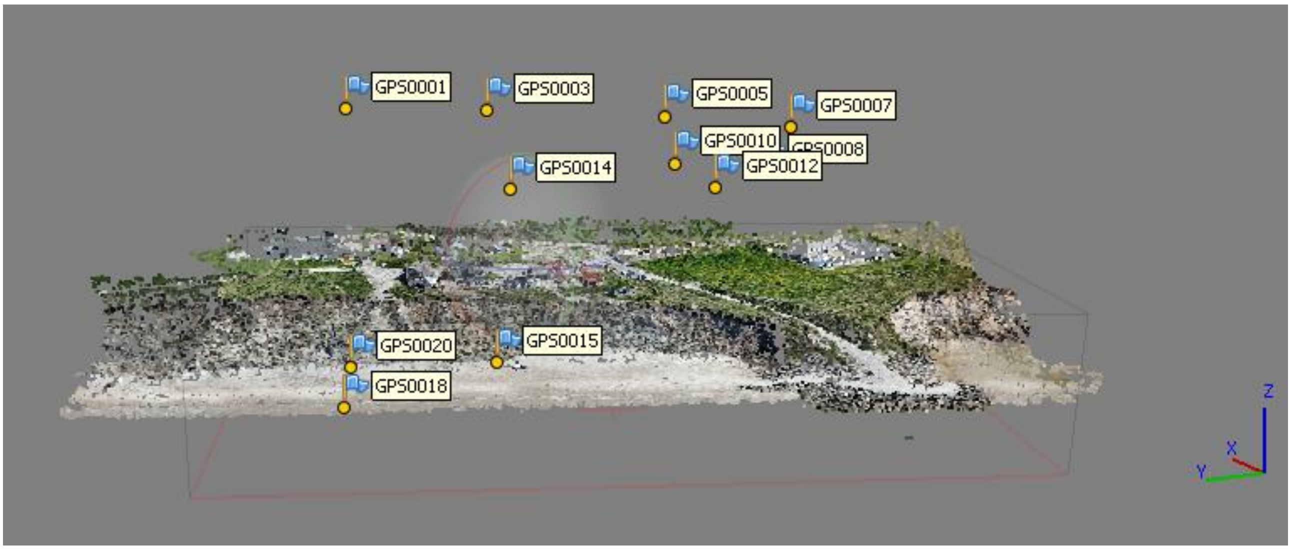


Figure 5.5 – The marker positioning of GCPs. GPS 18,20 and 15 is seen to have been placed while the remaining points still need to be positioned in the photos underlying the sparse point cloud.

the model building, research and frustration over processing time and lack of processing power, it was discovered that when building the dense point cloud processing time could be reduced by first building low, then medium and finally in high quality point clouds. This process can be batched together for processing overnight or in the background.

When building the Mesh surface type should be set to **"Height field 2,5D"** because:

"Height field surface type is optimized for modeling of planar surfaces, such as terrains or basereliefs. It should be selected for aerial photography processing as it requires lower amount of memory and allows for larger data sets processing." (Agisoft, 2018, s. 24)

The last step needed is building the texture of the 3D model. This incorporates both point coloring, height field, underlying mesh together in a complete 3D model which can be exported for further processing of optimization.

The overall processing time for the construction of the models from the 19th of April and from the 14th of May, ranged between 15hours and 24 hours.

6. Model results and quality

With all steps completed, DEM model and orthomosaic can be exported. When the models are exported, the grid sizing of the pixel are very relevant as these represent the raster grid sizes that will be used in ArcMap in the later processing and it is also of great value when estimating the precision of the DEM and orthophoto. The pixel size should generally not be lower than the GSD.

	Flying height	GSD	DEM Resolution	Orthophoto resolution
19th of April	30m	0,009m	0,05m	0,02m
14th of May	75m	0,025m	0,05m	0,04m

As it was only the model made for the 14th of may 2018 that passed the criteria for the DEM model, it is the only one that is presented in the following, this also applies for change detection from both Orthophotos and DEM. When the models is constructed for the area, it is necessary to test the quality, ensuring the Data or model is actually of high enough quality. This statement raises the question of what is actually good enough? Since the model is supposed to be compared to the Danish national DEM for change detection and volume change analysis, it must be compared to the same standards as specified for these.

6.1 3D model results

The textured 3D models from the 14th of May are presented in Figure 6.1 and Figure 6.2. Notice the grey spot on the beach in Figure 6.2, marked by the black arrow. This shows a deleted part of the Dense point cloud which was interpolated in the construction of the mesh. A car was parked and the beach, which needed to be removed for volume calculation. The model shows high degree of

Figure 6.1 – Exported image of the 3D model constructed from images aquired on the 14th of May 2018

Figure 6.2 - Exported image of the 3D model constructed from images aquired on the 14th of May 2018. The black arrow point to part deleted from Dense point cloud and interpolated in the texturing.

detail in the cliff and beach and is a high-quality model for presentation of the area in 3D. This does not confirm whether the model is to scale or not, which is why the horizontal and Vertical precision of the model must be evaluated.

6.2 Orthophoto and DEM results and Horizontal precision

The results of the Orthophoto and DEM are shown in Figure 6.3 and Figure 6.4. Notice the unremoved spikes in the water surface seen from the DEM model in Figure 6.3 – this is a good example on what consequence can be expected when depth filtering in the images does not match and it also underlines why it is necessary to investigate quality of the model despite the seemingly good results. The following statistical measures (Table 6.1) are applied for both the horizontal and vertical quality test as suggested in (Höhle & Höhle, 2009), but it varies as the error have not been converted into absolute error. Instead the true error (positive or negative) have been used.

Mean of Δz (m)	$m = \frac{1}{N}\sum_{i=1}^{N} \Delta z_i^2$
Std. deviation (S)	$S = \sqrt{\frac{1}{(N-1)}\sum_{i=1}^{N}(\Delta z_i - m)^2}$
Median (me)	The 50% quantile
Root Mean Squared (RMSE)	$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N} \Delta z_i^2}$

Table 6.1 – showing the description of the statistical measures used

Firstly, the horizontal precision of both DEM and Orthophoto. The precision is estimated automatically from the process and quality feedback report from the Agisoft-software. The report produces an overall RMSE value for the GCPs used for georeferencing presents in Table 6.2.

If GTP were georeferenced in agisoft the RMSE could also be estimated from this report, but it has been decided to perform it in ArcMap on the finished products. As the GCPs are placed on all plan view images there can be some points that has not been placed perfectly centered – a solution could be to use other targets, e.g. with 2 triangles pointing towards each other making a

	19th Of April 2018		14th of may 2018	
	Δz	XY position	Δz	XY position
RMSE	0,0187m	0,0469m	0,0578m	0,0253m

Table 6.2 – The RMSE has been found from the automated error report from agisoft. It presents values for both the 19th of April and the 14th of may.

Figure 6.4 – Final Orthomosaic from the 14th of May 2018. The resolution in the image is set to 0,04m.

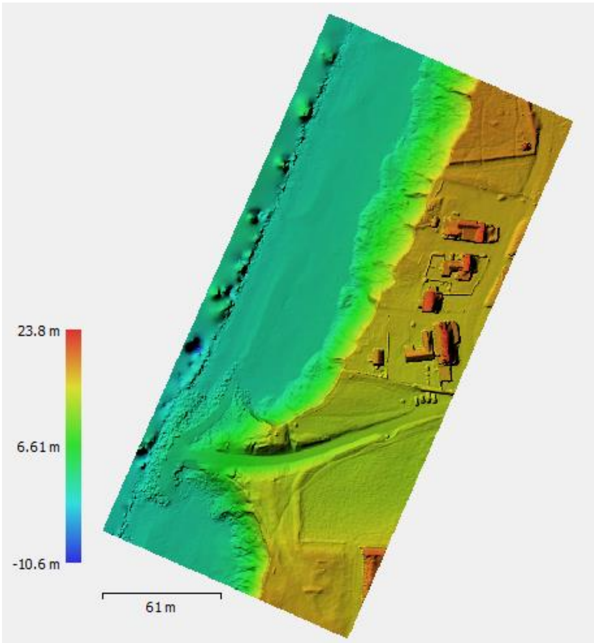


Figure 6.3 – DEM model from the 14th of may 2018. Notice the spikes left in the water surface. These have been left in the model deliberately for visualization.

more well-defined point for placing markers, than with the duct tape crosses as this is relatively wide and not very well defined as the GCP and GTP measurements is made in the middle of the cross. What is surprising is the RMSE values found for the Δz precision in the agisoft tool, is very different from the results found from the statistical analysis on vertical precision.

The RMSE presents a reasonable result for both models in the horizontal positioning, but to test for the quality in the overall surface the blue GTP positions are investigated using ArcMap. As the Orthophoto in this case is built using the texture which relies on the dense point cloud, the DEM and Orthophoto is investigated from the same parameters – the guidelines set for the national Danish DEM has been described in (Hawa et. al, 2011) where georeferenced rooftop corners are used to estimate the DEM model precision – as there are few buildings in the area and none stationary elements on the beach is found so the GTPs was used. With the fact that the DEM and Orthophoto is aligned, it can be argued their horizontal precision is the same.

The GTPs is imported as XYZ files in ArcMap to a point file. An additional new point file is created with manually set points in the center of the duct tape crosses for all GTPs found from the Orthophotos produced. This manual process is estimated to result in errors raging up to 1pix, but as the point is positioned in the center of the center-cell from the squares the errors are minimized as much as possible. The length between the GTPs dGPS position and the orthohoto GTPs positions are presented in Figure 6.5 and Figure 6.6 with the actual length of the horizontal errors described in Table 6.3

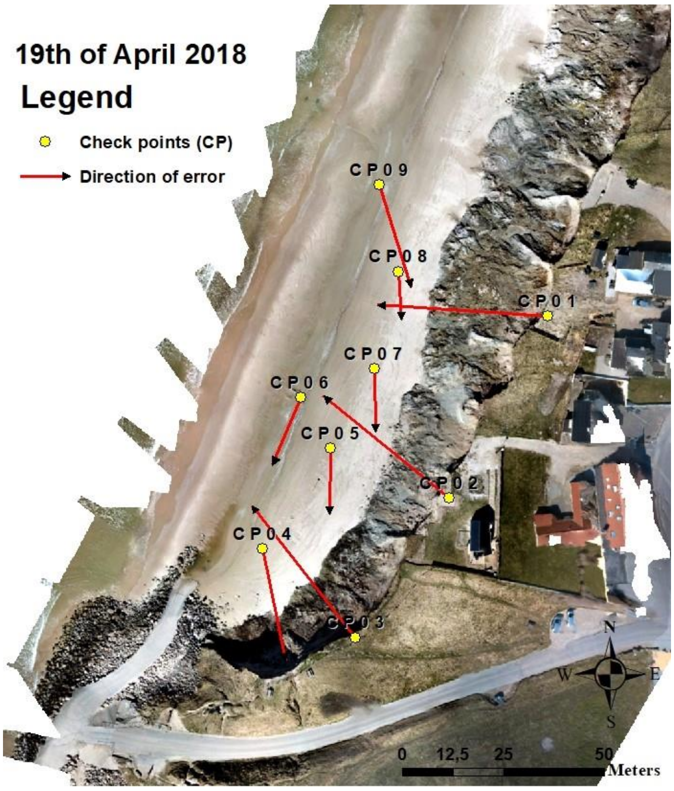


Figure 6.5 – Shows the length and direction of errors found from Table 6.3 for the 19th of April 2018. The length is multiplied by 500 for illustration purpose

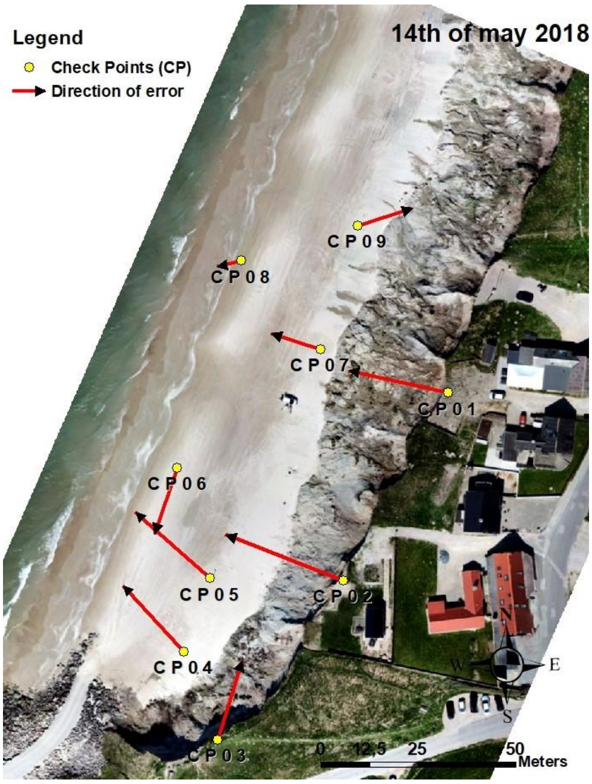


Figure 6.6 - Shows the length and direction of errors found from Table 6.3 for the 14th of May 2018. The length is multiplied by 500 for illustration purpose

The Orthophoto and DEM RMSE for Horisontal precision has been found to be 0,058m for the 19th of April and 0,043m for the 14th of May 2018. This is very different values found from the software statistical analysis, which reported precision of 0,025m for the 14th of May and 0,047m for the 19th of April. With GSD found at 0,01m (Orthophoto pixel size 0,02m) for the 19th April and 0,025m (Orthophoto pixel size 0,04m) the model is found to be almost within sub-pixel precision when remembering there is a 0,02m tolerance for the positions on the dGPS measurements, and the diffuse position of the center point on the GTP can have contributed to the model errors. The precision is found to be higher than specified for the national DEM which describes a horizontal precision requirement of 0,15m, but it is then again with a 0,4m grid size. The results will not be further analyzed as it is a satisfying result for both GTP and GCP precision.

	GTP Name	CP01	CP02	CP03	CP04	CP05	CP06	CP07	CP08	CP09	Mean	RMSE
14th of May 2018	Error Length (m)	0,052	0,065	0,042	0,046	0,051	0,036	0,027	0,013	0,029	0,04	0,043
19th of April 2018	Error Length (m)	0,085	0,080	0,083	0,057	0,033	0,036	0,031	0,024	0,053	0,054	0,058

Table 6.3 – describing the horizontal length between dGPS position of GTP and the GTP position found from the Orthophoto

6.3 Vertical Precision

To evaluate the vertical precision of the model, sporadic point measurements (SPM) was taken with dGPS at several positions right after both drone flights was completed. These were made to evaluate the difference in z-values between dGPS and the finalized DEMs.

The difference in height between dGPS and DEM can be found as:

$$\Delta z = z_{ref} - z_{model}$$

Where z_{ref} denotes the Z-value found from the dGPS and z_{model} denotes the Z-value found in the DEM (using the coordinates from z_{ref}). Set according to (Hawa et. al, 2011).

After construction of the model, it was imported into ArcMap. Here the sporadic dGPS measurements were used to extract the Z-value from the DEM model in the exact point corresponding to the SPMs point layer (ArcMap Tool: Extract values to point). This creates a new feature layer, containing original z_{ref} values, together with a new Field called "RASTERVALU" which is the z_{model} values. Creating a new field (DOUBLE) in the Attribute table, allows for calculation of Δz as described earlier. The attribute table values can now be exported as text files for further analysis in Excel.

6.3.1 Δz errors and Outliers

For the 19th of April, a total of 123 SPMs was used to assess the DEM model quality. Two measurements was removed from the sample of 123. Since the one did not qualify for the precision measures set for the dGPS and the other was taken on top of a Pole, which was manually removed from the surface model in a manual "spike filtering". Of the 121, the first 98 was made on the beach while the remaining 23 was conducted on the cliff top. The beach was measured in 4 rows, approx. in a 10mX10m grid, but this was not a goal for precision, so 10 steps was taken between each point and row.

For the 14th of May, a total of 81 SPMs was used to assess the DEM model quality. Only one value was disregarded as an outlier. This was GPS0115 with an error of 42cm. The measurement was conducted on top of a pole, which was manually removed from the surface model in a manual "spike filtering". The measurements were started in the Northern most corner of where the model was expected to extend to – from here longshore measurements was take approx. every 15m. in 4 rows

– 3 on the beach and 1 on the slope side. This resulted in 60 points in total, of which the 1st measurement has been deleted since it was taken outside of the model area. A problem regarding the dGPS was encountered, and the connection to the RTK stream was lost. Since sporadic measurements of the cliff top still needed to be done this presented a dilemma. As the 1st measurement was finished on the 19th of April, only a month before, it was decided to add dGPS measurements GPS100 – GPS123 (all made on the cliff top on the 19th of April) to the point measured on the 14th of May. This could have presented high error if there had been erosion of the cliff edge, vegetation changes etc. But it did not present any significant error.

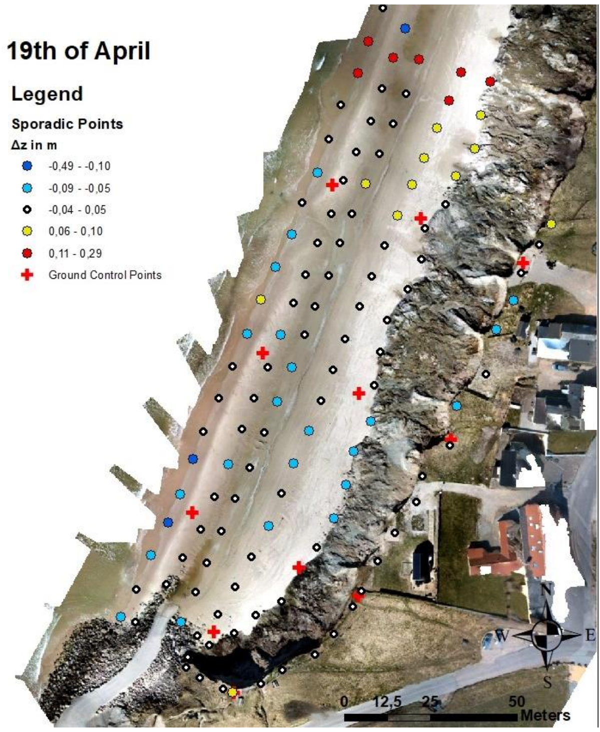


Figure 6.8 – The Δz errors are presented. Orthophoto is from the 19th of April 2018. The map is produced by the author in ArcMap under license of Aalborg university.

There are though some extreme outliers also shown in Figure 6.7 and Figure 6.8. Of the 81 sporadic test measurements 18 revealed a $|\Delta z|$ higher than 0,05m. For the model made on the 19th of April 2018 from 122 sporadic test measurements 43 revealed a $|\Delta z|$ higher than 0,05m – 10 of the 43 is between 0,05m and 0,1m. The model also presented significantly higher outlier errors and several of them is found in the middle of the maps.

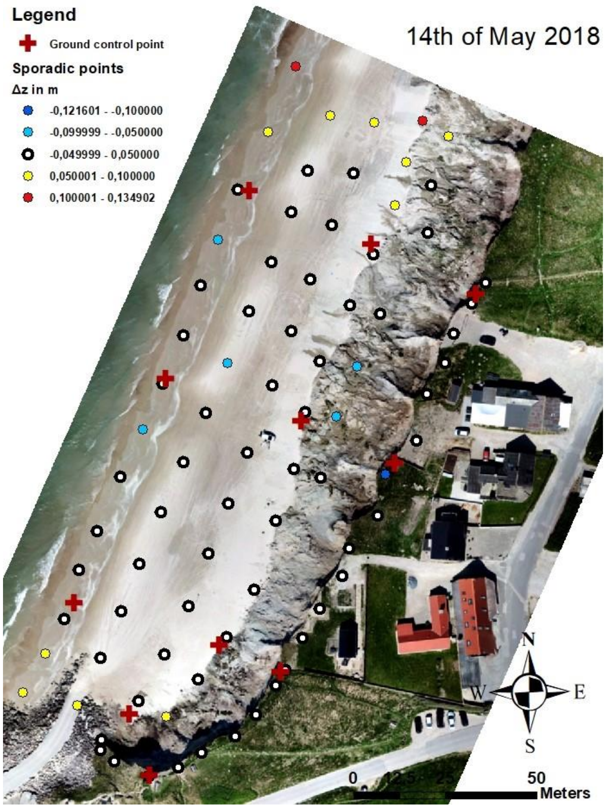


Figure 6.7 - The Δz errors are presented. Orthophoto is from the 19th of April 2018. The map is produced by the author in ArcMap under license of Aalborg university.

6.3.2 Normality test of Δz values

The Δz values found from both models made in Nr. Lyngby is presented in the Histograms found in Figure 6.9 and Figure 6.10. The intervals used in the x-axis for the histograms was found as the total difference between the two largest Δz (positive and negative respectively) and the divided with the desired number of boxes. As it is seen from both the figures, their distribution seems to be skewed and tail heavy.

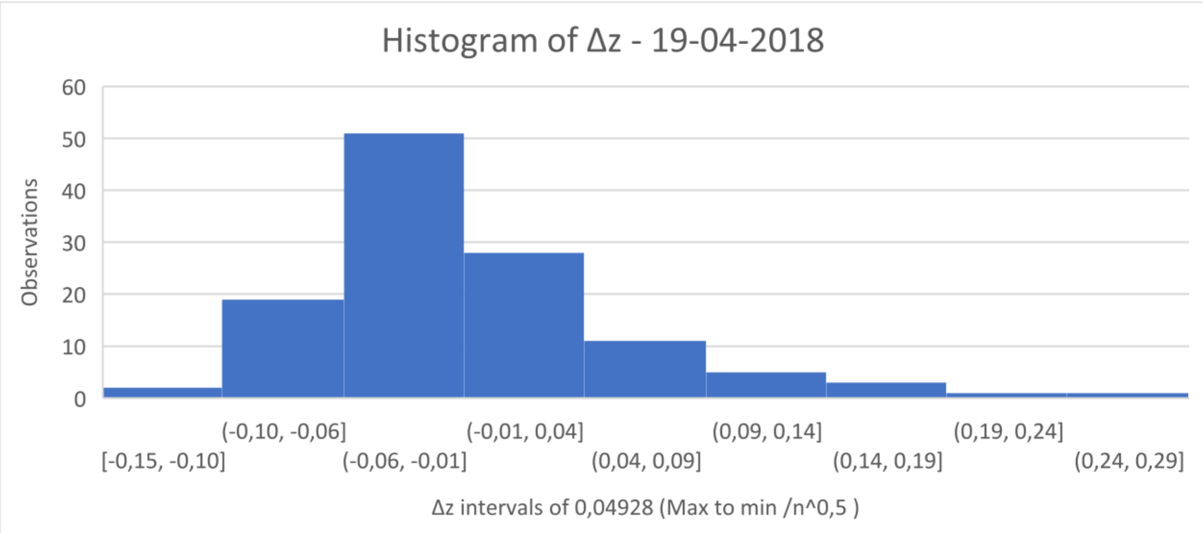


Figure 6.10 – Histogram presentation of Δz errors from the 19th of April 2018. It shows to be slightly tail heavy, most likely as a result of extreme outliers

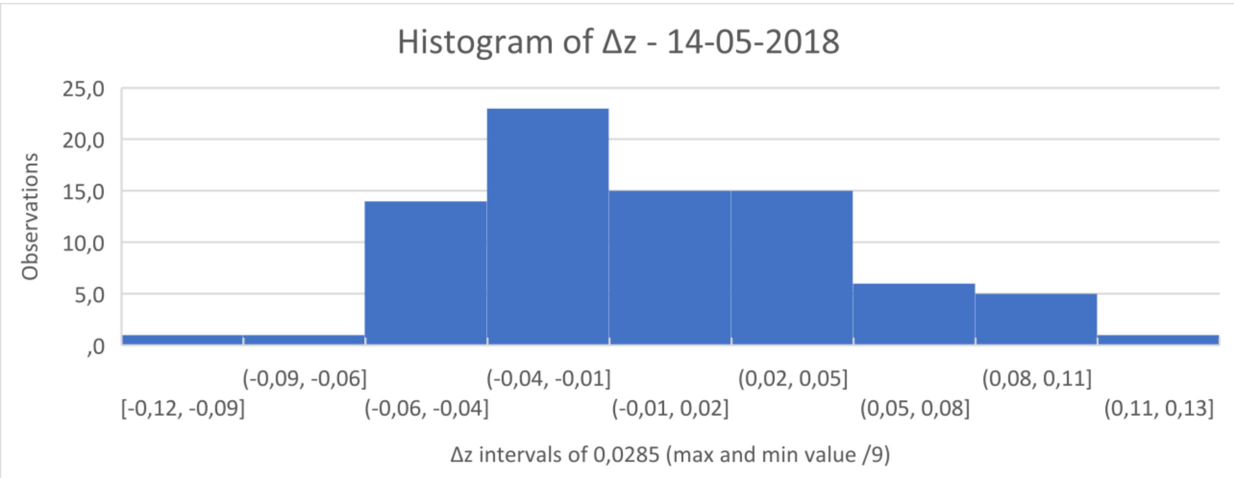


Figure 6.9 Histogram presentation of Δz errors from the 14th of May 2018. It shows to be slightly skew to the left.

A problem with a Histogram Is that it can be manipulated by using boxes of different size, therefor the empirical distribution:

$$F_n(x) = \frac{no.of\ obs. \leq x}{N}$$

Will be used to plot Δz in a density function. To visually check if the distribution of Δz is normally distributed, the theoretical distribution (found in excel using the excel command tool:

NORMAL.FORDELING(x,m,S,TRUE)) will be plotted together with the empirical. Seen in Figure 6.11 – The Empirical distribution and theoretical normality distribution has been presented for both data sets.

As it is seen the Theoretical Normal distribution describes the Empirical distributions quite well in both cases but not perfectly. A test for normality was conducted to ensure how to proceed in the statistical work. The Lillefors test for normality was chosen to investigate the distribution. Here the t value (the maximum difference found between the distributions presented) is found as

$$T_{max} = |F(x) - F_n(x)|$$

Where $F(x)$ is the value found from the theoretical function and the value found from $F_n(x)$ is from the empirical function. For the data presented $T_{max} = 0{,}11$

This t-value now must be compared to the values from the Lillefors table seen in Figure 6.12 – Values for the lilefors test. Table has been reproduced from where

$$d = N^{0,5} - 0{,}01 + 0{,}083/N^{0,5}$$

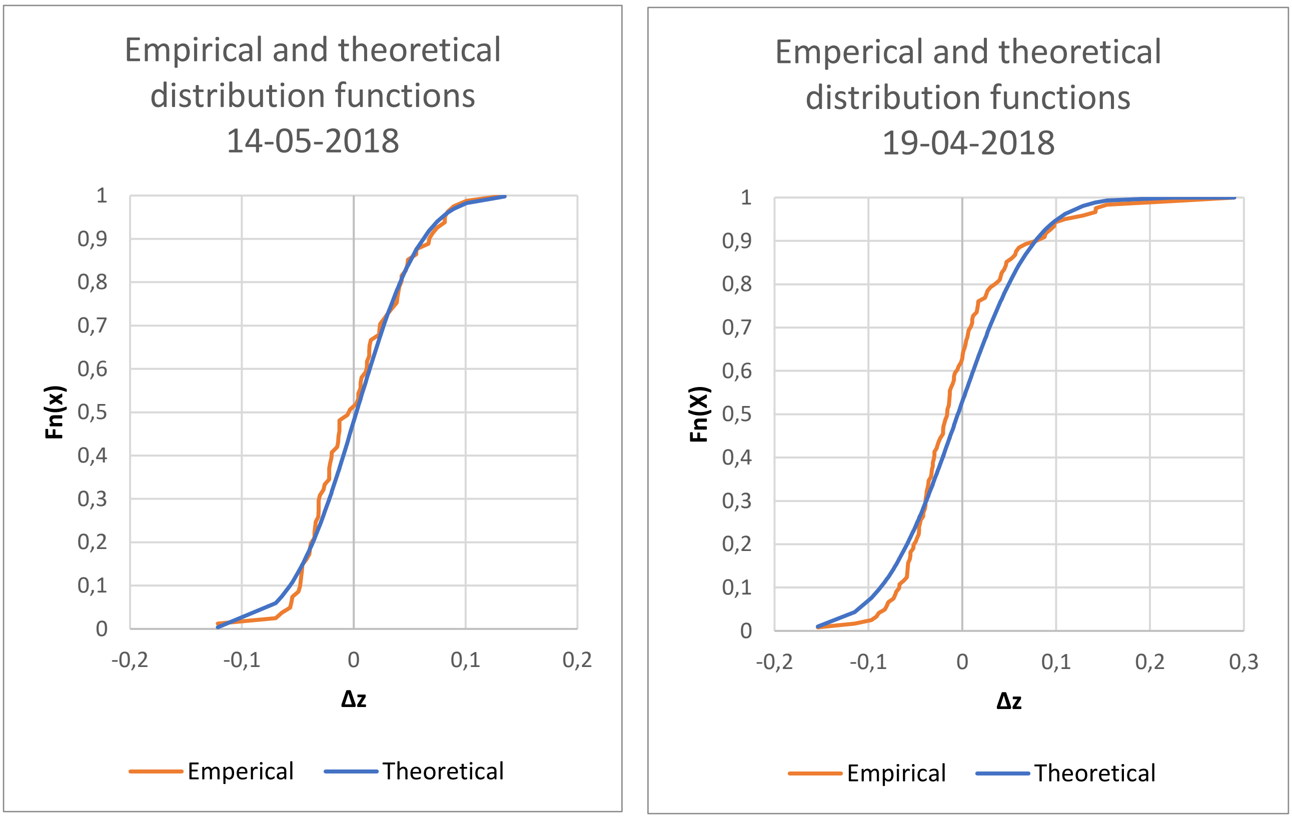


Figure 6.11 – The Empirical distribution and theoretical normality distribution has been presented for both data sets.

Nr. of Observations is 121		
α	0,05	0,02
d,nα	0,081382	0,067379
Tmax 19-04-2018 - 121 obs.	0,127599	0,127599
Nr. of Observations is 81		
α	0,05	0,2
d,nα	0,099453	0,08234
Tmax 14-05-2018 - 81 obs.	0,11004	0,11004

Table 6.4 - Shows the test statistics from the lillefors test on both data sets.

	α-value				
N	**0,20**	**0,15**	**0,10**	**0,05**	**0,01**
4	0,303	0,320	0,344	0,374	0,414
5	0,290	0,302	0,319	0,344	0,398
6	0,268	0,280	0,295	0,321	0,371
7	0,252	0,264	0,280	0,304	0,353
8	0,239	0,251	0,266	0,290	0,333
9	0,227	0,239	0,253	0,275	0,319
10	0,217	0,228	0,241	0,262	0,303
11	0,209	0,219	0,232	0,252	0,291
12	0,201	0,210	0,223	0,243	0,281
13	0,193	0,203	0,215	0,233	0,270
14	0,187	0,196	0,209	0,227	0,264
15	0,181	0,190	0,202	0,219	0,256
16	0,176	0,184	0,195	0,212	0,248
17	0,170	0,179	0,190	0,207	0,241
18	0,166	0,174	0,185	0,201	0,234
19	0,162	0,171	0,181	0,197	0,230
20	0,159	0,167	0,177	0,192	0,223
21	0,155	0,163	0,173	0,188	0,219
22	0,152	0,160	0,170	0,185	0,214
23	0,149	0,156	0,165	0,181	0,210
24	0,145	0,153	0,162	0,177	0,205
25	0,144	0,151	0,159	0,173	0,202
26	0,141	0,147	0,156	0,170	0,198
27	0,138	0,145	0,153	0,166	0,193
28	0,136	0,142	0,151	0,165	0,191
29	0,134	0,140	0,149	0,162	0,188
30	0,132	0,138	0,146	0,159	0,183
>=31	0,741/d	0,775/d	0,819/d	0,895/d	1,035/d

Figure 6.12 – Values for the lilefors test. Table has been reproduced from (TGP, 2005)

The values found from the table and the calculated Tmax values is presented in Fejl! Henvisningskilde ikke fundet.**.** The hypothesis of normal distribution can be disregarded

since, Tmax is bigger than the threshold value (dependent on N and a) in both cases of 0,05 and 0,2.

It could be argued that a different and weaker test such as the Kolmogorov-smirnov test, could possibly verify the thought of normality in the data sets, but it was decided to move forward with an empirical statistical approach as the statistical methods used in the following could also be applied to a normal distribution.

6.3.3 Numerical statistics

Since both measurements showed non-normality numerical statistics on the empirical distribution will be performed to test the model. To test the validity of the mean, median and 95% quantile of $|\Delta z|$, a two-sided 95% confidence interval will be found from a both percentile bootstrapping and percentile t-bootstrapping.

19^{th} of April 2018

The descriptive statistical measures are presented in Table 6.5. As it is seen the mean value gives a bad interpretation of actual error found in the data set, whereas the RMSE give an estimation on the absolute general error for all points. Since the Mean value is so small the RMSE and Std. Deviation will naturally be very close to each other. The normality test showed that the data was not normally distributed. Empirical statistics was applied to describe the quality of the measurements. Using percentile bootstrapping to estimate the confidence interval of the median and Percentile t-bootstrapping for the confidence interval of the mean.

	Date 19th of April 2018
Observations included (N)	121
Mean (*m*) of Δz	-0,0047
Std. deviation (S) of Δz	0,0643
Median (*me*) of Δz	-0,0159
Root Mean Squared (RMSE)	0,0642

Table 6.5 – Statistical values for the data set form the 19th of April 2018

The analysis was conducted in excel were 1000 sample sets was constructed with 121 observations, based on the empirical distribution. The median was then calculated for each of the new datasets and was plotted in Figure 6.13.

After all medians is found, they are ranked. With a 1000 sets an empirical, 95% confidence interval is found by selecting the medians at number me_{25} and me_{975} also described as me_{Lower} and me_{upper}

me_{Lower} = -0,0273m

me_{Upper} = -0,0078m.

A span of 0,0195m between the upper and lower median in the 95% confidence intervals provides a strong test of the median.

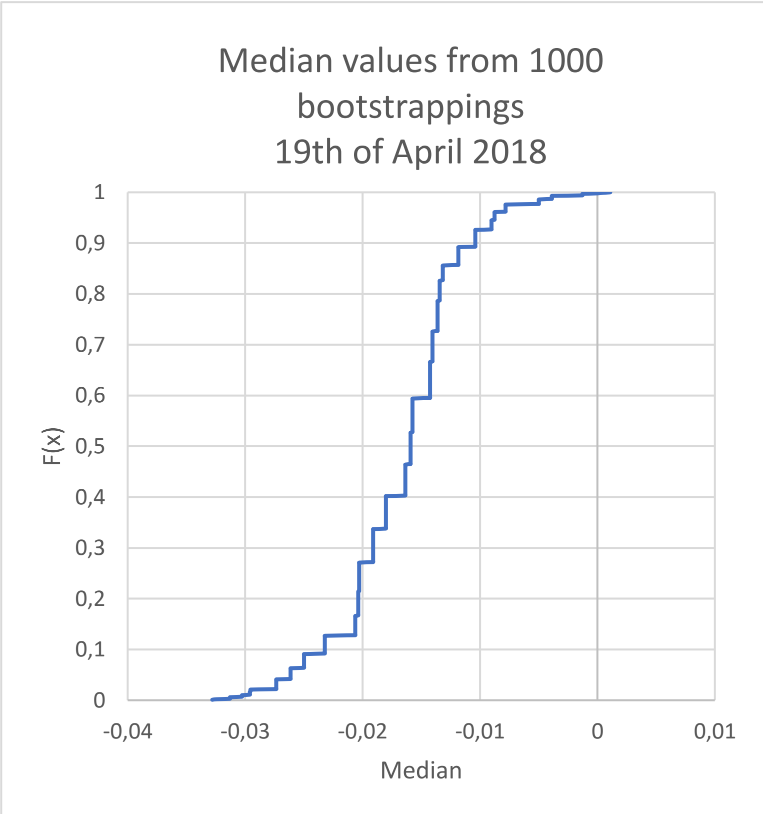


Figure 6.13 – Median values from bootstrapping on data from the 19th of April.

It was also a wish to estimate the 95% confidence interval for the mean value, but as percentile bootstrapping is a poor measure for the mean value, a percentile t-bootstrapping method was applied to investigate a two-sided 95% confidence interval of the mean value instead. For all 1000 new data sets created, a mean value and standard deviation was found for all. Instead of finding the 25th and 975th values the value T* was calculated for all new data sets:

$$T^* = \frac{m^* - m}{\frac{S^*}{\sqrt{N}}}$$

These values were then ranked, and the $T^*{}_{25}$ and $T^*{}_{975}$ were used to identifying the two-sided 95% confidence interval of the mean as:

$\mu_{lower} = m + T^*{}_{25} * \frac{S}{N^{0,5}}$ and $\mu_{upper} = m + T^*{}_{975} * \frac{S}{N^{0,5}}$

$\mu_{lower} = -0{,}0173m$ and $\mu_{upper} = 0{,}0063m$

This makes up a very narrow interval of only 0,0236m and gives a strong test for the mean value.

14th of May 2018

Since the distribution was not normal empirical statistics was applied to describe the quality of the measurements. Firstly, it was done by Percentile bootstrapping to estimate the confidence interval of the median. The analysis was conducted in excel were 1000 sample sets was constructed with 81 observations, based on the empirical distribution. The median was then calculated for each of the new datasets and was plotted in the Figure 6.14:

Date: 14th of may 2018	
Observations included (N)	81
Mean of Δz (*m*)	0,0025
Std. deviation (S)	0,0464
Median (*me*)	-0,0032
Root Mean Squared (RMSE)	0,0462

Table 6.6 - Statistical values for the data set form the 14th of May 2018

After all medians is found, they are then ranked. With a 1000 sets an empirical, 95% confidence interval is found be selecting the medians at number me_{25} and me_{975} also described as me_{Lower} and me_{upper}

me_{Lower} = -0,0196m

me_{Upper} = 0,0118m.

A span of 0,0376 between the upper and lower median in the 95% confidence intervals provides a strong test of the median. It was also a wish to estimate the 95% confidence interval for the mean value, but as percentile bootstrapping is a poor measure for the mean value, a percentile t-bootstrapping method was applied to investigate a two-sided 95% confidence interval of the mean value instead. For all 1000 new data sets created, a mean value and standard deviation was found for all. Instead of finding the 25th and 975th values T* was calculated for all new data sets:

$$T^* = \frac{m^* - m}{\frac{S^*}{\sqrt{N}}}$$

These values were then ranked, and the $T^*{}_{25}$ and $T^*{}_{975}$ which can then be used to finding the two sided 95%confidence interval of the mean as

$$\mu_{lower} = m + T^*{}_{25} * \frac{S}{N^{0,5}} \text{ and } \mu_{upper} = m + T^*{}_{975} * \frac{S}{N^{0,5}}$$

$\mu_{lower} = -0{,}0075$ and $\mu_{upper} = 0{,}0140$

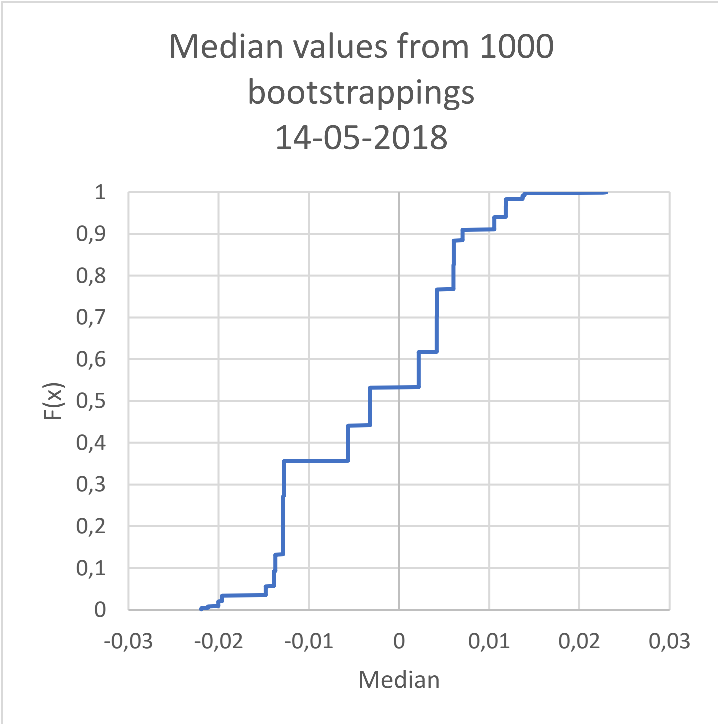


Figure 6.14 - Median values from bootstrapping on data from the 14th of April.

This makes up a very narrow interval of only 0,0215m and gives a strong test for the mean value.

6.3.4 Sum up

In conclusion there can be found significant differences between the two models both statistically and regarding the overall quality of the products. It is interesting that the model made from the 2nd drone flight on the 14th of May has increased the statistical accuracy, both horizontally and vertically. One would think that pictures taken closer to the area of interest, and more images would reveal a higher accuracy, but as the method for acquiring the imagery was not the same, it is a belief that the more structured flight planning and imagery acquiring from the second flight has been the main factor in optimizing the model But the tampering with at least 1 on the 11

	Date 19th of April 2018	95% Confidence interval $[lower\ ; upper\ ]$	Date 14th of May 2018	95% Confidence interval $[lower\ ; upper\ ]$
Observations included (N)	121	----------	81	----------
Mean (m) of Δz	-0,0047	$[-0{,}0173\ ; 0{,}0063m\ ]$	0,0025	$[-0{,}0075\ ; 0{,}0140\ ]$
Std. deviation (S) of Δz	0,0643	----------	0,0464	----------
Median (me) of Δz	-0,0159	$[-0{,}0273\ ; -0{,}0078\ ]$	-0,0032	$[-0{,}0196\ ; 0{,}0118\ ]$
Root Mean Squared (RMSE) of Δz	0,0642	----------	0,0462	----------

Table 6.7 – summing up the results found in the latter statistical framework.

GCPs on the 19th can also have affected the model. Even though the altitude of the flight was higher, and the number of pictures was lower in the second measurement it revealed a higher accuracy. A conclusion is that the results from the statistical test reveals that at least the 2nd model from the 14th of May are comparable with the national model in quality and is therefore reaching the desired precision.

6.3.5 Parameters effecting the quality of the model.

The quality of the final model is found to be dependent on many different parameters. For image acquisition it is with the outmost importance that the GCPs and GTP are not tampered with during the flight since this will disorientate the georeferencing of the model. The overlap of images is also a parameter that can influence the model quality, especially if the overlaps are too small. It was shown to be effective when using waypoint mission available for the drone. This can be optimized if using Flight plan software. DJI produces a ground control application with which flight plans, overlap of images, speed etc. can be set prior to flight which makes the drone flight strips much more controlled, but as the software is only available for Apple iPad it was not used. Other flight

´planner applications is available and the Pix4D application for android called Pix4Dcapture together with Pix4D ctrl makes flight planning with the DJI mavic pro possible as well. It is recommended to utilize these tools in automated mission as they also calculate the GSD automatically and the autonomous flight insures higher consistency in the image acquiring. Another optimization of the model quality would be, as mentioned, to use more well-defined targets, and it is also recommended to use a dGPS with a conical end instead of a cylindrical, as this again pinpoint the precise position of the reference point to a higher degree. It won't prevent error as the dGPS also has an standard error of approx. 2cm. but it will possibly minimize the errors.

The processing steps is in general determining the overall quality of the model, and despite AgiSoft being an almost automated easy to use tool, it is still regarded as highly necessary to understand the steps in the photogrammetric process since the option in the different tools applied to the model has an influence on the result. The tools utilized for optimizing the dense point cloud and mesh will also influence the model, which is why spike filtering, manual error detection, smoothening and quality control all are recommended in the post processing steps of the general modelling tools.

7. Coastal erosion analysis

As the presentation of the 3D modelling approach for the dry part of the coastal zone, is now done and a DEM and Orthophoto was created, these will be implemented in a real world study for costal erosion analysis. It will be compared with other methods for comparison of the different approaches. In the following chapter the use of transect measurements from the DCA for erosion/accretion analysis will be presented. For the second part analysis of the cliff edge retreat at Nr. Lyngby using orthophotos is presented - Here the Orthophoto from 14th of May just presented, will serve as the latest map. Finally, the DEM model created for the 14th of May 2018 will be used for calculation of the volume development between the latest national DEM and the DEM for the 14th of May 2018.

7.1 Transect measurements

When analyzing the changes in the landscape, clearly defined boundaries between the zones are needed in order to estimate and analyze the impact from different event. When dividing the coastal profile, morphological indicators can be used to delimit the different zones, and costal state indicators (CSIs) is suggested to ensure that quantitative measurements is comparable over time in (Lescinski, 2010) as it can be translated to policymakers in the form of keeping a certain safety level. Well-defined and robust measurement have been applied as e.g. the MCL (Momentary coast line) in Hollands "dynamic preservation" approach to coastal management in 1990s and in the 2000s (Koningsveld & Mulder, 2004) while in Denmark the DCA has applied some of these measures in the Nourtec and the COADAPT nourishment research projects. This is adapted in the transect measurement approach.

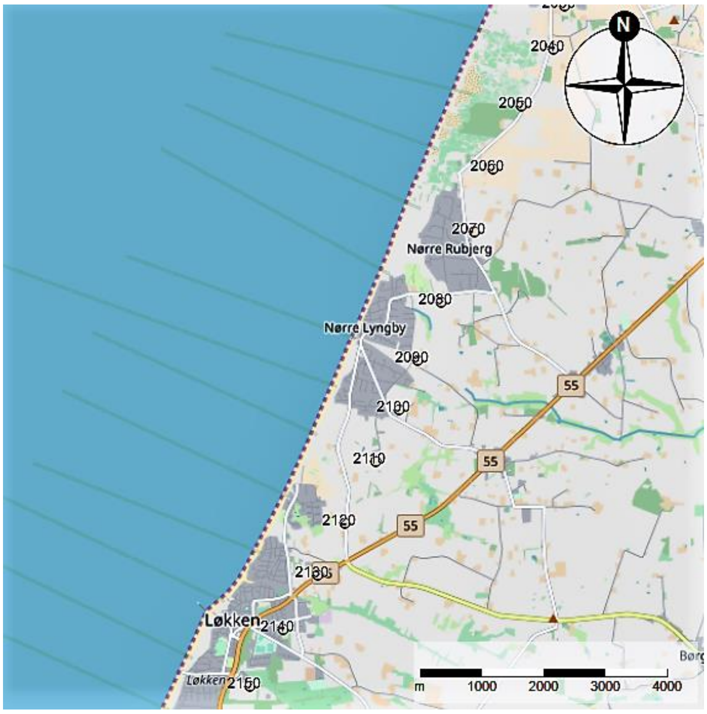


Figure 7.1 – the map has been exported from MorphAn showing the position of the WCLs. Notice that 2090 is set perpendicular to Nr Lyngby

To analyze the transects, for visualization and volume analysis, is performed with the open and freely available software MorphAn (Deltares, 2016) which will be used together with WCLs 2060 to 2120. The data used for analysis is kindly borrowed from the DCA in the form of WCL XYZ files converted into Jarkus files with which MorhpAn works. The focus here is to describe the development in the profile over the last 40 years from high resolution transect measurements known as westcoast lines (WCLs) seen in Figure 7.1. These transects has since the start 70s been conducted by the Danish coastal authorities (DCA). They are measured from dune/cliff top and approx. 4km out. and was initially set perpendicular to the coast, and they have been measured in the corresponding place throughout the years. The WCLs have been set with a sidewise spacing of 1000 meters between the transect, and with a referenced station approx. 1000 meters inland. (Kystdirektoratet E, 2018) Naturally it is impossible to analyze what is in between the measurements, but they are the only long-term derived data set available for analysis of the profile development in the wet part so they are still of great value. Profile assessment for evaluation of wave base or the outer limit of the shoreface can also be done from

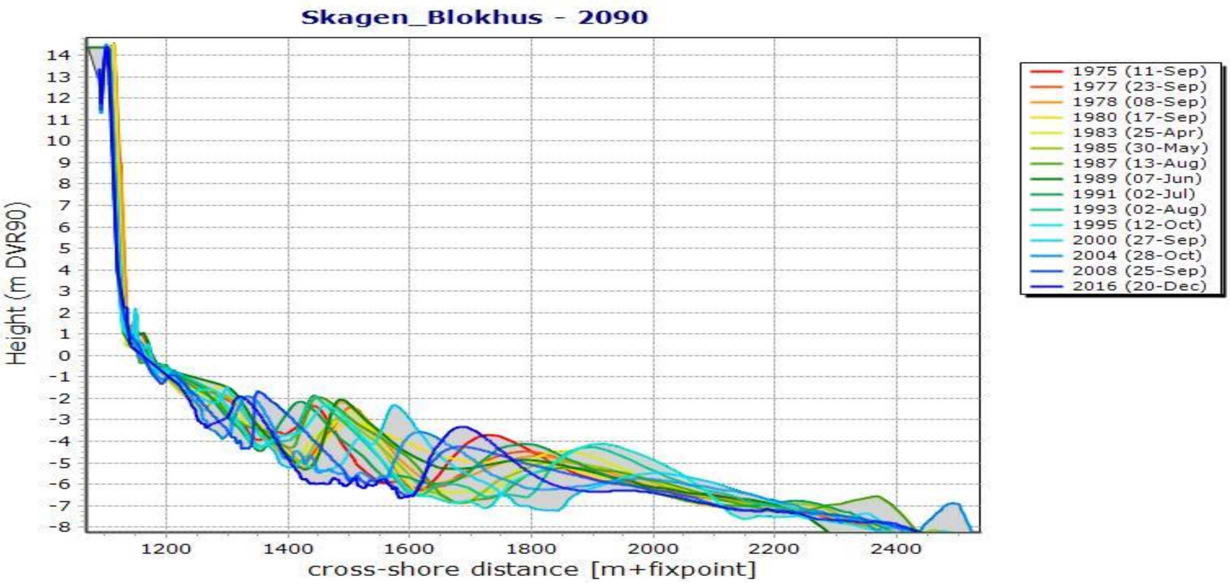


Figure 7.2 - Profile development for WCL 2090 at Nr. Lyngby between 1975 and 2016.

these transects. WCL nr 2090 is found directly in front of the access road from Nr Lyngby to the beach, which means it includes the breakwater protecting the access road - a visualization of the WCL 2090 profile measurements since the 1975 and 2016 is found in Figure 7.2. The sandbars are seen to move significantly between the different measurement periods, and 3 bars is noticed (1200m, 1300m and 1700m marks) in the 2016 transect (dark blue line). There are significant changes between the measurement below -8m, but it has been decided to use -8m for volumetric analysis as it seems to be the extent of the upper shoreface. This decision was based on the fact that it is from -8m and up the most significant yearly changes is seen and a break in slope was found beneath it for 2016.

Assessing Figure 7.2 only visually is not enough to estimate whether a general erosion is taking place, so a position and volume development analysis is performed to asses to general development of the profiles.

Momentary cliff-face position (MFP)

The MFP can be defined a horizontal distance between the inland reference point of the WCL to a volume defined position. The method for estimating it is a shown in Figure 7.3. Using MorphAn this is also possible from the same approach but by and automated method.

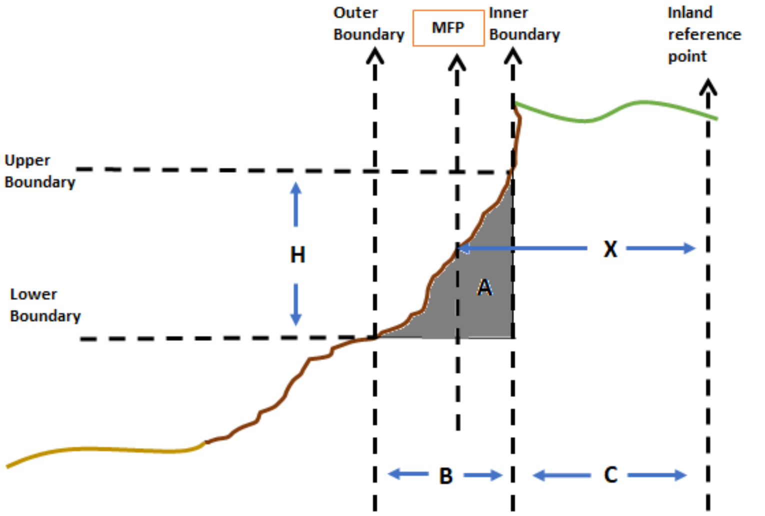


Figure 7.3 – The figure presents a method for determining the horizontal distance from a well-defined inland point to the MFP in horizontal length. The position of a cliff face is determined as follows:
A is Area under profile between upper and lower boundaries.
H is the vertical height between upper and lower boundaries.
C is the horizontal distance between inland reference point and inner boundary
B = A / H
X = B + C
The model is drawn with inspiration from (Koningsveld & Mulder, 2004)

The position reveals only a horizontal position for each profile measured. This position can then be used to analyze a retreat or advance in the cliff or dune face. Comparing for each year and a total retreat/advance can be found and a regression analysis can be performed to investigate the trend of and quality of the trend. The results have been gathered in Table 7.1 and complete lists of all results can be found in appendix C

Volume development Horizontal boundaries

The area found in Figure 7.3 can be used to estimate the volumetric development for the different transects. The area does though need to be extended to a common inland reference point so that the volume difference between to measurement can be found. If both volumes are extended from their respective inner boundary to e.g. the inland reference point with the same upper and lower boundaries, the difference between the profiles can be found be subtraction of the before storm volume from the after-storm value, gaining insight in the erosion as shown in Figure 7.4. As there are 1000 meters between the transects, it can be argued that each line represents 500 meters on each side, but as the lines are perpendicular to the coast, bisectors must be found between the lines to estimate the correct extend it represents. This will not be done for this stretch, as is it out of the scope of this project.

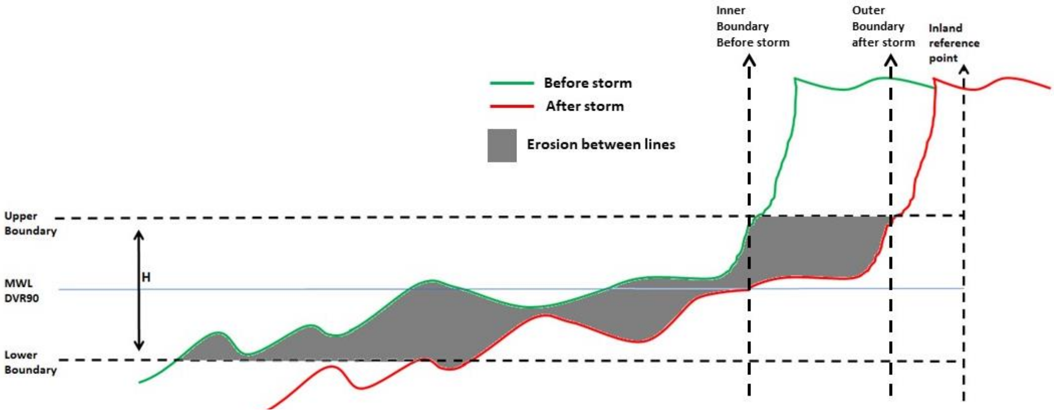


Figure 7.4 – Volume difference between before and after profile. This erosion can be estiated using MorphAn

Using MorphAn, horizontal boundary layers can be defined in vertical heights. The upper limit was set to +8 meters. This position does not reach the top of the cliff, but when applied for all included WCLs the +8m mark ensures that all profiles are included, and it also reaches far above any extreme water levels. The lower level has already been presented and is set to -8m. To estimate whether the sediment loss is primarily from the dry or wet part of the profile, additional volume calculation has been made for 0m to -8m which can be compared with the +8m to -8m, since the difference will be the erosion/accretion in the +8m to 0m. Take notice that all results have been prolonged to 1000m from inland fix point as described in the latter and from Figure 7.4. The results have been gathered in Table 7.1 while complete results is visualized in Figure 7.5 - A complete lists of all results can be found in appendix A and B.

	Volume analysis from 0m to -8m			Volume analysis from 0m to -8m			Cliff retreat (MCL +6 to +5)		
WCL nr.	Total change between 1977 and 2016 (m3/m)	yearly linear reg. (m3/m)	r2	Total change between 1977 and 2016 (m3/m)	yearly linear reg. (m3/m)	r2	Total movement 1977 to 2016 (m)	yearly (m) linear reg.	r2
2060	-283,79	-12,89	0,44	22,01	-4,77	0,10	-38,28	-1,04	0,98
2070	-732,91	-21,33	0,92	-373,78	-12,04	0,77	-43,71	-1,15	0,93
2080	-916,33	-27,29	0,78	-427,74	-15,13	0,60	-57,53	-1,59	0,93
2090	-576,98	-13,16	0,71	-494,32	-11,55	0,63	-10,8	-0,27	0,55
2100	-214,64	-6,42	0,31	-72,83	-3,25	0,09	-18,49	-0,49	0,63
2110	-162,42	-0,71	0,01	-92,87	0,26	0,00	-11,36	-0,30	0,53
2120	78,77	0,35	0,00	172,50	2,87	0,05	-16,7	-0,51	0,56

Table 7.1 – The table collects all the most relevant information's form appendix A, B, C and D. The table are colored for illustration purposes

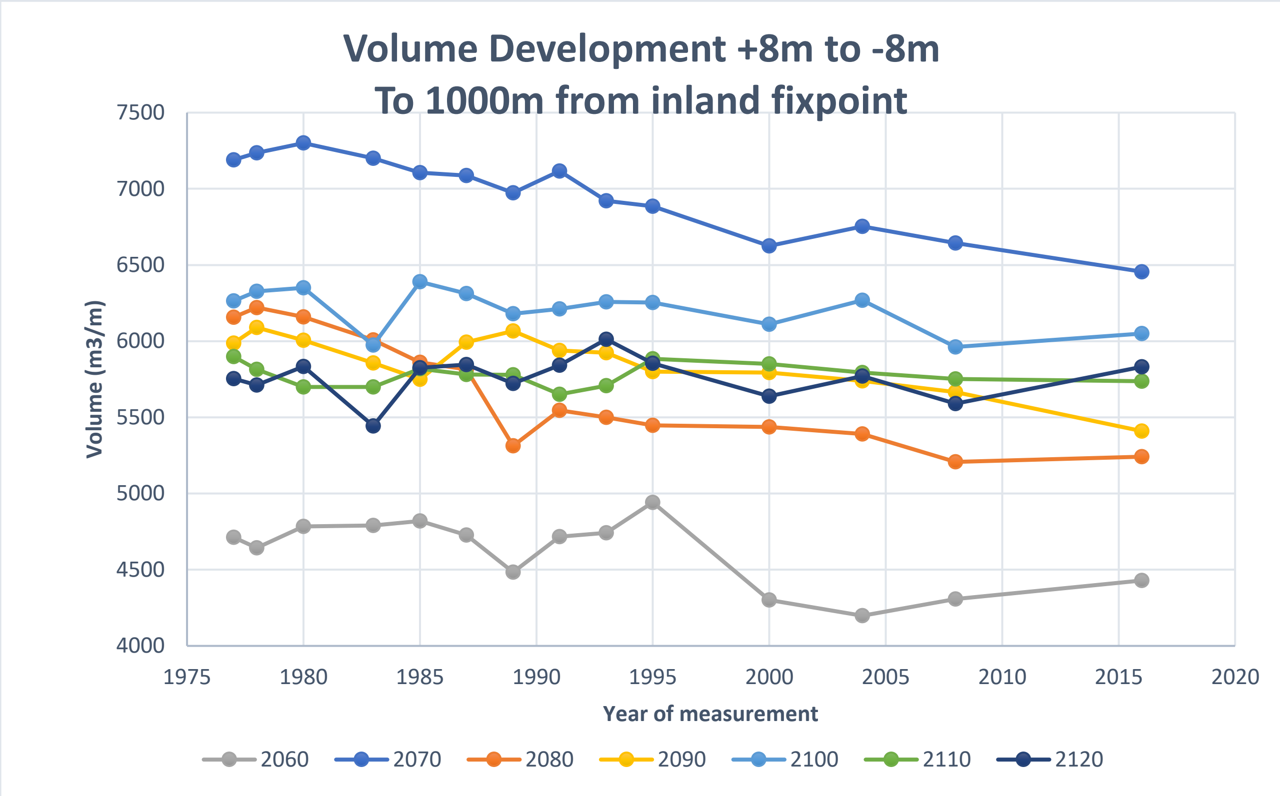


Figure 7.5 – Showing the volume development between +8m and -8m (from DVR90) for the included WCLs from appendix A,B,C and D. Visually it can be argued that a negative trend is experienced for most lines which is underlined in Table 7.1.

When looking in Table 7.1, keep in mind the WCL-numbers decrease when moving from south to north and WCL 2090 is the middle transect in this extraction since it is right in front of Nr. Lyngby. It is clearly seen that there is a much higher erosion rate on the northern side of WCL 2090. This is also what is found from visual inspection of the cliff faces in various orthophotos from different years. As WCL 2090 includes the breakwater in Nr. Lyngby it is a weak measure for the cliff erosion as it has not moved much since 1989 - Appendix C. Looking to historical flight photos it is also seen that the breakwater was installed between 1987 and 1992.

Using the m3/m from the transect in a shore parallel stretch can easily be performed. Since the stretch analyzed is 150meters long, the deficit of 11,55 m3/m/y - Table 7.1 - can be multiplied with the length giving a total deficit of 1725 m3/y between 0m and -8m - it must though be underlined that it at best is a rough estimate. This cannot be included in the 3D UAV modelling approach and should be included in the coastal analysis since it is a part of the general active profile and affected by erosion.

The erosion rate in the cliff face found from WCL 2090 gives a retreat of 0,27m/y. This is naturally not correct due to the position in front of the breakwater. It is estimated to be higher and is therefore evaluated from the closest line which is 2080 giving an erosion rate of 1,59m/y - Table

7.1. - which for a 150meter stretch with an average height of 16 meters gives 3816 m3/y – that is of course a very rough estimate as the volume from the cliff are deposited in landslides on the beach.

7.2 Using orthophotos for cliff erosion and volume estimations

There cannot be much debate on the erosion taking place, and it is taking place on both sides of Nr. Lyngby. But these transect measurements does not provide much information on the actual retreat of the cliff edge since no transects are found precisely on the area of interest. There for vegetation lines can be drawn for the are as polylines in ArcMap for desktop – and by limiting the area or interest these lines can then be used for creation of polygons and area calculation of the retreat as seen in Figure 7.6. The stretch is 150 meters long which can be used with the area to find an average retreat between the different years.

Average erosion rates 1995 to 2009

$1186{,}46m2\ /\ 150m\ =\ 7{,}91m$

$7{,}91m\ /\ 14years\ =\ 0{,}57m/y$

Average erosion rates 2009 to 2016

$1317{,}85m2\ /\ 150m\ =\ 8{,}79m$

$8{,}79m\ /\ 7years\ =\ 1{,}26\ m/y$

Average erosion rates 2016 to 2018

$(266{,}59m2 + 268{,}63m2)/\ 150m\ =\ 3{,}57m$

$3{,}57m\ /\ 2years\ =\ 1{,}79\ m/y$

Average erosion rates 1995 to 2018

$3039{,}53m2/\ 150m\ =\ 20{,}26m$

$3{,}57m\ /\ 2years\ =\ 0{,}88\ m/y$

The erosion rates show to increase in erosion rate for the different periods up to today, which could indicate an escalated erosion rate, but this must be further investigated with storminess to cross correlate it, which is outside of the scope. The volume loss in the cliffs in m3/y/m can be estimated as:

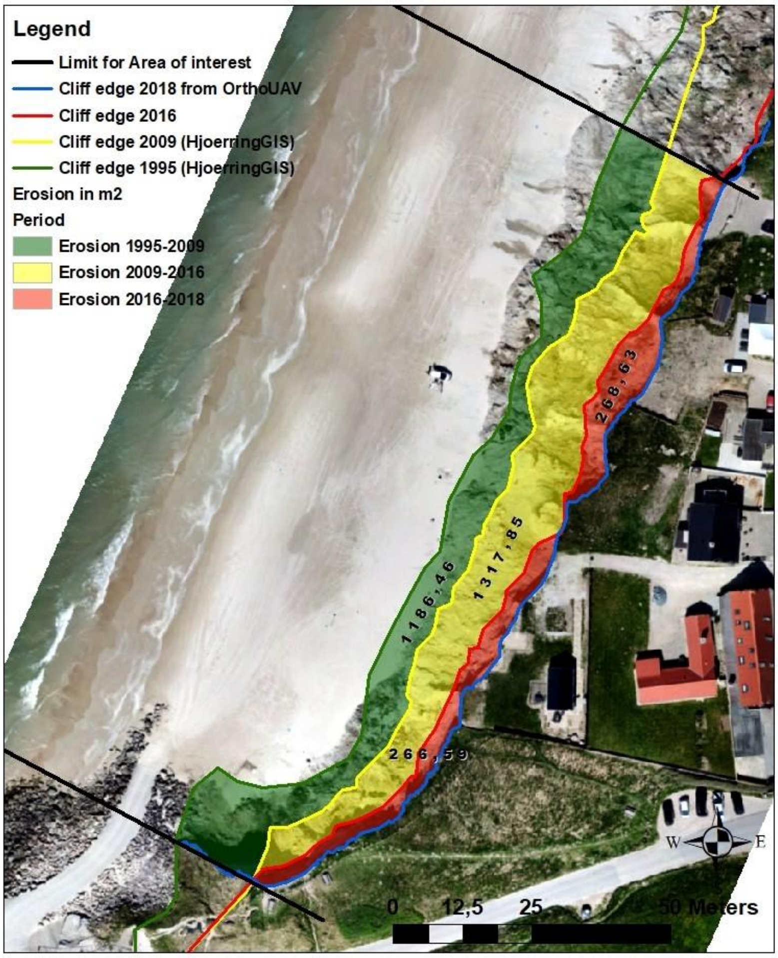


Figure 7.6 – Using Orthophotos from different years, approximated cliff edge lines have been drawn as polylines for the stretch investigated. 2 lines have been drawn using the web-based GIS solution found in Hjoerring municipality homepage. Although have been used together with the area limits to create polygons for which the planview area can be calculated and used for erosional analysis. The underlying orthophoto is the one produced from the 14th of May 2018. The map is produced by the author in ArcMap under license of Aalborg university, planning department.

$$3039{,}53m2 * 16m = 48632{,}48m3/23y/150m = 14{,}09\ m3/y/m$$

But this still does not include the beach or wet profile erosion

Another method for calculating the cliff retreat is by finding the distance between the former cliff edges to the cliff edge found today. This can be done by creating perpendicular lines to a cliff edged parallel line, which is then used for creating intersections between the cliff edge-polylines and the perpendicular lines. The distances can then be found from the parallel line to each point along the perpendicular lines. An illustration can be seen in Figure 7.7 and the method can be found in the ArcMap model builder and workflow chart depicted in appendix E. The method is well-known and also documented in a freely available tool referred to as DSAS (Digital shoreline analysis system) described in (Thieler et. all., 2008) but it was valued higher to create the process from the bottom to ensure as close monitoring with results as possible.

By finding the retreat in meters on the Cliff edge perpendicular lines seen in Figure 7.7, the averaged erosion can be found for the different periods as well as for the whole period – the following erosion rates are found from appendix D

<u>**Average erosion rates 1995 and 2009**</u>

$0{,}47m/y$

<u>**Average erosion rates 2009 and 2016**</u>

$1{,}28\ m/y$

<u>**Average erosion rates 2016 and 2018**</u>

$1{,}62\ m/y$

<u>**Average erosion rates 1995 and 2018**</u>

$1{,}06\ m/y$

The volume lost from the cliffs can also be estimated for this erosion estimation

$$1{,}06m/y * 16m = 16{,}96m3/m/y$$

Again, this does not include the erosion of the beach.

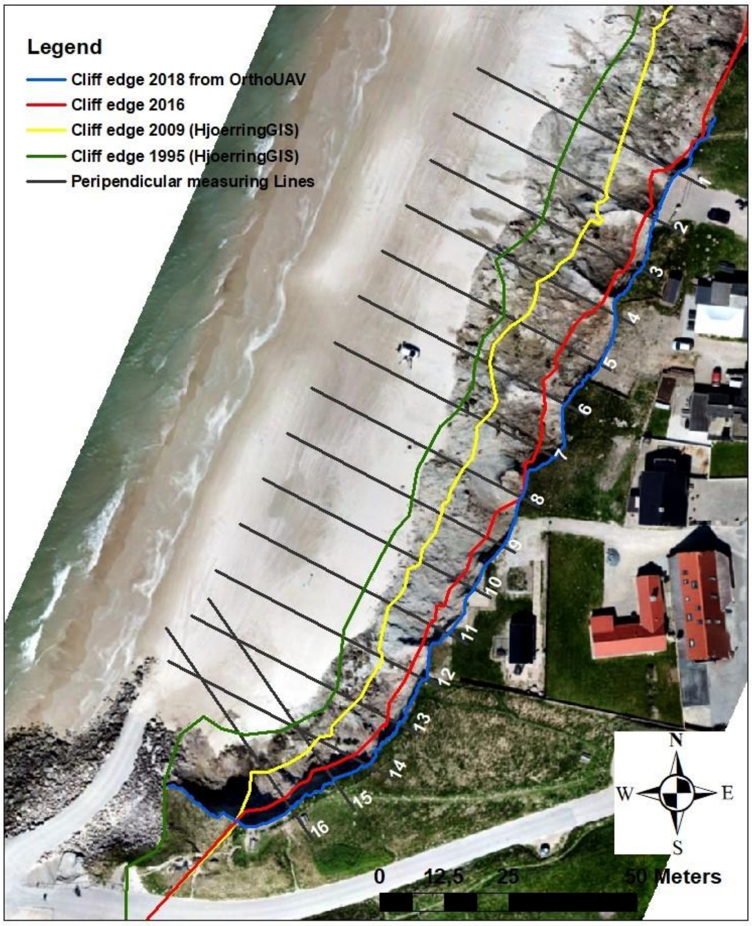


Figure 7.7 – in inland cliff parallel line have been used to create cliff parallel lines for estimation of the erosion in lines – the workflow process is described in appendix E. The underlying orthophoto is the one produced fro the 14th of may 2018. The map is produced by the author in ArcMap under license of Aalborg university, planning department.

From the different methods shown here it is clear that none of them is perfect and they are highly dependent on the way they are interpreted and where they are conducted from. The chronic erosion in the wet profile must be included for the stretch as it is a natural part of the overall system, but the beach erosion is still not included in any of the models, and the erosion rates found from the cliff edge retreat is at best an estimate since it is made from an average height over the whole length. Therefor the erosion model on the dry part of the beach could be estimated from high resolution dense point cloud derived from either LiDAR scans or from photogrammetric 3D modelling from UAVs.

7.3 Change detection – volume UAV vs. dk-DEM

This section will revolve around Figure 7.8 and the different erosion rates will be collected and related in the end of this chapter. As the produced DEM from the 14th og May did not undergo any classification of terrain or surface the DEM result is a pure surface model also referred to as DSM (DSM2018). When comparing it to the National model it is important that the corresponding model is used for change detection. The National DSM from 2014 (DSM2014) has been collected from kortforsyningen.dk to assess the volumetric changes between the two periods in order to estimate a more precise volume deficit in the cliff area and on the beach.

The two layers are imported into ArcMap, and a simple function under the raster tool box named “minus” was used to subtract the DSM2014 from the DSM2018 which reveal the elevational changes between the raster layers. As the two layers are not of the same grid size (DSM2014 is 0,4m while DSM2018 Is 0,05m) they are to some extent difficult to compare, but the result is created in a 0,4m grid, so the raster cells within the 0,4m cells are interpolated to a comparable height, therefore changing the DSM2018 model quality. By cutting the change detection raster layer by a defined polygon – here limited by the 0,3m simplified contour line, 2018 cliff edge line and the area outer limits – the volume between the model and a specified planar surface level can be found in arcmap using the “surface volume” tool. By setting the planar surface to 0 and calculating what is above and below that surface, the changed volume can be found.

In Figure 7.8 there is a negative volume change of -10.768,53 m3 which mainly comes from the cliff, the cliff face and the landslides eroded by the sea. But a positive change is also registered of 1687,05m3 which is seen mostly as accretion on the beach. This provides an erosion of in 9081,48m3 total. As this volume deficit is stretched over the 150 meters it can be divided by the extent to estimate the yearly deficit in m3/m/y as in the later erosion estimations. As it is difficult to say when the DSM over Nr. Lyngby was created it is considered as a 4year period (2014 to 2015) meaning:

$$9081{,}48\, m^3/150\, m/4years = 15{,}14\ \mathrm{m3/m/y}$$

Additionally, it should be noticed that if one is solely looking at the erosion from the cliff the erosion rates is then altered to $17{,}95\ \mathrm{m3/m/y}$. It is though interesting that sand has accumulated on the beach, but as it is has been a very calm spring with good weather the accretion is explained by the seasonal changes in the profile as a beach berm creation with overtopping waters carrying sediment.

The results from the different erosional analysis is collected in Table 7.2. One obvious advantage of the WCL transects is that the it extends into the wet profile which non-others do. The DEM is limited to handle the volumetric development as clear erosion rates are found from both cross-cliff line and Cliff. The DEM presents an erosion rate just in-between the once for Cross cliff line and cliff area. Even though the volumetric erosion rates per meters is almost identical between DEM evaluation and Transect estimation, it must be disregarded as is on set to 8 meters in elevation, WCL2080 is presented as WCL2090 was estimated as a unsatisfiable measure as it included the breakwater and the erision rates in cliff face and volume could be regarded incorrect if compared to the stretches few meters on each side. The WCL transects is not always placed in the perfect position for the given project, and they are only made for the west coast so not able for applications in the rest of Denmark. The traditional Cliff edge and area loss approach presents a well-founded approach for estimation on retreat rates in cliff edge while volumetric development must be considered as a qualified guess. The accuracy of the DEM insured model quality was high enough for comparison with the national model, at it is therefore estimated as a very accurate volumetric measure of the actual erosion/accretion in the dry part of the profile.

	Submerged Retreat in $\mathrm{m3/m/y}$	Retreat in $\mathrm{m3/m/y}$	Retreat in $\mathrm{m/y}$
Transect	13,16 (WCL 2090)	15,13 (WCL 2080 from0m to 8m)	1,59 (WCL 2080)
Cross cliff line	-	16,96	1,06
cliff area	-	14,09	0,88
DEM	-	15,14 (17,95)	-

Table 7.2 – showing results of the erosional analysis.

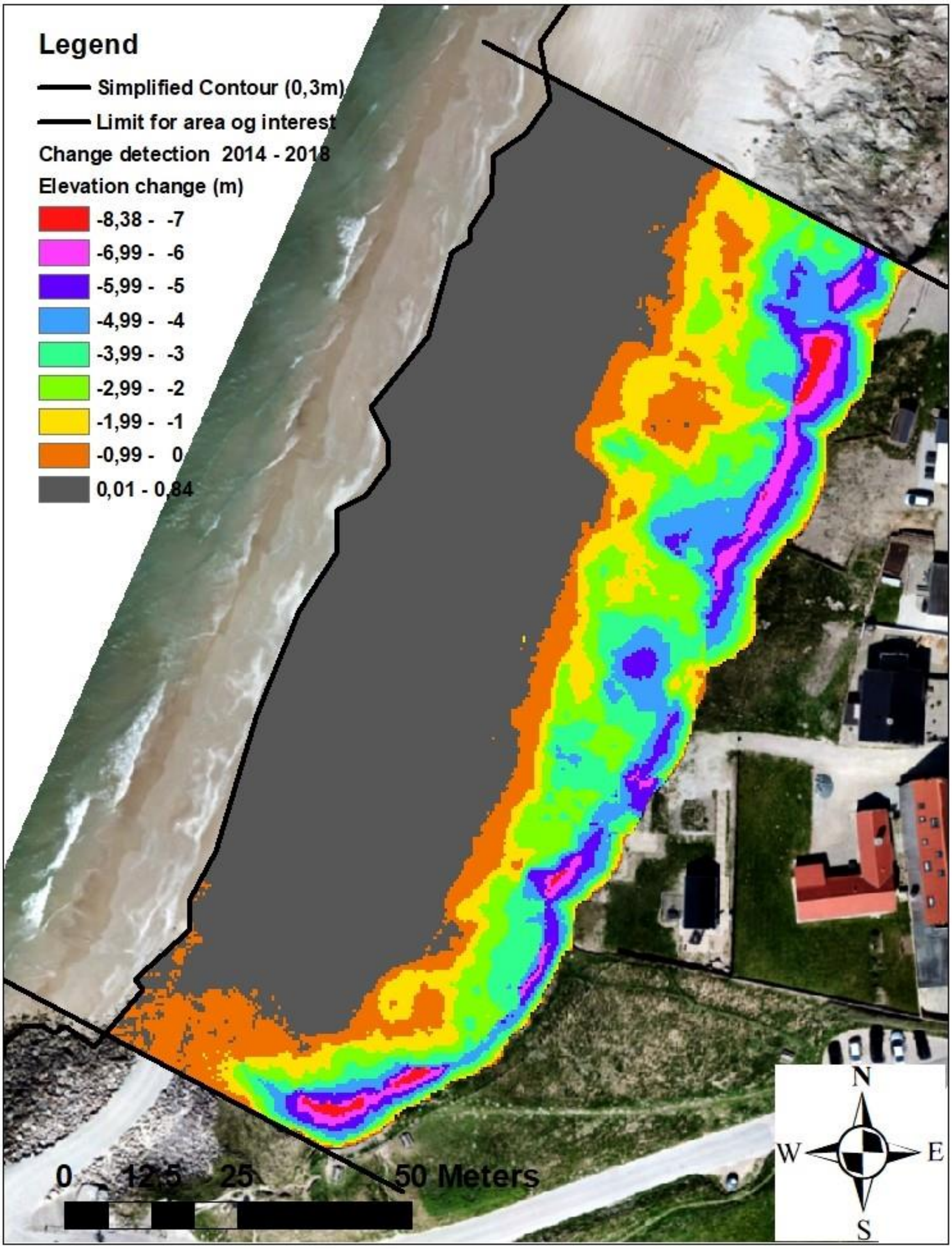


Figure 7.8 – The map is created from subtracting the 2014 national DSM from the newly created DSM from the 14th of April. The result has been cut to a limited area defined as the area of interest limits, the cliff edge from the 14th of May 2018 and the 0,3 simplified contour line from the 14th of May 2018. This seaward limit was chosen as it looks to be a fairly good position of the maximum swash extent – this is based on the highest water level up to 5 days before reached +20cm and there seems to be a natural deposit of white material along the 0,3-contour line which could show a deposition of lighter material at the maximum swash extent on the beach berm. The underlying orthophoto is the one produced from the 14th of May 2018. The map is produced by the author in ArcMap under license of Aalborg university.

8. The need for UAV based coastal monitoring

Changes of the laws governing the coastal areas of Denmark has meant restructuring and changes as: dispensations from other laws being included in the coastal protection law, freedom of method, one-stop shop solution where it is no longer required to apply at several institutional levels and changes in requirements for the necessity and price of installations for private ground owners, are all elements in the law. This could suggest that more private coastal erosion protection is to be installed in the near future. As it is still a requirement that no negative effects, around coastal protection structures or at the neighbor stretches can be allowed, this needs to be incorporated in both technical designs and permissions for the installation, and this could include documentation requirement. When Large-scale projects is being implemented on institutional levels requirements of reporting and documentation on nourishment quantities and effect is needed. Installations, weather and climate changes are all features that has the potential to change the outline of the coastline and ease-of-use methods for high resolution spatial and temporal monitoring could possibly be implemented in coastal management for monitoring and change detection.

Using UAV imagery for DEM and Orthophoto production has proven to be possible with high enough planimetric and altimetric precision for comparison with national models. Whether the tool can be described as a cost-efficient or even low cost is difficult to assess as pricing for the measured stretch with LiDAR has not been evaluated. But it is though expected to be as the DJI mavic Pro is a consumer priced drone and it is easily transported making it possible to do UAV based measurement with higher temporal repetition as the equipment needed is easily brought to the field while planning, if the weather allows, is highly flexible and can be performed on a day to day basis. There shall be no doubt about the LiDAR measurement being a better tool when working in larger areas since GCPs and GTPs is not required in the same way as for the UAV approach. If a survey was to be conducted in e.g. a 1000X1000m area this would increase the requirements and processing time for the UAV measurement substantially. Even though processing is necessary for the LiDAR derived DEM, it is still not found to have much processing time after acquisition, since internal referencing systems far excides the precision of the INS/GLONASS system found in the DJI mavic Drone.

There has been found some disadvantages from the UAV approach. Requirements according to the new Danish “Drone Law” must be followe. Windspeeds must be under 10m/s and preferably 8m/s for the drone to autonomously follow the flight plan intended. Rainfall is a natural obstacle as the drone and sensor lens cannot be wet. The weather conditions strongly effect the window for possible monitoring campaigns as sunny days with windspeeds under 10-8 m/s are limited in the coastal zone. Although the method could be implemented right after storm conditions, heavy swell can be a challenge as the waves will travel fare up on the beach making it difficult to acquire the

GCPs and GTPs while the depth information in the images will introduce noise to the model as structures in the beach surface will frequently change.

The advantages from the UAV monitoring approach is that it can be made with high temporal repetition in smaller scaled monitoring campaigns, although the extent of the survey area is limited as it is dependent on flight time restrictions from the amount of batteries, it is still considered to be useful in larger areas than presented in the report. It is to some extent cost effective as the field trip planning is very flexible and can be done from day to day if the weather allows for it. The equipment requirements are low, and easily handled by one of two persons while the workload from the field trip, setting GCPs and GTPs, measuring the latter and acquiring imagery was only found to be 3 hours for 1 person in the measured area – that is if the initial flight is successful. The processing time og 15 to 24 hours for construction of the model can be time consuming, but as the workload in hours is highly dependent on the number of photos acquired and their quality, predetermined model quality criteria also implies decreasing of processing workload e.g. by flying in a higher altitude over the area gaining a higher GSD, and thereby reducing the amount of images needed. – this was implemented for the 14th of May where a more structured planning resulted in fewer photos, and surprisingly higher model quality. As mentioned high resolution orthophotos and DEMs of high temporal resolution as well, makes monitoring during seasons or after storms possible. The applications of the models have been used for change detection in both cliff edge retreat and dry profile volume change for estimations of erosion rates. There cannot be much doubt about the quality of model is at least to the same precision if not better than the transect measurements, on dry land. As the models cannot be constructed for the bed contours, the profile measurement in the vet profile is still necessary to incorporate for complete erosional analysis of a stretch. The scale for the transect measurement are of course also very different, and as the transects are set every 1000 meters they are supposed to create a more overall view on the general conditions of the coastal development, while the UAV Drone based method is better applied for shorter stretches (dependent on drone type, battery quantity and life) for more accurate change detections from DEM comparison and orthophoto change detection. The DEM cannot stand alone, and it is recommended to be used in combination with orthophoto analysis as the erosion rates in m/y is often used to estimate when a property is expected to be critically endangered from the erosion. Independent measurements such as GTPs and SPMs should in general be included in a UAV based photogrammetric approach, and it is suggested to use well defined targets making rereferring even more precise. Despite the quality control tool available in AgiSoft, it is still recommended to use the GTPs and SPMs for estimation and documentation on model quality. Validation of the statistical measures should be performed so the model parameters can be verified. Model quality is also a factor for the applications of the model as 5cm vertical error for the model in the measured areas could result in a volumetric deficit of surpluses. The model is though thought to have high validity when compared to the LIDAR DEM, orthophotos and transect measurements, both regarding workload and accuracy.

9. Conclusion

How can the use of Orthophotos and DEMs derived from UAV imagery be utilized in coastal management and what model requirements should be fulfilled?

As the changes in the coastal profile is dependent on coastal dynamics over seasons to decades, the fact that high temporal measurements are available from the presented method makes future investigation of effects from coastal protection and storms more accessible than ever before. And as monitoring can be conducted continuously during the season in high resolution orthophotos and DEMs the method could also be used for time series analysis over years.

The UAV approach for monitoring volumetric changes is expected to become more and more influential as monitoring campaigns could be a necessity for both small-scale and large-scale projects. The DEMs and Orthophotos derived from UAV imagery can be implemented with great success in coastal science for monitoring and change detection. It is possible to produce models, as precise as the National models and thereby is can be implemented in change detection, erosion rate estimations and temporal monitoring of the coast.

Bibliography

Agisoft. (2018). *Agisoft PhotoScan User Manual - Professional Edition, Version 1.4.* Agisoft.

Balstrøm, T., Jacobi, O., & Bodum, L. (2013). *Bogen om GIS og Geodata.* København: Forlaget GIS og Geodata.

Brunier et. all., G. (2016, February 26). Close-range airborne Structure-from-Motion Photogrammetry for high-resolution beach morphometric surveys: Examples from an embayed rotating beach. *Geomorphology*, pp. 76–88.

Cook, K. L. (2016, November 15). An evaluation fo the effectiveness of low-cost UAVs and structure from motion for Geomorphic change detection. *Geomorphology*, pp. 195-208.

Deltares. (2016). *MorphAn 1.5.0, user manual.* Delft: Deltares.

DHI, H. &. (2015). *Kystdynamik og kystbeskyttelse.* Lemvig: Kystdirektoratet.

Erhvervsministeriet. (2017, june 1). *Erhvervsministeriet.dk.* Retrieved from http://em.dk/: http://em.dk/nyheder/2017/06-01-planlov-vedtaget

Erhvervsstyrelsen. (2018, March 30). *Bekendtgørelse af lov om planlægning*. Retrieved from www.retsinformation.dk: https://www.retsinformation.dk/Forms/R0710.aspx?id=200614#ided93efb3-3071-43dd-9726-b5aaab27c76d

F, K. (2012). *Højvandsstatistikker - 2012.* Lemvig: Kystdirektoratet.

Folketinget. (2017, may 30). Lov om ændring af lov om planlægning, lov om naturbeskyttelse og lov om aktindsigt i miljøoplysninger. *Folketingstidende H*. København.

GeoDanmark. (2014). *Specifikation FOT 5.1 forenklet udgave.* København: GeoDanmark.

Geoforum, O. (2011). *Specifikationer for ortofotos.* København: Styrelsen for Dataforsyning og Effektivisering. Retrieved from http://sdfe.dk/saadan-arbejder-vi-med-data/flyfotos-og-laserscanning/

Gonçalves, G. R., Pérez, J. a., & João, D. (2018, march 08). Accuracy and effectiveness of low coast UASs and open source photogrammetric software for fordune mapping. *International journal of remote sensing*.

Gonçalves, J., & Henriques, R. (2015, March 25). UAV photogrammetry for topographic monitoring of coastal areas. *ISPRS Journal of Photogrammetry and Remote Sensing*, pp. 101-111.

Hawa et. al, M. n. (2011). *Horizontal Accuracy of Digital Elevation Models.* Copenhagen: Danish ministry of Environment.

Hjoerring Kommune A. (2016). *Natura 2000 handleplan for Rubjerg Knude og Lønstrup Klint.* Hjoerring: Hjoerring Kommune,.

Höhle, J., & Höhle, M. (2009, March 19). Accuracy assessment of digital elevation models by means of robust statistical methods. *ISPRS Journal of Photogrammetry and Remote Sensing*, pp. 398-408.

IPCC, 2. (2014). *Climate Change 2014: Synthesis Report.* Geneve: IPCC.

James, M., Robsonb, S., & et. all. (2016, December 3). Optimising UAV topographic surveys processed with structure-from-motion: Ground control quality, quantity and bundle adjustment. *Geomorphology*, pp. 51 - 66.

Jaud, M., & Passot et. all, S. (2016). Technocal note: Assesing the accuracy of high resolution digital surface model computed by Photoscan and MicMac i sub-optimal survey conditions. *Remote sensing*, p. 465.

KMS / Geografisk Infrastruktur, G. (2012). *Danmarks Højdemodel 2007, DHM-2007/Terræn.* København: Kort & Matrikelstyrelsen.

Koningsveld, M. v., & Mulder, J. P. (2004, Spring). Sustainable Coastal Policy Developments in the Netherlands. A Systematic Approach Revealed. *Journal of Coastal Research*, pp. 375-385.

Kystdirektoratet A. (2018). *Kommune med kystansvar modul 1.* Lemvig: Miljø- og fødevareministeriet.

Kystdirektoratet B. (2015). *Tilladelse til tildækket skråningsbeskyttelse med kompensationsfodring ud for og på matr. nr. 22es, 22ec, 22eb, 22b, 22bm, 22bl, 22bi, 121d, 121bu, 22es, 22dm, 22et Furreby By, Furreby og 121a Løkken Ladeplads, Furreby, Hjørring Kommune.* Lemvig: Kystdirektoratet.

Kystdirektoratet C. (2016, 07 08). *Tilladelse til tildækket skråningsbeskyttelse med kompenserende fodring ved Nørlev Strand... Hjørring kommune.* Lemvig: Kystdirektoratet.

Kystdirektoratet E. (2018, May 28). *kyst.dk*. Retrieved from soeterritoriet.kyst.dk: http://soeterritoriet.kyst.dk/opmaaling-af-strand-og-havbund.html

Lescinski, J. (2010, May). Description of coastal state indicators. *Concepts and Science for Coastal Erosion*. Retrieved from www.conscience-eu.net

Longhurst, R. (2010). Semi-structered Interviews and Focus Group. In N. Clifford, S. French, & G. Valentine, *Key Methods in Geography* (pp. 103-116). London: SAGE publications Inc.

M.J. Westoby et. all, J. B. (2012, September 6). 'Structure-from-Motion' photogrammetry: A low-cost, effective tool for geoscience applications. *Geomorphology*, pp. 300-314.

Martin Olesen, e. (2014). *Fremtidige klimaforandringer i Danmark.* København: Danmarks Meteorologiske Institut. Retrieved from www.dmi.dk/klimaforandringer

Masselink et. all., G. (2011). *Introduction to COastal processes & geomorphologi.* New York: Routledge.

Miljø- og fødevarerministeriet A. (2018, Februar 28). Lov om ændring af lov om kystbeskyttelse. *www.retsinformation.dk*. Retrieved from https://www.retsinformation.dk/Forms/R0710.aspx?id=198230

Miljø- og fødevarerministeriet B. (2017, februar 19). Bekendtgørelse af lov om kystbeskyttelse. *www.retsinformation.dk*. Retrieved from https://www.retsinformation.dk/Forms/R0710.aspx?id=186247

Miljø- og fødevarerministeriet C. (2017, Juni 27). Bekendtgørelse af lov om naturbeskyttelse. *www.retsinformation*. Retrieved from https://www.retsinformation.dk/Forms/R0710.aspx?id=192144

Miljø- og fødevareministeriet D. (2018, Marts 15). Lov om ændring af lov om kystbeskyttelse, lov om miljøvurdering af planer og programmer og af konkrete projekter (VVM), lov om naturbeskyttelse, lov om jagt og vildtforvaltning og forskellige andre love1). *Folketingstidende A*. Retrieved from http://www.ft.dk/samling/20171/lovforslag/L187/som_fremsat.htm

Miljø- og fødevareministeriet E. (2018). *Kommune med kystansvar - Modul 1.* Lemvig: Kystdirektoratet.

Miljø- og fødevareministeriet F. (2017, November 15). Forslag til Lov om ændring af lov om kystbeskyttelse. *Folketidende A*. Retrieved from http://www.ft.dk/samling/20171/lovforslag/l100/index.htm

Miljøstyrelsen. (2018, March 16). *miljøstyrelsen.dk.* Retrieved from https://mst.dk: http://mst.dk/natur-vand/natur/national-naturbeskyttelse/3-beskyttede-naturtyper/

MVFM. (2017, june 1). *mvfm*. Retrieved from mvfm.dk: http://mfvm.dk/nyheder/nyhed/nyhed/det-bliver-nemmere-og-hurtigere-at-kystbeskytte/?utm_medium=email&utm_source=fvm_nyhedsmail&utm_campaign=det-bliver-nemmere-og-hurtigere-at-kystbeskytte&cHash=17d503b657f799f8a0fa38b5893593dc

Pedersen et. all., S. A. (2016). RUBJERG KNUDE - KLINT, KLIT OG KLIMA – en geologisk historie om Vendsyssels dannelse. *Geoviden - Geologi og geografi Nr. 3*, pp. 1 - 20.

Regeringen, D. f.-S. (2016, june 9). *erhvervsministeriet.* Retrieved from https://em.dk/aftaler-og-udspil/: https://em.dk/aftaler-og-udspil/16-06-09-planlovsaftale

Ruessink, B., Arens, S., Kuipers, M., & Donker, J. (2017, July 4). Coastal dune dynamics in response to excavated fordune notches - article in press. *Aeolian research*.

Sand-Jensen et. all., K. (2012). *Naturen i Danmark - Geologien.* København K: Gyldendal.

SDFE, s. (2016). *Danmarks Højdemodel, DHM/Terræn.* København: Styrelsen for Dataforsyning og Effektivisering.

Short, A., & Aagard, T. (1993, Spring). Single and multi-bar Beach Change Models. *Journal of coastal research*, pp. 141 - 157.

TGP. (2005). *Geostatistics - Advanced statistical data treatment.* Aalborg: Aalborg universitet.

Thieler et. all., E. H. (2008). *Digital Shoreline Analysis System (DSAS) version 4.0—An ArcGIS extension for calculating shoreline change (ver. 4.4, July 2017).* U.S. Geological Survey Open-File Report 2008-1278. Retrieved from https://pubs.er.usgs.gov/publication/ofr20081278

Transport-, B. o. (2017, November 29). *Bekendtgørelse om flyvning med droner uden for bymæssigt område.* Retrieved from Retsinformation.dk: https://www.retsinformation.dk/Forms/R0710.aspx?id=194974

Aargard et.all., T. (2008). *Kystmorfologi.* København: Institute of Geography and Geology.

A. Appendix – volume analysis between +8m and -8m

	Line number - m3/m between +8m and -8m

Year	2060	2070	2080	2090	2100	2110	2120
1977	4713,49	7189	6157,61	5986,58	6264,18	5898,55	5753,65
1978	4643,17	7235,99	6220,8	6089,44	6327,83	5813,85	5711,88
1980	4784,32	7300,12	6160,11	6005,52	6349,74	5699,08	5833,49
1983	4789,8	7200,69	6008,38	5856,97	5975,25	5698,77	5444,11
1985	4819,03	7105,95	5861,69	5749,44	6389,44	5819,61	5824,85
1987	4726,55	7087,29	5814,49	5992,43	6311,46	5781,52	5846,49
1989	4483,46	6973,06	5313,79	6066,23	6179,32	5779,07	5723,47
1991	4716,6	7117,06	5546,63	5938,55	6211,5	5651,25	5842,79
1993	4742,41	6921,12	5499,4	5923,29	6257,72	5707,21	6012,63
1995	4942,26	6886,21	5448,33	5800,12	6254,03	5883,28	5855,73
2000	4300,88	6624,82	5436,05	5794,78	6111,12	5850,39	5639,26
2004	4198,08	6753,92	5391,16	5738,37	6268,72	5793,72	5771
2008	4308,01	6643,72	5207,51	5666,4	5961,86	5750,81	5591,17
2016	4429,7	6456,09	5241,28	5409,6	6049,54	5736,13	5832,42
Total Change (m3/m)	-283,79	-732,91	-916,33	-576,98	-214,64	-162,42	78,77
Lineare reg - Avg. yearly development (m3/m)	-12,89	-21,33	-27,29	-13,16	-6,42	-0,71	0,35
r2	0,44	0,92	0,78	0,71	0,31	0,01	0,00

B. Appendix – volume analysis between 0m and -8m

	Line number - m3/m between 0m and -8m						
Year	2060	2070	2080	2090	2100	2110	2120
1977	3917,49	5326,58	4916,72	4911,09	5092,83	4939,58	5025,84
1978	3847,18	5379,92	5031,51	5015,52	5152,47	4854,3	4991,32
1980	4024,61	5445,18	4970,82	4980,93	5236,92	4780,17	5108,09
1983	4030,75	5344,19	4900,31	4845,69	4898,01	4800,5	4785,45
1985	4060,36	5250,66	4753,63	4742,52	5303,38	4955,24	5198,23
1987	3996,55	5329,61	4760,02	4991,37	5257,98	4883,43	5221,34
1989	3783,36	5258,97	4312,63	5063,37	5123,51	4894,43	5114,81
1991	4022,98	5412,71	4578,9	4944,97	5194,87	4767,62	5230,6
1993	4090,06	5213,22	4561,01	4925,17	5236,64	4856,72	5409,42
1995	4283,73	5210,75	4551,03	4810,61	5219,67	5017,68	5238,76
2000	3679,01	4963,94	4546,23	4772,42	5052,71	4914,43	5030,37
2004	3615,57	5116,77	4534,36	4751,4	5224,02	4892,76	5139,67
2008	3769	5033,66	4347,21	4671,97	4930,5	4852,12	4985,43
2016	3939,5	4952,8	4488,98	4416,77	5020	4846,71	5198,34
Total change between 1977 and 2016 (m3/m)	22,01	-373,78	-427,74	-494,32	-72,83	-92,87	172,5
Lineare regression - avg yearly change (m3/m)	-4,77	-12,04	-15,13	-11,55	-3,25	0,26	2,87
r2	0,10	0,77	0,60	0,63	0,09	0,00	0,05

C. Appendix – Duneface analysis (+6m to +5m)

	Line number - Cliff face position from inland fix point (m) (+6m to +5m)						
Year	**Nr. 2060**	**Nr. 2070**	**Nr. 2080**	**Nr. 2090**	**Nr. 2100**	**Nr. 2110**	**Nr. 2120**
1977	1095,16	1226,72	1146,61	1127,50	1135,95	1114,93	1082,90
1978	1095,16	1227,06	1146,16	1129,15	1136,18	1115,57	1083,48
1980	1089,64	1227,06	1146,16	1123,18	1133,95	1111,99	1085,13
1983	1089,64	1227,06	1134,71	1122,78	1123,96	1108,95	1077,04
1985	1089,64	1227,06	1134,71	1120,93	1126,97	1106,25	1072,15
1987	1084,28	1215,24	1125,04	1119,46	1122,09	1106,78	1067,01
1989	1082,73	1209,31	1121,12	1116,42	1119,50	1105,14	1065,30
1991	1081,95	1207,93	1117,44	1116,55	1118,25	1103,28	1065,19
1993	1078,04	1209,38	1112,02	1117,15	1118,06	1100,98	1064,87
1995	1077,95	1205,16	1107,83	1116,92	1117,85	1101,66	1067,39
2000	1071,19	1201,10	1103,03	1120,37	1117,87	1106,76	1064,19
2004	1067,21	1200,50	1099,53	1116,08	1117,89	1103,49	1065,26
2008	1059,78	1196,55	1100,09	1116,69	1117,36	1102,24	1064,66
2016	1056,88	1183,01	1089,08	1116,70	1117,46	1103,57	1066,21
Total change (m)	-38,28	-43,71	-57,53	-10,80	-18,49	-11,36	-16,69
Lineare reg. – horizontal movement (m/y)	-1,04	-1,15	-1,59	-0,27	-0,49	-0,30	-0,51
r2	0,98	0,93	0,93	0,55	0,63	0,53	0,56

D. Appendix - Cliff edge erosion rates

The table below describes the retreat of the cliff edge in meters between different periods. The cliff edges were drawn manually in ArcMap and in hjoerring Web GIS. The original distances have been found to an inland coast parallel line. The distances has then been subtracted from the 2018 cliff edge line to find to find the real retreat until the 2018 cliff edge line. The workflow for extracting the distances can be found in appendix E. Line nr. Refers to the cliff edge peripendicular lines numbered in Figure 7.7

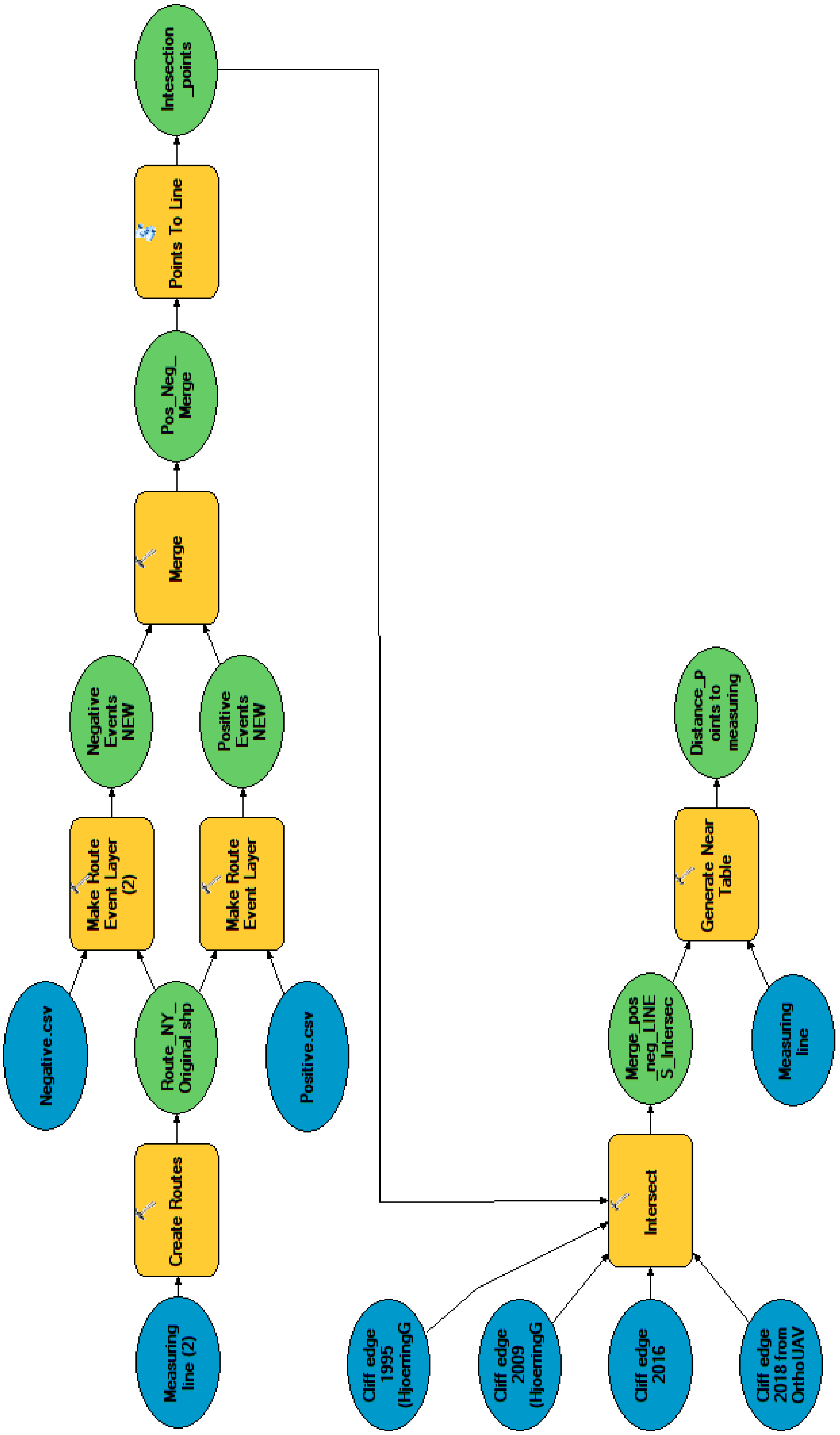
	Erosion 1995 - 2009 (m)	Erosion 2009 - 2016 (m)	Erosion 2016 - 2018 (m)	Total erosion 1995 - 2018 (m)
Line nr. 1	-9,27	-10,64	-1,81	-21,73
Line nr. 2	-7,08	-8,18	-3,51	-18,76
Line nr. 3	-6,15	-8,41	-4,02	-18,59
Line nr. 4	-8,66	-5,92	-3,54	-18,12
Line nr. 5	-4,80	-6,88	-2,34	-14,02
Line nr. 6	-4,92	-6,38	-3,41	-14,71
Line nr. 7	-5,37	-4,96	-2,90	-13,23
Line nr. 8	-4,60	-4,17	-2,38	-11,15
Line nr. 9	-10,64	-8,87	-1,86	-21,37
Line nr. 10	-8,17	-10,90	-2,68	-21,75
Line nr. 11	-9,49	-11,71	-3,62	-24,82
Line nr. 12	-3,09	-10,01	-8,02	-21,12
Line nr. 13	-2,92	-11,85	-4,49	-19,26
Line nr. 14	-5,20	-12,03	-3,65	-20,89
Line nr. 15	-7,77	-12,74	0,19	-20,32
Line nr. 16	-6,33	-9,92	-3,66	-19,92

On the following page the averaged yearly retreat can be found.

The table below is made from the erosion rates in meters from the above table divided with the amount of years it took for the erosion, meaning between the available polylines for 1995, 2009, 2016 and 2018. Line nr. Refers to the cliff edge peripendicular lines numbered in Figure 7.7

	Erosion 1995-2009 (m/y)	Erosion 2009-2016 (m/y)	Erosion 2016-2018 (m/y)	Total erosion 1995-2018 (m/y)
Line nr. 1	-0,66	-1,52	-0,91	-1,27
Line nr. 2	-0,51	-1,17	-1,75	-1,05
Line nr. 3	-0,44	-1,20	-2,01	-1,05
Line nr. 4	-0,62	-0,85	-1,77	-1,02
Line nr. 5	-0,34	-0,98	-1,17	-0,87
Line nr. 6	-0,35	-0,91	-1,71	-0,89
Line nr. 7	-0,38	-0,71	-1,45	-0,88
Line nr. 8	-0,33	-0,60	-1,19	-0,80
Line nr. 9	-0,76	-1,27	-0,93	-1,25
Line nr. 10	-0,58	-1,56	-1,34	-1,17
Line nr. 11	-0,68	-1,67	-1,81	-1,32
Line nr. 12	-0,22	-1,43	-4,01	-1,08
Line nr. 13	-0,21	-1,69	-2,25	-1,11
Line nr. 14	-0,37	-1,72	-1,83	-1,05
Line nr. 15	-0,55	-1,82	0,09	-1,12
Line nr. 16	-0,45	-1,42	-1,83	-1,04
Average Erosion (m/y)	-0,47	-1,28	-1,62	-1,06

E. Appendix – ArcMap workflow for estimation cliff edge erosion rates



F. Appendix – Interview

Interview with:

Lise Holm

Project manager on "The future of the north shore"

Conducted on the 08th of May 2018 at 14:30

Interview Guide

Erfaringer fra helhedsprojektet

- Kan du give en kort introduktion til Helhedsprojektet for den nordsjællandske kyst?

- Har i haft nogen udfordringer i forbindelse med at skabe helhedsprojektet?
  – Administrativt, Borgerinddragelse, bidragsfordeling, økonomi, tværkommunal løsning eller kystteknisk design?

- Hvordan er udfordringerne blevet løst?

- Er der opbakning blandt borgene til Projektet? (Hvordan har man inddraget borgene i projektet)

Hidtidig Kystbeskyttelse og ny lovgivning

Ændringerne af kystbeskyttelse loven (inkl. de kommende fra September 2018) gør jer kommunerne til myndighed på området og der vil være mulighed for at dispensere for de fleste andre lovgivning efter en kystbeskyttelse tilladelse.

- Har man i Gribskov oplevet konflikter mellem myndigheder og borgere grundet den tidligere kystsikringslov? Hvis ja – hvilke og hvorfor

- Vil lovændringen have indflydelse på hvordan man i fremtiden vil håndtere kystbeskyttelse sager i kommunen? – Hvordan?

- Vil ændringen af Kystbeskyttelses loven have indflydelse designet af de kysttekniske anlæg der vil kunne blive tilladt i Gribskov? Vil det ændre på de forslag der allerede er sat op i Helhedsprojektet.

Administration af anlæg

- Hvordan kan kommunerne tilsikre man at vilkår for kystsikrings tilladelser overholdes?

Bliver der på nuværende tidspunkt ført tilsyn med eksisterende kystsikrings anlæg på kommunens nordkyst? – Vil der blive ført tilsyn hvis man overtager myndighedskompetencen?

Transcription

Speaker	Start time for sentence	
Henrik:	00:27	Ja Allerførst – Lise holm Projekt leder nordkystens fremtid kan jeg forstå, vil du fortælle lidt om hvad du laver i Gribskov kommune
Lise:	00:35	Jeg er projektleder på et fælles kystbeskyttelses projekt som: Halsnæs, Gribskov og Helsingør sammen finansiere projekteringen af, så jeg arbejder i virkeligheden for alle tre kommuner.
Henrik:	00:51	ok så det er simpelthen alle tre du er ansat ved.
Lise:	00:55	Ja
Henrik:	00:57	Godt, jamen vil du lave en kort introduktion til hvad det her helheds projekt for den nordsjællandske kyst det går ud på?
Lise:	01:03	ja det går ud på at lave en helhedsbeskyttelse i form af det man kalder for strandfodring, altså det vil sige at det fælles projekt det skal finde i omegnen af 10millioner m3 sand ude i Kattegat og så skal det lægges ind på øh sådan cirka 60 km in på et sted mellem 7 og 9 forskellige fodrings strækninger. På den måde yder det kystbeskyttelse af den samlede nordkyst
Henrik:	01:37	Ja det var en meget præcis beskrivelse jo. Til det; vil der indgå hård kystsikring i det her?
Lise:	01:47	Nej det vil der ikke i det fællesprojekt. Det fælles projekt anviser hvor der eventuelt kan anlægges hård kystbeskyttelse, men der er ikke noget hård kystbeskyttelse med i det fælles projekt, det er grundejerne selv der skal stå for det.
Henrik:	02:01	Yes, så forslag til placering kan jeg godt notere, men ingen finansiering eller…
Lise:	02:06	Ingen, Nej ingen finansiering og ingen projektering af konkrete anlæg
Henrik:	02:12	Okay, fedt. Yes jamen eeh vi tager lige Næste spørgsmål så, **har i, i forbindelse med projekteringen af Helhedsprojektet oplevet nogen, hvad hedder det, udfordringer**
Lise:	02:23	Øh ja, en af de udfordringer som øh som er ret væsentlig det er at det er nyt for myndighederne, dvs især miljøstyrelsen og skulle håndtere sådan et projekt som det her, når det er 3 kommuner som ansøger sammen.
Henrik:	02:50	Ja

Lise:	02:51	Normalt når miljøstyrelsen får ansøgninger ind på hhv. råstof og kystbeskyttelses projekt, så er det én bygherre og det er ikke særligt tit at det er en offentlig bygherre som ansøger, så derfor så er det, så er myndighedshåndteringen af det, er en udfordring. Og så for det ikke skal være nok, så er kystbeskyttelses loven også under ændring – Kraftig ændring.
Henrik:	03:15	Ja
Lise:	03:16	På flere forskellige leder og kanter og det ramler vi også ind i, vi kan også risikere at skulle skifte myndighed midt i projektet – eller ikke risikere, det kommer til at ske at myndigheden overgår fra miljøstyrelsen til kommunen midt i det hele og også en del af den myndighed der ligger i kystdirektoratet overgår også midt i projektet
Henrik:	03:41	Ja
Lise:	03:43	Det er en udfordring, en anden udfordring det er, øh det er at det er virkeligt mange interessenter
Henrik:	03:52	ja
Lise:	03:53	…Som jo især er kyst grundejere som vil skulle betale for det og det er selvfølgelig fordi der er, ja det er sådan en lang strækning
Henrik:	04:04	ja
Lise:	04:05	… og det er så stort det her projekt
Henrik:	04:08	Der bor mange ned langs med vandet der på den strækning, så vidt jeg…
Lise:	04:12	Ja den er jo faktisk beboet på største delen af de 60 kilometer, det er sådan set beboet med sommerhuse, sommerhusejere det er ikke nødvendigvis sådan de har samme interesse alle sammen
Henrik:	04:28	Okay
Lise:	04:30	Så håndtering af så mange interessenter det er også en udfordring
Henrik:	04:35	Ja, hvordan øh, **hvordan har i løst, hvad skal man sige, udfordringerne indtil videre i forhold til det med at søge som tre kommuner også forhold til det her med og jonglere grundejernes interesse e.g.**
Lise:	04:46	Jamen altså det som vi prøver, så vidt muligt, det er og have forhånd dialog. Både når det angår myndighederne og når det angår interesserne
Henrik:	05:03	Ja
Lise:	05:04	For at prøve, med myndighederne der er det for at prøve og altså, vi spørg dem når vi har et forslag til hvordan man kan lave en myndigheds behandling, eller have en løbende myndigheds behandling. Så spørger vi dem først: ”kunne det være en vej og gå frem” og så siger de Ja eller neeej måske ikke lige, og så prøver vi og tilpasse så at vi ikke, altså det er for at undgå at vi laver en masse arbejde på et stort projekt som så myndighederne vil sige det kan vi ikke tage stilling til eller det er ikke fyldest gørende nok det her for at vi kan tage stilling til det, for ikke og skabe forsinkelser i projektet.
Henrik:	05:44	Ja, så en løbende tilpasning af, hvad skal man sige af….
Lise:	05:48	Ja altså et forsøg på løbende myndighedsbehandling og så, så meget forhånds dialog som vi overhovedet kan have for at sikre os at vi er på rette vej
Henrik:	06:00	Ja, jamen…
Lise:	06:02	Og det gælder sådan set også for interessent håndtering og prøve og have dialog undervejs
Henrik:	06_06	Ja
Lise:	06:07	Så det løsninger vi kommer frem til de ikke kommer som et chok for grundejerne og borgerne

Henrik:	06:15	Ja, ja det kunne jeg forstille mig. Ja men hvad hedder det: med hensyn til borgerne, øh, oplever i så der er, hvad skal man sige, opbakning til projekt permanent, skulle jeg til at sige, til helhedsprojektet på kyst strækningen. Her tænker jeg på dem som ligger indenfor dem som ligger indenfor de her 300 meter fra kysten specielt, da det er dem der mest berørt.
Lise:	06:38	Det er meget forskelligt. Der en nogen der bakker op om det og der er nogen som bestemt ikke bakker op om det. Det er virkeligt meget forskelligt. Der er nogen borgere som ikke er overbevist om at det her strandfodring, altså sand som beskyttelse metode, som ikke er overbevist om at det overhovedet er virkningsfuldt.
Henrik:	07:03	okay
Lise:	07:05	Og så er der nogen borgere som syntes det er en god ide med strandfodrings projekt, men de syntes at staten eller kommunen skulle betale for det.
Henrik:	07:18	Ja, yes. Ja det har man jo hørt før
Lise:	07:23	Ja
Henrik:	07:25	Er det noget i oplever tit det her med, hvad skal man sige, de økonomiske udfordringer for de interessenter, det vil så sige i det her tilfælde borgerne, der er et stort problem for det her med hvem skal betale og hvordan klarer vi betalingen
Lise:	07:38	Jamen, ja vi er ikke så langt med bidrags fordelingen endnu at vi har lavet en konkret forslag til hvordan det skal foregå. Men det er jo noget ad det som vi forventer at der kommer rigtigt mange klager på
Henrik:	07:53	Ja ja
Lise:	07:54	Øhm fordi i sidste ender er det jo en politisk beslutning med hvem man skal, hvem man pålægger, hvem man pålægger bidrag og det vil man… Ja man kan jo vælge virkelig mange måder og gøre det på og der en ikke én måde som er rigtig og derfor vil man altid kunne diskutere om der var en anden måde som der var mere rigtigt eller som der var mere fair
Henrik:	08:23	Ja, jamen helt sikkert, det var også lidt det jeg regnede med der ville blive sagt. Øhm men det sådan lige lidt om helhedsprojektet, det var faktisk det jeg sådan lige havde af erfaringsmæssigt spørgsmål til det. Der spiller jo en masse forskellige sager her, rundt oppe i Nordjylland, det har man jo næsten ikke kunne undgå at se hvis man har kigget på medierne, så det er jo meget godt at have lidt erfaring med derfra til sådan nogen projekter
Lise:	08:49	Ja, ja
Henrik:	08:51	Øhm så har jeg så lidt spørgsmål til den hidtidige kystbeskyttelse og den nye lovgivning, bl.a. også administrationen anlæg nu og i fremtiden – Jeg ved ikke om du har tid til lige at tage det med også?
Lise:	09:02	Ja
Henrik:	09:04	Nu snakkede vi jo om det her med ændringerne af kystbeskyttelses loven også de kommende; det her med at kommunerne skal være myndighed på området og der også vil mulighed for dispensere for de fleste andre lovgivninger i forhold til kystbeskyttelses tilladelser og sådan nogle ting – Så myndighedsopgaven den skifter jo
Lise:	09:18	Ja
Henrik:		Men altså har man oplevet, et problem med myndighedsplaceringen nu. Altså hvor der er opstår konflikter mellem myndighed og borger pga. den tidligere lovgivning

Lise:	09:35	Jeg tror, altså det bliver lidt noget gæt, dels fordi at jeg ikke sådan en som sidder og sagsbehandler de der sager, så jeg kender det ikke helt, plus at det har jo så ligget et andet sted. Det har jo ligget i Kystdirektoratet, så der er rigtigt mange at de sager der som kommunen slet ikke kender til fordi dialog jo er foregået mellem grundejerne og kystdirektoratet. Så det ved jeg faktisk ikke – Jeg ved der er rigtigt mange grundejere om glæder sig til at kompetencen overgår til kommunen og der er begyndt og be om og få deres sager behandlet selvom at det først er, efter planen, 1 september at myndigheden overgår.
Henrik:	10:31	Ja, når jamen det er da positivt at det er taget vel imod kan man sige
Lise:	10:35	Ja, altså borgerne glæder sig meget og jeg tror, ja jeg tror altså, dels fordi at selve formåls ændringen er trådt i kræft så man i større grad kan kystbeskytte yderligere, så tror jeg at de maske syntes at kystdirektoratet har været lidt lagt væk, så de glæder sig til at sagsbehandlingen kommer lidt tættere på rent geografisk
Henrik:	11:06	Ja okay, tættere på det er jo meget godt at få med. I forhold til det her med myndighedsopgaven tror du det vil have indflydelse sådan på helhedsprojektet det her med grundejernes tilknytning og interesse i projektet nu hvor de lige pludselig kan få lov til og, for dem som har fået afslag, genansøge, om de anlæg de tidligere har ansøgt om.
Lise:	11:33	Øh ja, jeg tror at det sådan set vil bekræfte både tilhængerne og støtterne i deres overbevisning fordi dem som tvivler på det er et godt projekt de vil sige nu får vi jo lov og beskytte højere grad end tidligere, så er jo i hvert fald slet ikke nogen grund til alt det sand. Og dem som er tilhængere af projektet de vil sige det er rigtigt godt at kystbeskyttelsen går på to ben altså at der både er brug for den hårde kystbeskyttelse og at der også er brug for sand
Henrik:	12:16	Ja, okay det er noteret. De her lovændringer som er sat op, vil det have nogen indflydelse på det kysttekninske design som man foreløbigt har lavet i helhedsprojektet.
Lise:	12:40	Vil det få indflydelse på hvad for et design siger du?
Henrik:	12:42	Det kysttekniske, altså sådan i forhold til….
Lise:	12:45	Nej det vil det ikke
Henrik:	12:48	Jamen super, det var også meget et ja og nej spørgsmål, kan man sige så det fint. Ja og så lidt mere her om administrationen af anlæg, nu ved jeg ikke om det er noget du er indeover nu du ikke så meget i sagsbehandling som du sagde, men ved du om der på nuværende tidspunkt fra kommunens side af bliver ført tilsyn med de eksisterende kystsikringsanlæg på nordkysten
Lise:	13:10	Nej det gør der ikke
Henrik:	13:12	Det gør der ikke!
Lise:	13:14	Det gør der ikke udover i den forstand at kommuen jo nogen steder er med i de forskellige kystsikringslag fordi kommunen ejer en grund e.g. der er inde i et kystsikrings lag, så på den måde er kommunen med som part men det er jo på lige fod med andre. Der bliver ikke, der er ikke en myndigheds opgave der går og tjekker de eksisterende anlæg
Henrik:	13:43	Nej okay. Når så man overtager den her myndigheds kompetence, er det så noget man vil påbegynde på trods af det ikke er, som sådan i forhold til kystsikringsloven ændringer eller den nuværende kystsikringslov, er et krav

Lise:	13:58	Altså, det bliver jeg lidt i tvivl om, men man kan sige at hvis man som myndighed bliver gjort opmærksom på et ulovligt forhold har man jo pligt til at gøre noget ved det, hvis man er myndgihed for det, så på det punkt har myndigheden jo pligt til e.g. at gøre noget ved et ulovligt forhold som de bliver bekendt med
Henrik:	14:28	Ja jamen allright. Men så tror jeg faktisk at jeg har fået svaret på det som jeg havde tænkt mig at spørge om. Også i forhold til erfaringer mht. myndighedsopgaver og så kan jeg jo nu præsentere hvad det er jeg egentligt sidder og laver. Det kunne jeg måske have sagt fra starten men jeg laver simpelthen et projekt i mit specielle her hhvor jeg forsøger at lave drone opmållinger med 3D modellering som formål, altså simplethen lave det der hedder fotogrametri, lave ortofoto og 3D modeller til sediment bestemmelse, sediment transport indenfor kortere perioder til sammenlign over længere tid og så bruge de elevationsmodeller som ligger offentligt tilgængeligt. Det er kombineret med overgangen af myndighedsopgaven til kommunerne er så meningen at det skal lægges som grobund for et nyt værktøj der kan benyttes i kommuner eller rådgivende ingeniørvirksomheder. Så det er sådan set det som det lidt går ud på, så det er derfor jeg har de her lidt større overvejlser med omkring hvorfor er det interresant med de her store projekter.
Lise:	15:48	Ja jamen det er jo virkeligt interressant fordi der en jo næsten altid en tidshorisont, og vi arbejder jo med en tidshorisont på 50 år, hvor vi jo gerne skulle dokumentere at vi vedligholdelse fodrer på de rigtige tidpunkter altså så dermed registrere hvordan tingene rent faktisk ser ud, det, altså det kunne være super relevant for os. Vi har faktisk søgt nogen penge hos regionhovedstanden til at prøve og udvikle en lidt billigere måde og overvåge på end de der…
Henrik:	16:28	Ja LiDAR scanninger
Lise:	16:30	Ja nemlig, de der lidt kostbare undersøgelser for netop og kunne monitorer og også optimere vores vedligeholdelses fodringer. Så det er hvert fald meget relevant i vores regi og måske særligt når vi kommer til at skulle planlægge vores vedligehold, så det lyder super relevant, det tror jeg der er rigtigt mange kommunerne der kunne have glæde af at have kendskab til …. [17:04 Fall out from bad connection]
Henrik:	17:08	Hov nu falder du falder du lige lidt ud der, men jeg tror jeg fik noget af det
Lise:	17:15	[Connection reestablished] Når ja men essensen var sådan set at det vil være rigtigt relevant ikke kun for os, men for rigtigt mange flere fordi det bliver så afgørende at man hele tiden kan dokumentere det projekt man laver det rent faktisk opfylder de målsætninger som man har sat ned for det
Henrik:	17:43	Ja det var i hvert fald også mit håb, nu skal jeg lige have modellen verificeret så jeg sidder lige og arbejder på de sidste detaljer i den for at kunne offentligøre den for vejleder osv.
Lise:	17:	Ja jamen spændende, hvis du har lyst, må du meget gerne sende noget materialle når du har det færdigt, fordi vi kan jo også altid blive klogere
Henrik:	18:12	Ja det tænkte jeg også at tilbyde, først fremsender jeg lige en kopi af transkriberingen og et sammendrag af samtalen. Når jeg så er færdig, skal jeg nok fremsende kopi af projektet til jer. Endnu engang tak fordi du ville være med og tak for hjælpen.