UiT
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Morphodynamics of a sandy beach during a one-year cycle at Sandbukt, Breivika, Troms, northern Norway

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Abstract

Six cross-shore beach profiles were monitored in a monthly interval at Sandbukt Beach at Breivikeidet, from October 2014 to October 2015, in order to study impact of storms on the beach profile and understand monthly, seasonal, and annual changes in the beach profile. Change in beach volume showed erosion and decrease in beach width on the southern part of the beach during the winter season, while there was a slight accretion on the northern part. There was an increase in the beach volume at every profile during the summer season, while during the winter season the beach volume decreased at the southern part of the beach, while small increase was observed at the northern end. The profile data at Profile A showed onshore transport of a sandbar, and subsequent welding of said sandbar onto the beach. The welding of sandbars could play a major role in berm and beach ridge building at Sandbukt. The effect of storms were minimal when the wind direction during the storms was from the south, while erosion occurred during storms from the north, eroding large portions of the beach profile. Erosion caused by northern storms was possibly decreased when a thick cover of snow and ice was present on the berm. Textural characteristics and sub-surface architecture of the beach during the summer season in 2015 were studied as well. The beach was dominated by medium sand, with both fine sand and fine gravel present as well. The beach shows a variation in grain size, with grain size decrease from north to south, indicating longshore transport of sediments from the north to the south.

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Thank you,

Jóhannes M. Jóhannesson
Tromsø, December 2015

1 Introduction

1.1 Project objectives

The project comprises a morphological and sedimentological study of the modern beach at Sandbukt and its changes over a one year cycle, from October 2014 to October 2015. The purpose is to document the long- and short-term changes of the beach profile, distribution in grain size over different parts of the beach and to correlate both surface morphology and sub-surface architecture to different tidal and wave conditions.

Specific objectives of this study are:

1. To estimate the increase or decrease in the sediment volume of Sandbukt Beach and the direction and extent of net transport along the beach. This includes observing the sediment transport paths from the two rivers found at Sandbukt beach.
2. To interpret monthly, seasonal, and annual beach profile changes and its responses to different tidal cycles, wind directions and storms.
3. To determine the morphological changes of the beach berm during the seasons.
4. To try to ascertain how sand bars form, grow, and move over the course of a one year cycle, and what role, if any, sand bars play in the formation of berms and beach ridges.
5. To observe and examine the influences of snow cover and ice formations on beach profiles, and what, if any, structures are preserved by ice melt-out.
6. To identify sub-surface features, and attempt to relate them to changes in the beach profile and morphology of the berm and the berm crest.

In order to reach these objectives, six profile lines where established at Sandbukt beach in October 2014 (fig.1.4). These profile lines where then measured monthly until October 2015. The measurements were taken either on the day of spring tide or in the days following, and extended from about 10 meters behind the modern beach ridge to sea level. Along with the monthly measurements, a general survey of surface features at every profile was done during the same time, and from May to October in 2015, four to five sediment samples were taken from different parts of each beach profile for sedimentological analysis. During the summer and autumn of 2015, a trenche was dug on Sandbukt beach to see how morphological features were preserved and reveal the depositional architecture.

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1.2 Study area

Sandbukt beach is located at Breivikeidet, in Troms, Northern Norway (lat. 69° 39N, long. 19° 36E), (fig 1.1). Breivikeidet is a valley located in between Ramfjord and Ullsfjord, and is also the name of a small village and a ferry crossing situated near Sandbukt beach. The beach opens up into Ullsfjord, facing north to northeast and extends across most of the width of the mouth of the valley. The beach is flanked by two mountains, Fjellenden on the north side, and Nakkeenden on the south side. Both of the mountains extend farther into Ullsfjord than the beach, barring it somewhat and reducing the wave energy the beach experiences during north-western and north-eastern winds. The area is a popular site for outdoor activities, such as fishing, wind surfing and hiking, so human interference is quite high, especially on the eastern side of Sandbukt. It is also popular to have a campfire there and several fire pits can be found on the berm along the beach.

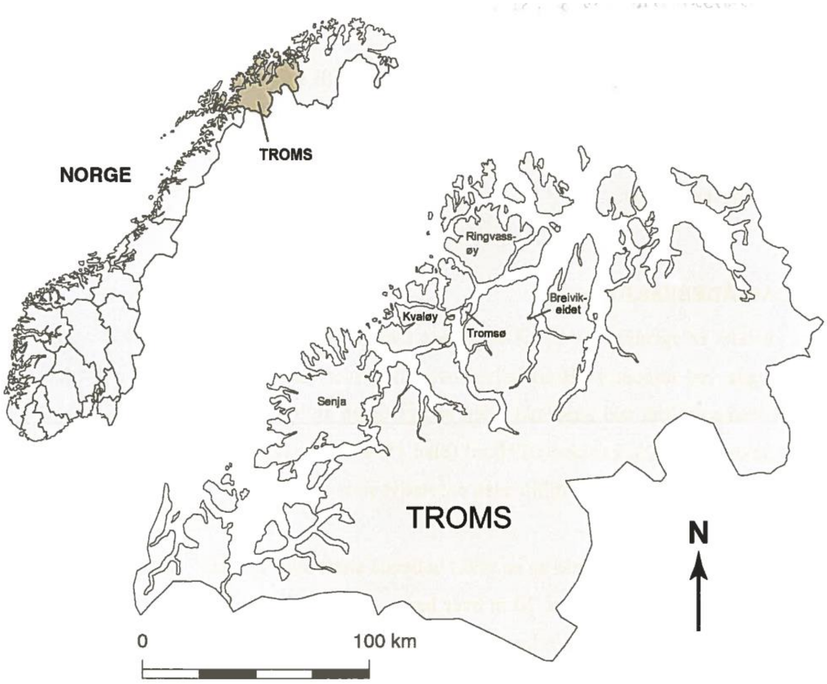

Fig. 1-1 Map showing the location of Breivikeidet, in Troms, Northern Norway (Kramvik 2000).

1.2.1 Previous studies at Breivikeidet

A number of studies have been made at Breivikeidet over the last three decades, both on the field of glacio-isostatically raised beach ridges and the modern beach at Sandbukt. Fjalstad (1986) studied the post-glacial sediments found at Breivikeidet and the depositional environments in which the sediments were being deposited in, Corner and Fjalstad (1993) looked at Spreite trace fossils at same location, Møller (1995 and 2002) studied Sandbukt Beach as a possible indicator for changes in relative sea level, storm frequency and climate changes, and Kramvik (2000) studied the modern beach and the field of raised beach ridges.

1.2.2 River systems

Three fluvial systems are located at Breivikeidet, Breivika River, Nakke River and Filma Stream (fig. 1.2). Two of them have their outlet at Sandbukt beach, Breivika River on the western end and Filma on the eastern, but Nakke River is a tributary and flows into Breivika River not far from the outlet of Breivika River. Breivika River is much larger than Filma, and brings in a high amount of sediment to the beach system of Sandbukt, especially during spring flooding. Breivika has a large, tidal dominated delta, with numerous sandbars on both sides of the spit (fig 1.4). Both rivers must have remained quite stable, as evident by the raised beach ridge field being well preserved and continuous. Breivika River has however eroded parts of the field, and continues to do so (Fjalstad, 1986). There is an abandoned river terrace in the last bend of Breivik river that lies about 1,5 meter above the current river bed. This terrace extends some distance into the field and has been converted into farming fields (fig 1.4).

1.2.3 Beach ridges and swales

Behind the modern day beach lays a field of beach ridges and swales that have been raised above sea level by postglacial isostatic uplift (fig. 1.3). The area is still being uplifted and the rate of emergence is about 2mm per year (Sørensen et al., 1987; Dehls et al, 2000). The field of beach ridges extends for about 1,4 to 2 km inland from the modern beach (Fjalstad, 1986; Kramvik, 2000) and is approximately 20 m.a.s.l. where it is at its highest point (Fjalstad, 1986). The beach ridges differ both in height and width, with both the width and height decreasing somewhat the farther away they are from the modern beach (fig 1.3). This difference in ridge height has been attributed to changes in wind-climate conditions during winter time, with more moderate to calm conditions during the formation of the smaller ridges, while the larger ones indicate greater variation between periods of stormy and calm winter conditions during the Little Ice Age (Møller, 2002). There is also a height difference within the ridges themselves that are closest to the modern beach ridge, being higher on the northern part than on its southern part. The highest ridge is about 2 meters in height, but most of them are within a meter high. Most of the ridges have dense and stable vegetation cover, made up of Lyme grass (*Leymus arenarius*), Red fescue (*Festuca rubra*), Sea sandwort (*Honkeya peploides*), and Ray‘s knotweed (*Polygonum raii*) (Geir Arnesen, 2007), but some have blow-out features that are usually found on their northern side.

The swales also differ in depth and width, and follow the same trend as the ridges with increase in depth and width with increased distance away from the modern beach. The swale closest to the modern beach ridge experienced some aeolian erosion in the 20th century (Fjalstad, 1986) and flooding from Filma river (Møller, 2002), but has since then become fully covered with vegetation, such as Lyme grass (*Leymus arenarius*), Red fescue (*Festuca rubra*), Sea pea (*Lathyrus japonicus*) (Geir Arnesen, 2007), and is relatively stable. Some aeolian processes are still ongoing in the raised field during high winds, evident by sporadic patches of sand deposited on top of the vegetation cover that include Lyme grass (*Leymus arenarius*), Red fescue (*Festuca rubra*), Sea pea (*Lathyrus japonicus*), Wavy Hair-grass (*Avenella flexuosa*), Common juniper (*Juniperus communis*), Crowberry (*Empetrum nigrum*), Lingonberry (*Vaccinium vitis-idaea*), Scots lovage (*Ligusticum scoticum*), Fleshy starwart (*Stellaria crassifolia*), Sea sandwort (*Honkeya peploides*), Gravel sedge (*Carex glareosa*), Slim-stem small reed grass (*Calamagrostis stricta*), and Mountain bladderfern (*Cystopteris montana*) (Geir Arnesen, 2007). The sand brought in is most likely from the modern beach, but some quantity could also be derived from the river banks of Breivika River. In the field itself, there are several summer houses connected by a road that runs through it, along with several old trails for cars and off-road vehicles.

Fig. 1-2 Topographic map of lower Breivikeidet. Vegetaded areas are marked by green, but vegetation extends closer to the Sandbukt beach than is shown here. The portrudion of the mountains on either side of Sandbukt can be seen. All three rivers of lower Breivikeidet can be seen here, as well as the road and summer houses, marked by the blue-green line and black dots, in the field of raised beach ridges. Map from http://geo.ngu.no/kart/granada/

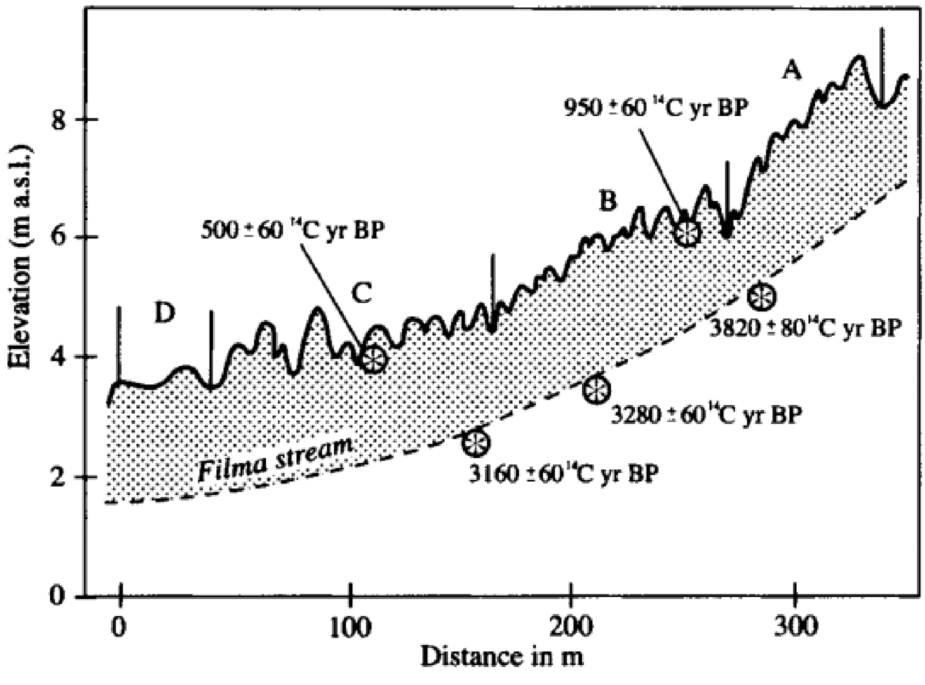

Fig. 1-3 Diagram of a370 meter long profile of the field of raised beach ridges at Sandbukt. The profile is divided into 4 morphostratigraphical units (A-D), based on the most profound swales in the series. (Møller, 2002)

1.2.4 Sandbukt beach

Sandbukt beach is about 1,6 km in length and lies in a north-west to south-east direction (fig.1.4). The beach has a well-developed beach ridge that is almost fully vegetated during the summer months, and the vegetation then extends down to the boundary of the beach ridge and the berm. The vegetation species found at the berm are Lyme grass (*Leymus arenarius*) and Sea sandwort (*Honkeya peploides*) (Geir Arnesen, 2007). The berm is wide and has remnants of old beach cusps close to the start of the beach face. Newly formed beach cusps can be found in the transition zone between the berm and the beach face, and often has two rows of them. The beach face has a gentle slope and ends in a step separating it from the beach terrace. There is large sand spit on the west side of the beach and multiple sandbars around the river mouth of Breivika River (fig. 1.4). The beach is fairly straight, but has two bends on it. The first bend is on the south-east side and is fairly minor, the second is where the sand spit starts and is at about 45° angle to the beach.

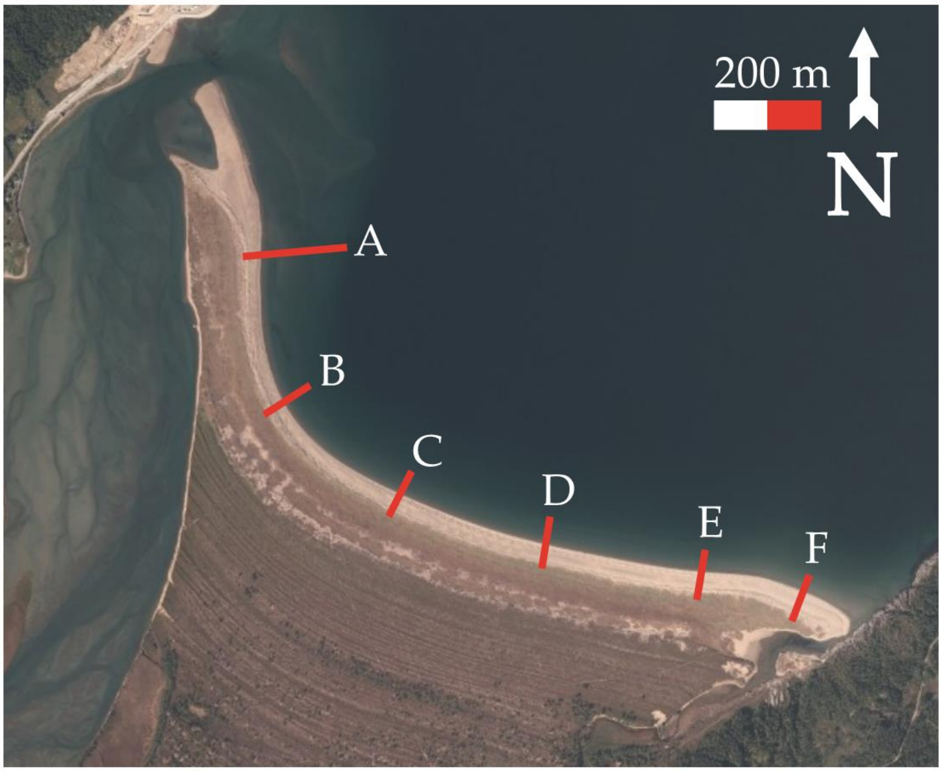

Fig. 1-4 Map showing Sandbukt beach, the six profiles established there and the raised beach ridge and swale field behind the beach. Breivika River is the large river on the upper part of the image, and Filma stream can be seen in the bottom right corner. A part of the farmland can be seen in the lower left corner. The unvegetaded area behind the vegetated modern beach ridge is the swale where aeolian erosion has occurred. Modified from Norgeibilder.no.

1.2.5 Tide, wave and wind regime at Sandbukt Beach

There is no meteorological- or tide-measuring station located at Breivikeidet. The nearest meteorological station with wind measurements and with similar conditions as found at Breivikeidet, is at Tromsø island, about 21,7 km away from Breivikeidet and lies at 100 m.a.s.l. (yr.no). The nearest measuring station for tides is in Tromsø as well. There is a -10 minutes correction factor for time between the two locations and a 1,08 correction for tidal height (Statens Sjökartsverk 2014). The average neap high-tide at Tromsø was 50 cm above the Norwegian vertical datum of 1954 (NN) in 2015, while the mean high water spring was 105 cm. The mean high water was at 78 cm and the mean low water at -90, with the difference of a 168 cm (Statens Sjökartsverk 2015).

The tide at Sandbukt is semi-diurnal and tide height can be substantially influenced by both atmospheric pressure and wind direction. The atmospheric pressure has the effect on tides where an increase in pressure of one hectoPascal (1 millibar) will decrease the tide height by 1 cm and a decrease in pressure of one hectoPascal will increase the height of the tide by 1 cm (Statens Kartverk Sjøkartverket). The effect that wind direction at Sandbukt has on tides is that when the wind is coming from south-west the height of the high tide is reduced while north to north-easterly winds increase it. In fig. 1.5 an example of a tide cycle at Sandbukt can be seen, as well as the mean values for tides in 2015. The mean high water neaps (MHWN) at Sandbukt was 55 cm above NN in 2015, while the mean high water springs (MHWS) was 114 cm. The mean low water neap (MLWN) was -68 cm and the mean low water spring (MLWS) was -127 cm. The difference between mean low water (MLW) and the mean high water (MHW) for Tromsø was 181 cm, with the mean low water being -97 cm and the mean high water being 84 cm (Statens Kartverk Sjøkartverket). The highest tide at Sandbukt from 3rd October to 31st of December 2014 was 164 cm above the NN on the 27th of October, and the lowest tide was -178 cm beneath the NN on the 9th of October. In 2015 the highest tide was 183 above the NN cm on the 21st of February, and the lowest tide was -201 cm on the 21st of March. The largest tidal range at Sandbukt during the one year cycle was 323 cm in March 2015. The tidal conditions at Sandbukt are therefore meso-tidal conditions, since the tidal range falls within 2-4 meter range. (Short, 1991). The modern beach at Sandbukt is a mid- to high wave- energy system (Möller, 2002) with the highest wave energy experienced during north and north-east wind direction.

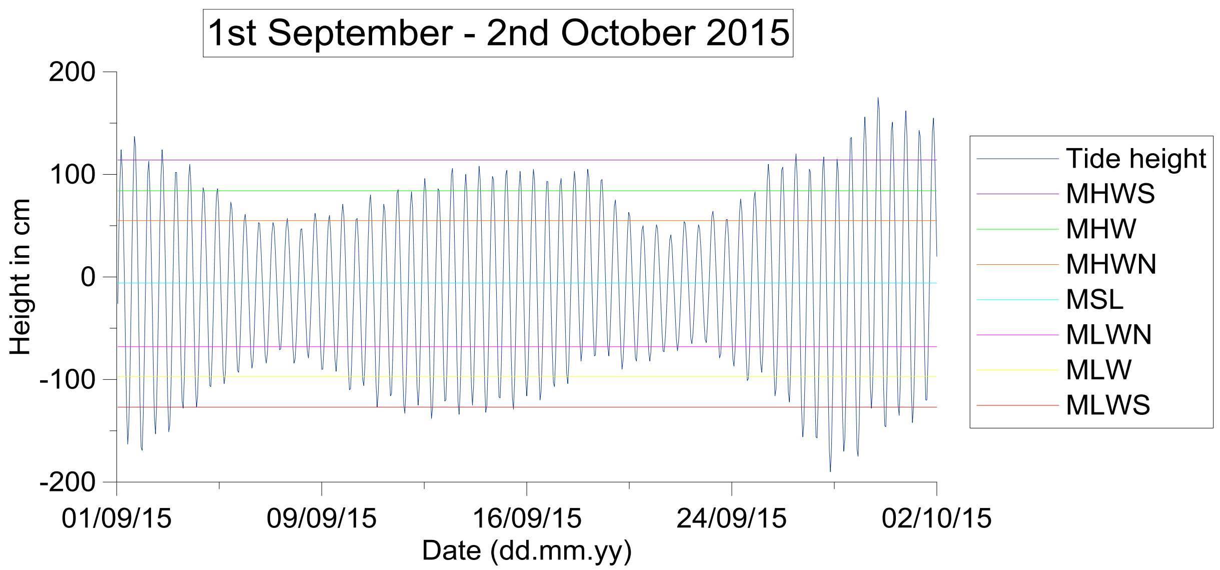

Fig. 1-5 Tidal range for Breivikeidet from 1st of September to 2nd of October 2015. The transition between two spring tide to neap tide cycles can be observed. The tidal range increases during spring tide, while it decreases during neap tide. Data http://kartverket.no/sehavniva/.

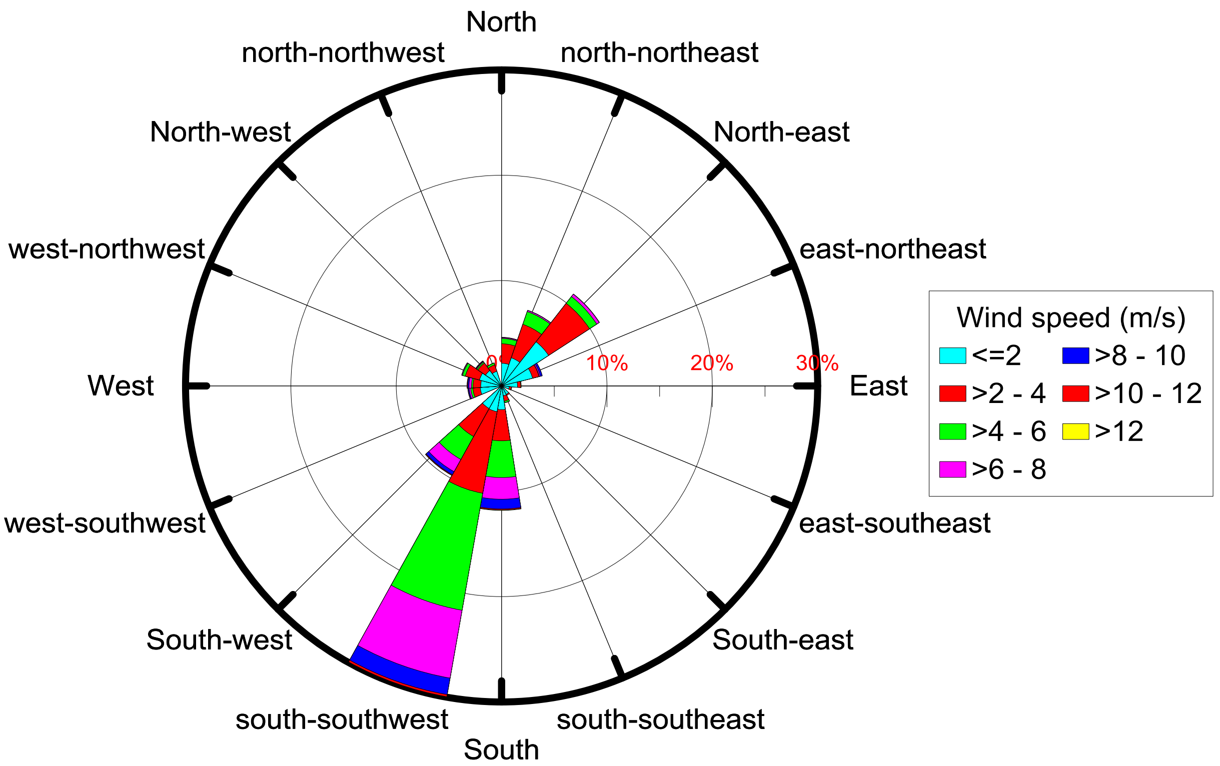

Fig. 1-6 A wind diagram showing the wind direction and the wind strength for the period 3rd October 2014 – 2nd October 2015. The wind data comes from the meteorological station in Tromsø where hourly measurements of wind speed and direction are taken. The prevailing wind direction is south-southwest and the strongest wind are also experienced during this wind direction. South and south-west wind directions are also common, as are north-east and north-northeast. Data from yr.no.

The prevailing wind directions in Tromsø during the one year cycle was south-southwest, with wind coming from that direction about 30% percent of the time. The strongest winds during the cycle were also from this direction. Winds from south, south-west, north-northeast and north-east are also common with the southerly winds being higher in wind speed and the northerly winds more gentle (fig 1.6). Although the annual wind direction is dominated by winds from the south-southwest, there is both a large seasonal and monthly differences in the dominating wind direction and wind strength.

1.3 Bedrock geology of the region

Breivikeidet valley is located within two different geological complexes. Most of Breivikeidet is within the Tromsø Neppe Complex, but the surrounding area of Sandbukt is part of the Balsfjord group in the Lyngen Nappe complex (fig. 1.7). The Balsfjord group is made up of metamorphed sandstone, clay- and glimmer-schists, calcite and dolomite marble sequences, meta-psammites, diamictite, limestone, minor volcanics and conglomerates. (Lindström and Andresen, 1995; Coker-Dewey et al., 2000; Fossen et al., 2013). The conglomerates are made up of greenstone, marble and quartzite (Fossen et al., 2013) and the volcanics are metabasalt containing some pillow structures (Coker-Dewey et al., 2000). In the Ullsfjord area the lithostratigraphy is dominantly schists and meta-psammites (Lindström and Andresen, 1995). The depositional environment for the Balsfjord groupis likely to be a marginal-marine shelf depositional environment (Coker-Dewey et al., 2000)

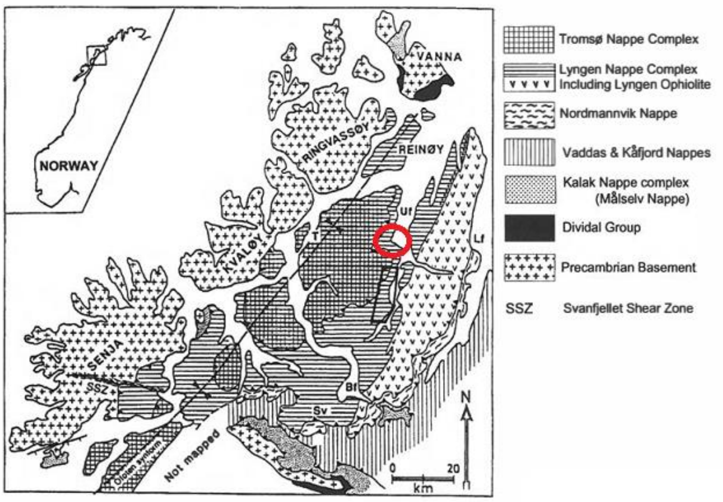

Fig. 1-7 Tectonic map of the Troms region, including Sandbukt beach at Breivikeidet which is marked by the red cyrcle. Breivikeidet is within the Balsfjord Group that is in the Lyngen Nappe Complex. Modified from Coker-Dewey et al. (2000)

1.4 Quaternary geology

1.4.1 Declaciation history of the region

During the Late Weichselian the Fennoscandian ice sheet extended out to the shelf break, but at about 14.6 14C ka BP the ice sheet started to reced from the shelf break, followed by a rapid deglaciation of the continental shelf. The recession of the ice sheet slowed down ones it reached the coast. (Vorren and Plassen, 2002). During the the Older Dryas, glaciers advanced and the Skarpnes moraines were formed. Following this advance, glaciers started to recede again around c.a. 12.200 14C yr BP (Eilertsen et al., 2005) and during the Alleröd period the glaciers in the region retreated from large areas near Breivikeidet, including Tromsø island (Fimreite et al., 2001), areas in Balsfjord (Eilertsen et al., 2005) and to the fjord heads in the region (Vorren and Plassen, 2002). The rate of recession was at a minimum of 20 m/year in the vicinity of Tromsö Island (Solveig et al., 2001). During the younger Dryas a readvance of the outlet glaciers in the region occured and reached their outer extent after 10.7 14C ka B.P.(Vorren and Plassen, 2002; Solveig et al., 2001) The Tromsö-Lyngen marginal moraines (fig. 1.8) were formed during this readvance and are just south of Sandbukt beach, making it plausable that the region was ice-free by that time (Andersen, 1968). The glaciers retreated from the Tromso-Lyngen moraines before 10.3 14C ka BP (Vorren and Plassen, 2002; Fimreite et al., 2001; Forwick and Vorren, 2002) and their reccession was rapid (Corner, 1980; Forwick and Vorren, 2002). Multiple moraines were deposited in the region during the following centuries (Eilertsen et al., 2005; Forwick and Vorren, 2002), but the glacier in Balsfjord disappeared before 9.6 14C Ky B.P.(Forwick and Vorren, 2002), the glacier in Andfjord-Vågsfjord area retreated to the inner fjord areas before 9.7 14C Ka B.P., (Vorren and Plassen, 2002), the drainage basin of the Malangen-Målselv are was probably ice-free by c. 9000 14C yr B.P. (Eilertsen et al., 2005) and in the Lyngen-Storfjord area final deglaciation took place between 9700 – 9100 B.P. (Corner, 1980).

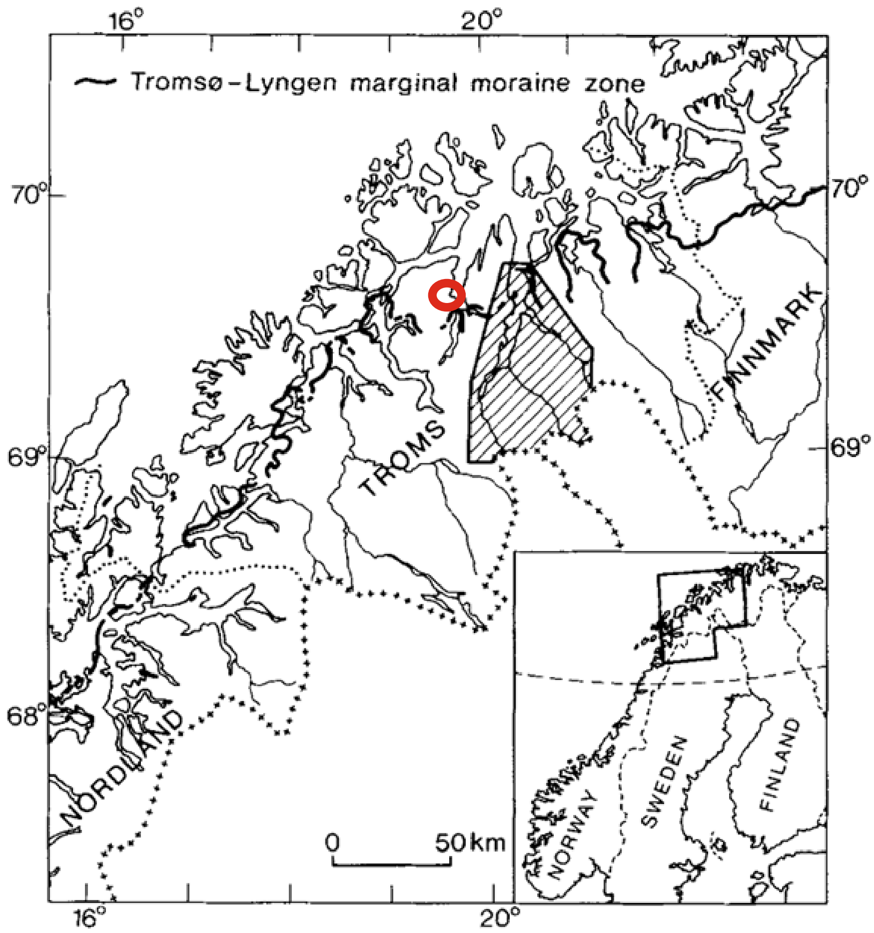

Fig. 1-8 Location map showing the range of the Tromsö-Lyngen marginal moraines (thick black lines). The location of Sandbukt beach is shown by the red circle. The marginal moraines of the Tromsö-Lyngen event are south of Breivikeidet. Modified from Corner, 1980.

1.4.2 Shoreline changes

The marine limit and shoreline changes during the deglaciation in Northern Norway have been studied extensevely (Andersen, 1968; Fjalstad, 1986; Møller, 1987 and 1989; Corner and Haugane, 1993), where two shorelines, the Late-glacial Main shoreline and the Post-glacial Tapes shoreline, are the most dominant (fig. 1.9) (Andersen, 1968).

The nearest sea level curve to Breivikeidet comes from Lyngen in Ullsfjord (fig. 1.10), which is in the same fjord and just north of Sandbukt, and is likely to show similar changes as occured at Breivikeidet. The curve is based on dated isolation contacts in lake basin sediments cores and other data (Corner and Haugane 1993). The marine limit during deglaciation lies at approximately 57 m.a.s.l at Lyngen, and was formed about 10.500 – 10.300 B.P. (Corner and Haugane, 1993). The rate of regression was relatively rapid, at about 15 mm/year, until the Tapes transgression started. The Tapes transgression occured from 8500 – 6000 B.P., and the

Tapes shoreline was formed during the Tapes transgression maximum at ca. 7000 B.P. The shoreline formed at the maximum lies at about 20,5 – 22,5 m a.s.l. Once regression started again, the average rate of regression was 3 mm/year at Lyngen (Corner and Haugane, 1993).

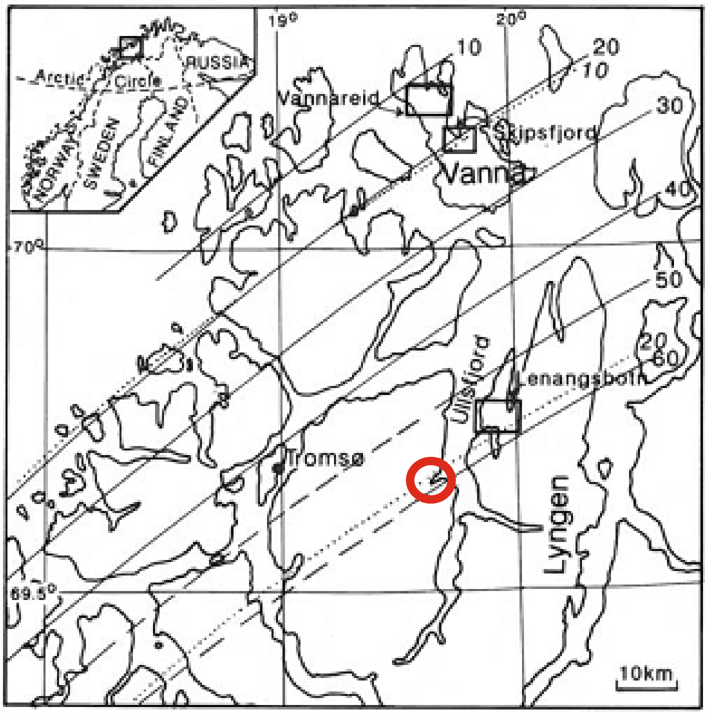

Fig. 1-9 Map of north Troms, where Sandbukt location is marked by the red circle. The Main shoreline is represented by continuous and dashed lines and , while the Tapes transgression maximum shoreline is represented by the dotted lines.Both of the shorelines are isobases and are ± 1-2 m. Modified from Corner and Haugane, 1993.

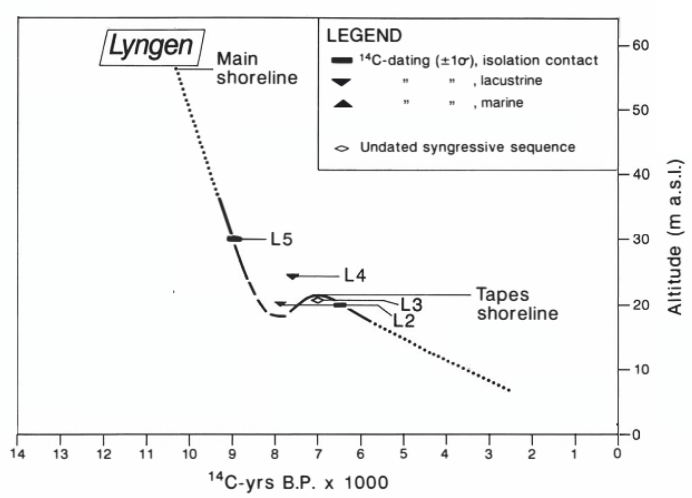

Fig. 1-10 Shoreline-displacement curve for Lyngen. The curve shows the regression after the formation of the Main shoreline, the Tapes transgression and following regression. The dotted parts on the curve are interpolated or based on regional data while the dashed and continouous parts represent a relative degree of uncertainty for the curve. Modified from Corner and Haugane, 1993).

1.4.3 Valley-fill of lower Breivikeidet

After Breivikeidet was ic free, the coastline was at c.a. 57,6 m over modern s.l. and regression occurred. During the regression postglacial sediments were deposited in fluvial, deltaic and marine environment and lower Breivikeidet would have been an estuary with a large sedimentary basin (Fjalstad, 1986). A period of fairly stable sea level followed by transgression occured from about 8000- 6000 B.P. during the Tapes transgression. A large terrace was formed there during that time (below the tapes maximum) and once regression started again after the Tapes maximum, the rivers at Breivika, Breivika River and Nakke River, started to erode into the terrace (Fjalstad, 1986). In fig. 1.11 the distribution of sediments at lower Breivikeidet can be seen and the depositional environment it was deposited in.

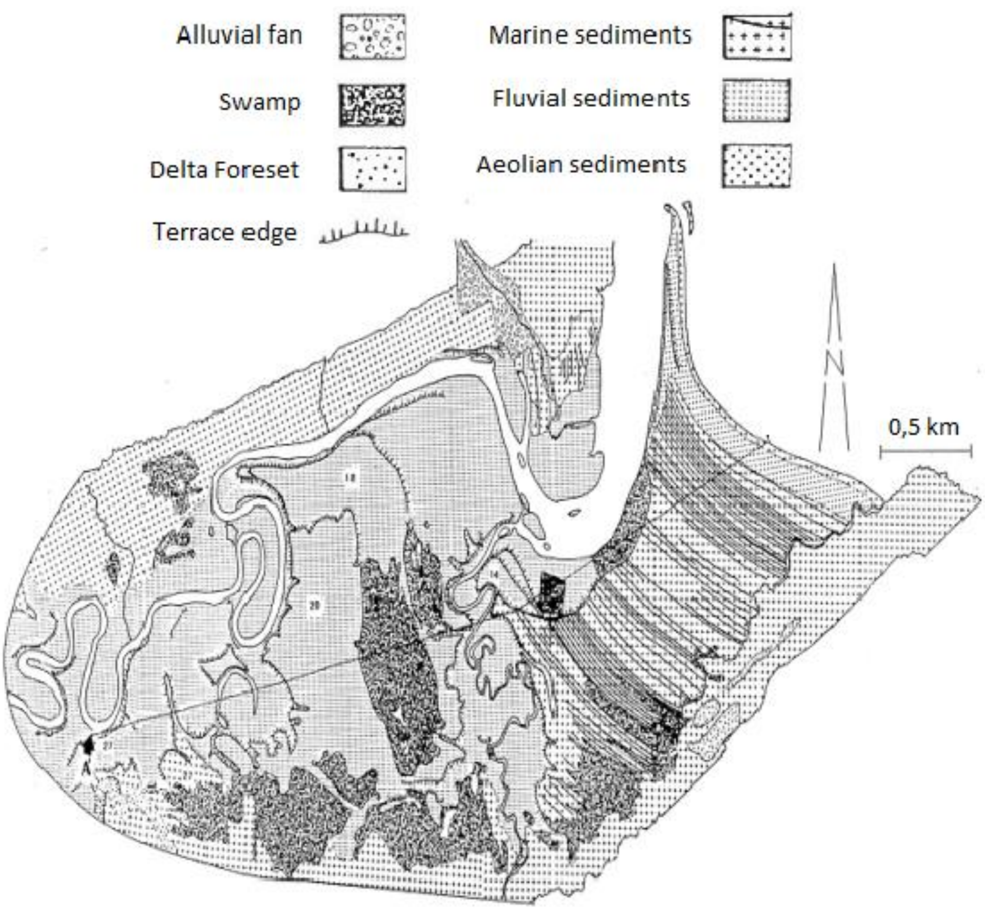

Fig. 1-11 Map of Breivikeidet. Number of different sedimentary deposits are present near Sandbukt Beach. Individual beach ridge lines are well distingushable, as are some of the sandbars around the spit. Breivika river and Nakke River can be seen on it as well, but Filma stream is not visible. From Fjalstad, 1986.

2 Materials and methods

In order to cover the different parts of the beach, six profiles (Fig. 3.1) were established at Sandbukt Beach in September and October 2014. Profile A was the first profile to be established and its location was chosen to include one of the sandbars near Breivika River's mouth. After Profile A was established, the other five profiles were established 300 meters apart from each other, except in the case of Profiles E and F, which were 200 meters apart. Each profile was marked by hammering two wooden pegs into the ground at each profile, the first one, hereafter named peg 1, at about 10 m behind the top of the modern beach ridge, and the second one, hereafter named peg 2, on top of the modern beach ridge. At Profile A however, peg 2 was on top of the first beach ridge behind the modern beach ridge and peg 1 was 12 meters further inland. The purpose of the pegs was both to mark the location of each profile, and to give a reference point to the direction of each profile when measured to minimize deviation from the intended profile line.

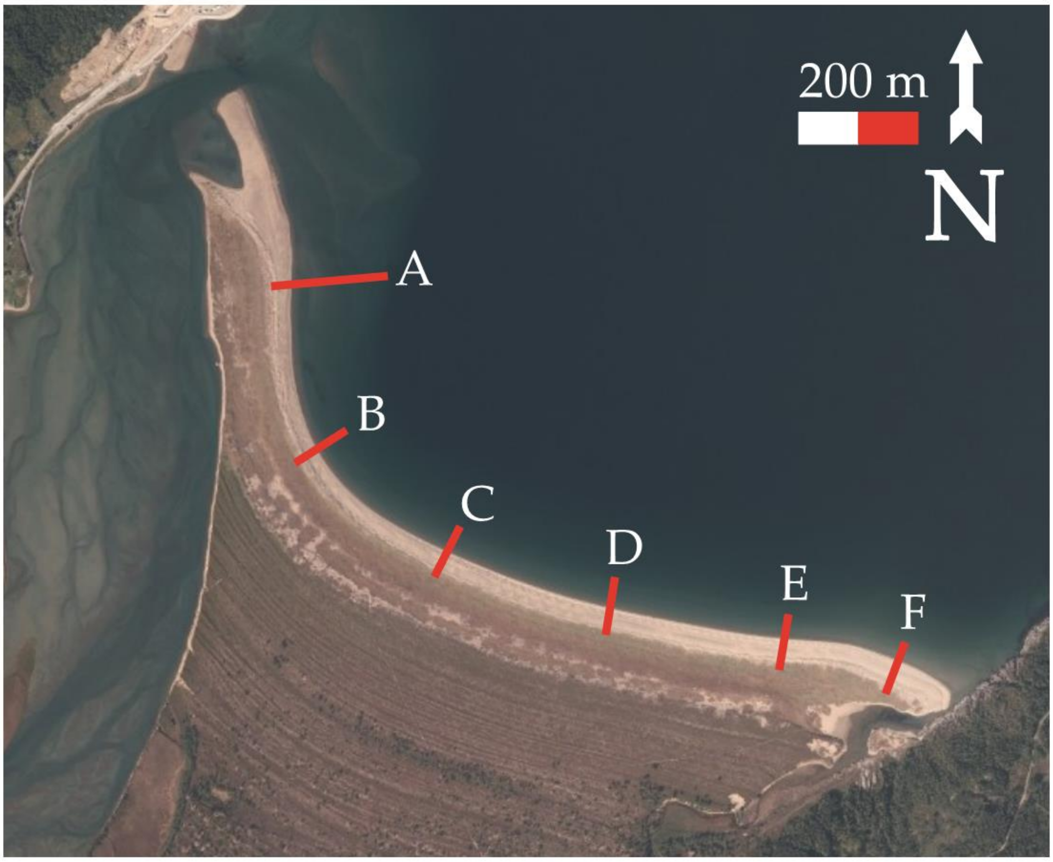

Fig. 2-1 Map showing profiles A – F, established at Sandbukt Beach in September and October of 2014. modified from Norgeibilder.no

2.1 Profile Measurements

2.1.1 Error estimation for the GPS measurements.

Three methods for measuring the beach profiles were considered for this project, leveling measurements, GPS point measurements and GPS continuous measurements. In order to choose which method was to be used, profile F was measured using all three techniques in October 2014. The criteria for choosing between these methods was how accurate each method was and with how much ease each method could be used in the field.

The leveling measurement was done by using peg 1 and 2 as reference marks and a GPS measurement was made at them both. From there, small markers were placed every 5 meters down to the shoreline. A precision levelling instrument (Zeiss Ni42) was placed near the profile and used to read heights on a levelling rod placed at 5 meter intervals, from the waterline to peg 1. The GPS measurement of peg 1 was then used to get the actual height over sea level for that location, and with that the actual height of the rest of the beach profile could be calculated and plotted along with the distance to create a measured beach profile.

The GPS continuous measurement was done by walking with the GPS from peg 1 down to the shoreline, while the device takes measurements twice every second.

The GPS point measurement methods consist of taking point measurements at every change in angle of the beach, from peg 1 down to the shoreline. This method will be explained in greater detailed in next sub-chapter.

The results from the comparison (fig 2.1) were that all three techniques showed similar results and do not deviate greatly from each other. Both of the GPS methods show greater detail of the profile than the leveling measurement does, as these details get overlooked with the leveling measurement due to distance between two measured locations on the profile.

The reasons for why the GPS point measurements method was chosen are that unlike the leveling method, it needs only one person to be operated shows the profile in greater detail and is less time consuming. It has the additional factor of also being able to work during low light conditions and during bad weather, and the risk of man-made error during measurements is more likely than with levelling. The GPS point measurement method was chosen over the GPS continuous measurement method because the point measurements allows for knowing the precise locations of each measurements in regard to the morphology of the beach, is useful to mark where for example sediments samples and trenches were taken and the total amount

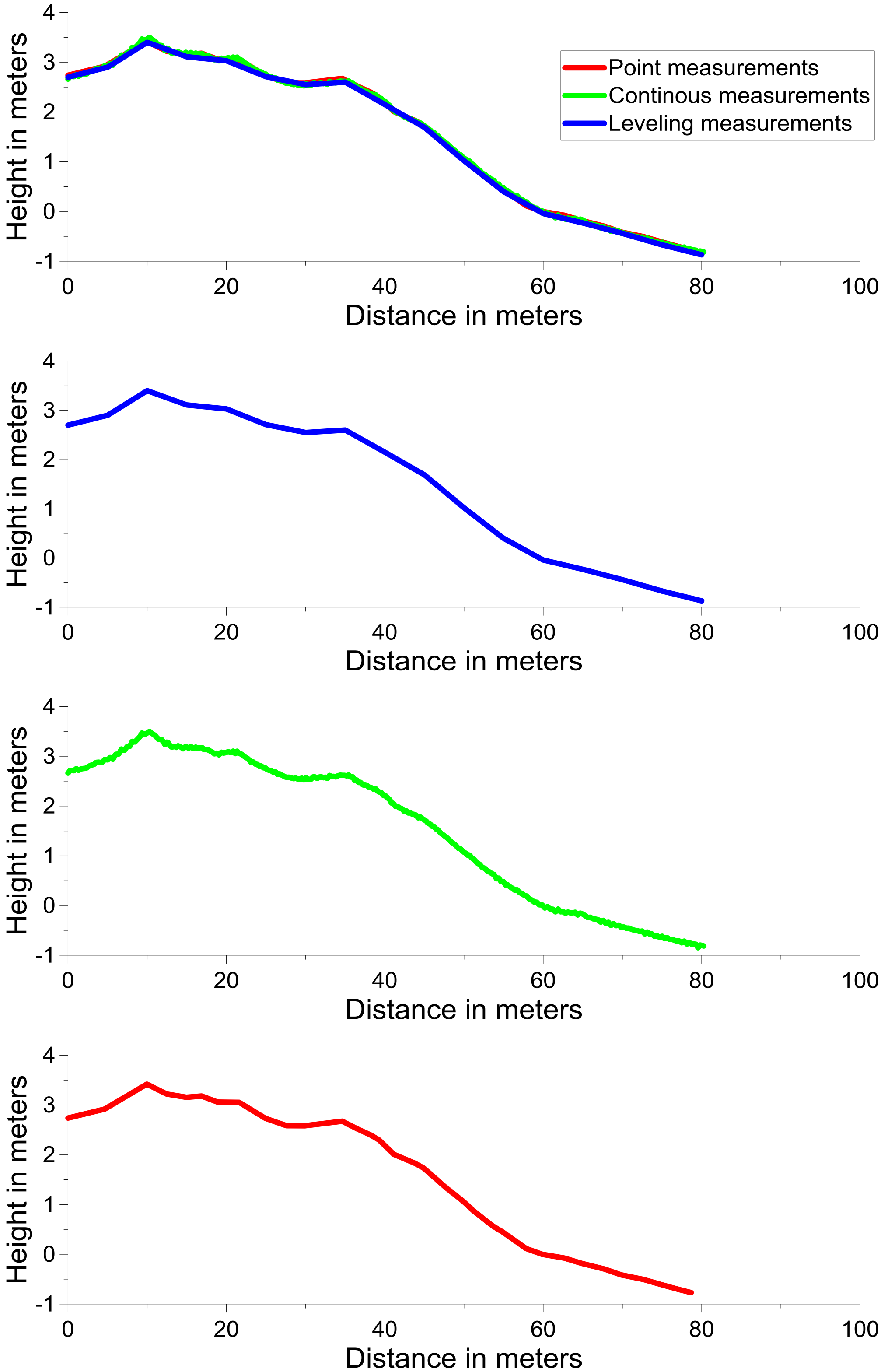

Fig. 2-1 Profile F in October 2014, where the results of leveling measurement method, and continuous and Point GPS measurement methods are displayed. All three methods are shown together at the top image, then the leveling method, GPS continuous measurements and finally the GPS point measurement.

of GPS points taken while measuring with the continuous method are much more numerous than with the point measurement method and therefore make the work on the data more time consuming.

2.1.2 GPS point measurements

The profiles were measured using a Trimble R4 with Juno T41 X Handheld tablet, and the measurements were taken using GPS point measurements. The precision of the measurements are ± 8mm horizontal and ± 15 mm vertical (Trimble R4 datasheet). The setup of the devices while measuring a profile is that the Trimble R4 is on top of a 2 meter high pole, with the Juno T41 attached to the pole. A point measurement is made by placing the pole, with the Trimble and the Juno, where the point is supposed to be measured and kept stationary for 10 seconds while the GPS takes the point measurement. The pole is kept vertical during the measurement by the aid of a level on the pole. Pegs 1 and 2 were the only fixed location at each profile and a measurement was taken at those locations each month, except when the snow cover was too thick to locate peg 1, then the location of peg 2 was only measured. Once peg 1 had been measured, measurement was made whenever there was a change in the angle of the slope of the beach, and at an about 5 meter intervals where there was no change in the slope over a long distance.

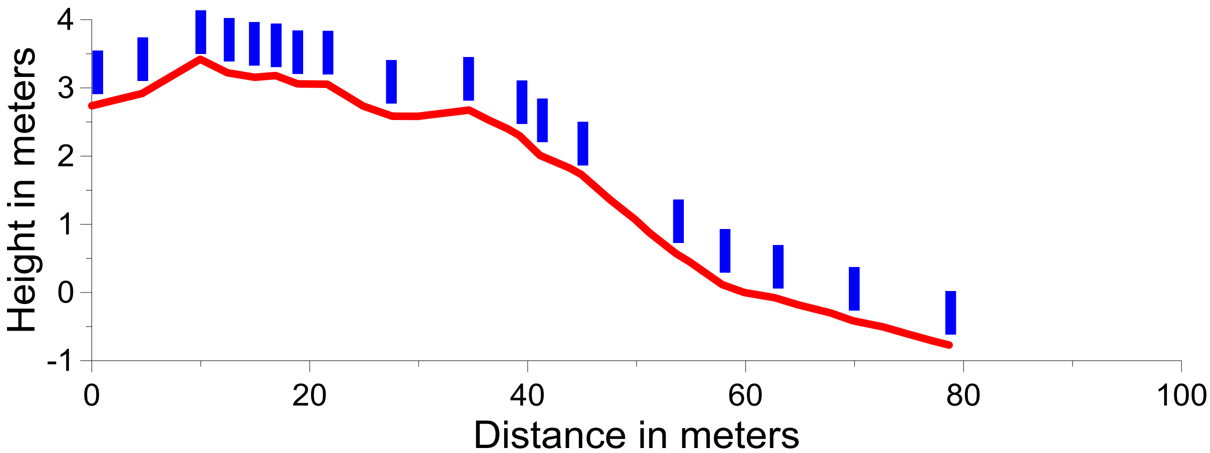

Fig. 2-2 Profile showing where GPS point measurements would be taken at a profile. The red line shows a profile measured at Profile F in October 2014. The blue markers show where measurements were taken, with peg 1 and 2 being markers nr. 1 and 3. In total, 33 measurements were taken while measuring this profile, but only 18 locations are shown on the image in order to give the best visual representation of measurement location.

Two bamboo poles were attached to peg 1 and 2 during the measurements, in order to follow the profile more precisely, since peg 1 at each profile is not visible from large portion of the beach. Fig 2.2 shows an example of where point measurements were made while measuring a profile. Once measurement was completed, the data was imported on to a laptop. The data from the GPS consist of the coordinates, in Euref89 UTM33, and the height of each point above or below NN. The distance between each successive point from each profile was then calculated using an application of Pythagorean Theorem:

$$Equation\ 1 \qquad d = \sqrt{x^2 + y^2} \rightarrow d = \left(\sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}\right)/1000$$

Where d is the distance between two measured points, x is the northing for the two points, and y is the easting for the two points. Once the distance is known, along with the height, each point can be plotted and a graph of the profile made (fig 2.2).

2.2 Volume calculation

The volume of the seasonal and annual erosion and/or accretion was calculated for each profile by dividing the area, where erosion or accretion occurred, into triangles. The sides of each triangle were then calculated by using the height and cumulative distance from peg 1 of the measuring points as x and y coordinates. Once the length of each side of the triangle had been calculated, Heron's formula was used to calculate the area of each triangle.

$$Equation\ 2 \qquad s = \frac{a + b + c}{2}$$

$$Equation\ 3 \qquad A = \sqrt{s(s - a)(s - b)(s - c)}$$

Where a, b, and c are the sides of the triangle, s is the semiperimeter of the triangle, and A is the area of the Triangle. Once the area for each triangle had been calculated and added together, the total area for the erosion or accretion was known, and the volume of the triangular prism could be calculated by:

$$Equation\ 4 \qquad Volume = Aw$$

Where A is the area of the triangle and w is the width of the triangular prism, in this case the width of the beach profile section in question. Each beach profile section is half the distance from a profile to the other two profiles on either side of it, except for Profiles A and F where they have one side towards the ends of the beach. Therefore, the beach section that contains Profile A is from the top of the spit and half the distance to Profile B, and the beach section that contains Profile F is from half the distance to Profile E and to the outlet of Filma Stream. The length of profile section A is 370 m, profile sections B, C and D are 300 m long each, profile section E is 250 m and profile section F is 180 m. Once the volume for each triangular prism, or beach section, was calculated, they were added together giving the total volume for the erosion and/or accretion of the beach.

2.3 Linear interpolation

Due to individual measuring points along each profile being taken at varying distance from peg 1, linear interpolation was used to obtain common points for the mean profiles. The points used to make the mean profiles were at every 5 m interval, starting from peg 1 as the 0 mark, and ending as far out as the measured profiles went. In order to calculate the height at each five meter mark, equation 5 was used, where two measured points on either side of the five meter mark are used to calculate the height at the mark.

$$\mathit{Equation}\ 5 \qquad y = y_1 + (x - x_1)\frac{y_2 - y_1}{x_2 - x_1}$$

Where x_1 and x_2 are the distance from peg 1, y_2 and y_1 are the height at the distance, x is the meter mark for distance from peg 1 for the average profile, and y is the height at that distance.

2.4 Sediment sampling and grain size analysis

2.4.1 Sediment sampling

The sediments for grain size analysis were collected from all six profiles during the monthly GPS measurements. The sample period was from May to October 2015, where three to five samples were collected from each profile. The sample sites at each profile were I) at the beach ridge, II) at the middle of the berm, III) in the middle of the beach slope, IV) at the boundary of the beach face and the low tide terrace, and V) at the low tide terrace. The samples were all collected from the top 1 cm of the top layer, and to insure that only the top layer was sampled, a small ditch was made in order to see the thickness of the top layer. The sample was then scraped of the top by a spatula and put into a labelled sample bag.

2.4.2 Grain size analysis

After collection each sample was dried at room temperature and once dried, large shell material and vegetation were removed, the sample weighed, and then each sample was sieved. The samples were placed in a sieve shaker for 10 minutes with size of sieves ranging from -3 to 4 phi (Φ), at a $^1/_4$ phi interval, and with a pan at the bottom. After the sampled had been sieved, the content of each sieve was poured in to a pre-weighed aluminum tray. The tray with the sediments was then weighed to 0,01 g and its own weight subtracted. The retained weight, weight in percentages (%) and cumulative weight in % was then calculated using Microsoft Excel 2010. The mode, mean, sorting, skewness and kurtosis were calculated using Gradistat v8 (Blott and Pye, 2001), that uses the equations from Folk and Ward (1957). In fig. 2-3 the grain size scale used can be seen (Gradistat program), as well as the phi (Φ) scale converted into millimeter (mm) and micrometer (μm) scale. For further information on grain size parameters, see Blott and Pye (2001) and Folk and Ward (1957).

Grain size		Descriptive terminology			
phi	mm/µm	Udden (1914) and Wentworth (1922)	Friedman and Sanders (1978)	GRADISTAT program	
			Very large boulders		
−11	2048 mm				
			Large boulders	Very large	
−10	1024				
			Medium boulders	Large	
−9	512	Cobbles			
			Small boulders	Medium	Boulders
−8	256				
			Large cobbles	Small	
−7	128				
			Small cobbles	Very small	
−6	64				
			Very coarse pebbles	Very coarse	
−5	32				
			Coarse pebbles	Coarse	
−4	16	Pebbles			
			Medium pebbles	Medium	Gravel
−3	8				
			Fine pebbles	Fine	
−2	4				
		Granules	Very fine pebbles	Very fine	
−1	2				
		Very coarse sand	Very coarse sand	Very coarse	
0	1				
		Coarse sand	Coarse sand	Coarse	
1	500 µm				
		Medium sand	Medium sand	Medium	Sand
2	250				
		Fine sand	Fine sand	Fine	
3	125				
		Very fine sand	Very fine sand	Very fine	
4	63				
			Very coarse silt	Very coarse	
5	31				
			Coarse silt	Coarse	
6	16	Silt			
			Medium silt	Medium	Silt
7	8				
			Fine silt	Fine	
8	4				
			Very fine silt	Very fine	
9	2	Clay			
			Clay	Clay	

Fig. 2-3. A modified Udden-Wentworth scale that was used to descripe the grain size of the sediment samples from Sandbukt Beach. From Blott and Pye, 2001.

2.5 Profile trenches

Both the trenches were dug at about 3-10 meters north of each profile in order to minimize the effects of the trench on the evolution of the profile, but at the same time be close enough to the profile to have the same or similar sub-surface architecture. Before a trench was dug, a small peg was placed about 3-10 meters north of peg 2 at the profile in question. Then a small peg was placed at every 5 meter interval down to the start of the beach slope, and at every 1 meter interval were the trench was supposed to be. A point measurement, using the Trimble GPS, was then taken at the location of the pegs with 1 meter interval. The trench was then dug using a shovel, and once the trench was dug the section on the northern side was cleaned with a large spatula. Each meter long section was then drawn onto a millimeter paper, photographed, and the grain size of each layer was determined using a grain size chart. Once that was completed, the trench was filled back up.

2.6 Graphs, illustrations, maps and photographs

All Graphs were made by using Golden software Grapher™ 11, illustrations and maps were made using Adobe Illustrator CS5 and CorelDraw X5. Photographs were taken with Nikon COOLPIX P7000. Panorama images were made using Image Composite Editor

The wind and tide cycle diagrams were made using Grapher 11 and data from yr.no and Statens Kartverk. The wind data consists of average wind speed, in meters per second, and wind direction at an hourly interval. The tide data consist of hourly measurements of tide height at Tromsø, and corrected for the time displacement and height to be correct for Sandbukt. The annual wind and tide diagrams were constructed using data from the 3rd of October 2014 to 2nd of October 2015. The seasonal diagrams were made using data from 3rd of October 2014 to April 21st and from April 21st to 2nd of October 2015. The monthly diagrams were constructed using data from the time between each two profile measurements.

2.7 Echo profiling

The Echo profiling took place at 16th of September 2015 and the nearshore at all six profiles were measured using a Garmin Fishfinder 240 and the Trimble R4. The instruments were fitted on to a small boat, and then the boat was sailed from the end of each beach profile out to about 25 m water depth. The Garmin Fishfinder measures the depth of the ocean bottom, while the Trimble R4 takes GPS measurements. This allows for a profile to be plotted in the same manner as a beach profile.

3 Results

3.1 Beach morphology and profile measurements

3.1.1 Beach description and morphology

The beach at Sandbukt has an extensive range of morphology and bedforms that extend either over the whole length of the beach or are confined to certain areas. Observation of the beach morphology was made monthly during profile measurements. The beach morphology of the backshore, the foreshore and the shoreface at Sandbukt Beach can be divided into five groups and each of these five groups contains a range of secondary morphological features and bed forms (fig 3.1). These five groups are: I) beach ridge, II) berm, III) beach face, IV) low tide terrace and V) sand bars. In fig. 3-1A the location of the groups can be seen in regard to their location on a beach profile, and in fig. 3-1B the secondary morphological features found in the groups are shown. Not only do these zones differ from each other with respect to the morphological features found there, but there are often some differences within each of these zones depending on the location at Sandbukt.

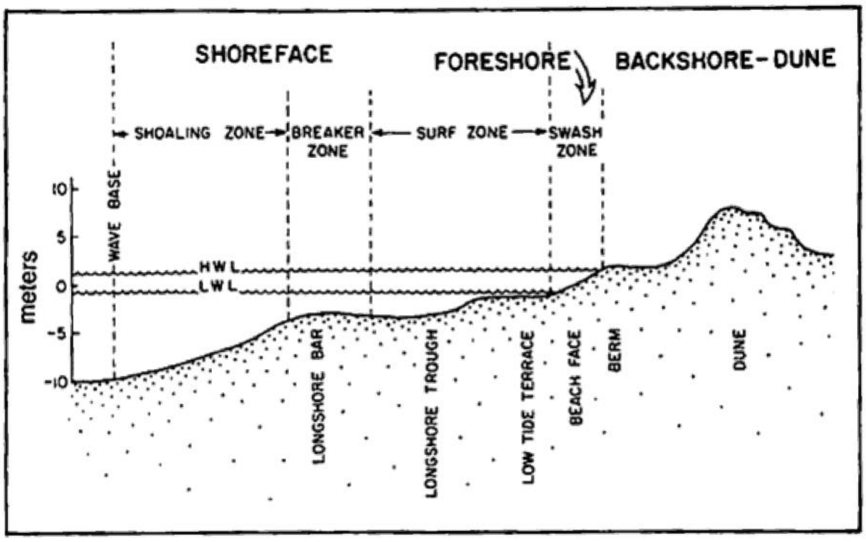

Fig. 3-1A. Beach profile, showing the locatin of different zones within the shoreface, the foreshore, and the backshore, From Boggs, 2006.

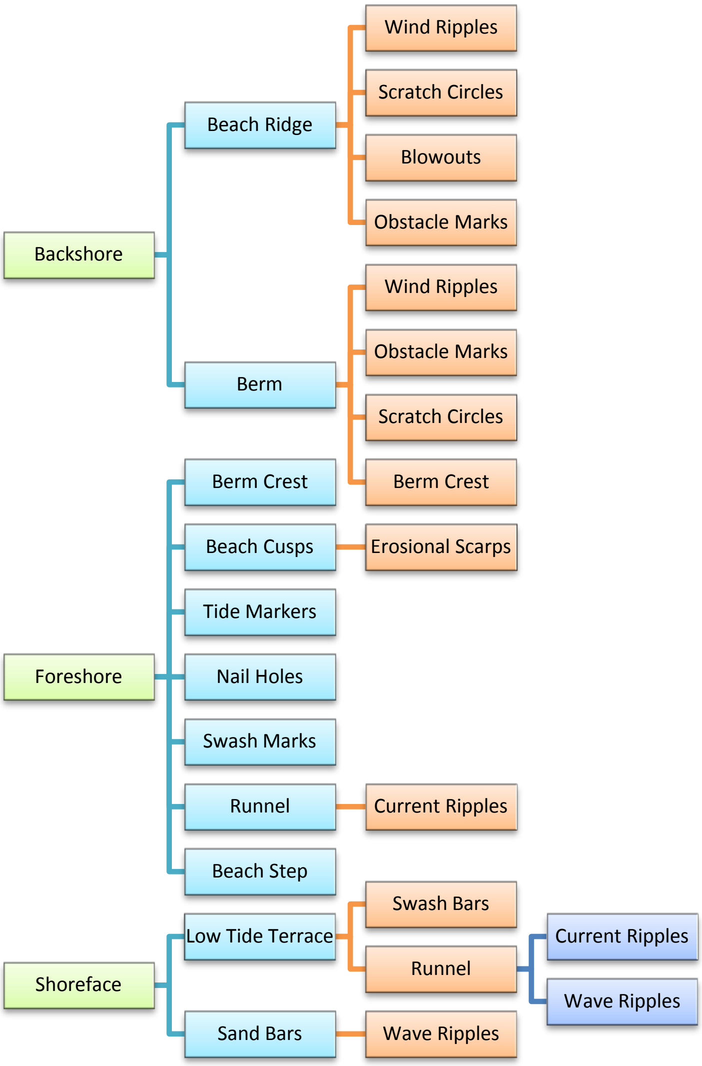

Fig. 3-1B Diagram of the morphology found at Sandbukt beach, split into the backshore, foreshore and shoreface. The morphology of each is shown, as are the secondary morphological features and bedforms found there.

3.1.1.1 The Backshore

The modern beach ridge extends along the whole of the beach from the top of the spit, at the outlet of Breivika River, south to the outlet of Filma Stream on the other end. The ridge differs in size depending on location (fig. 3.2), and can be divided into three different zones (fig 3.3), based on height and width. The overall form of the ridge remains mostly the same throughout these zones, but some zone have a steep slip face and more gentle seaward facing slope, while for other it is the other way around.

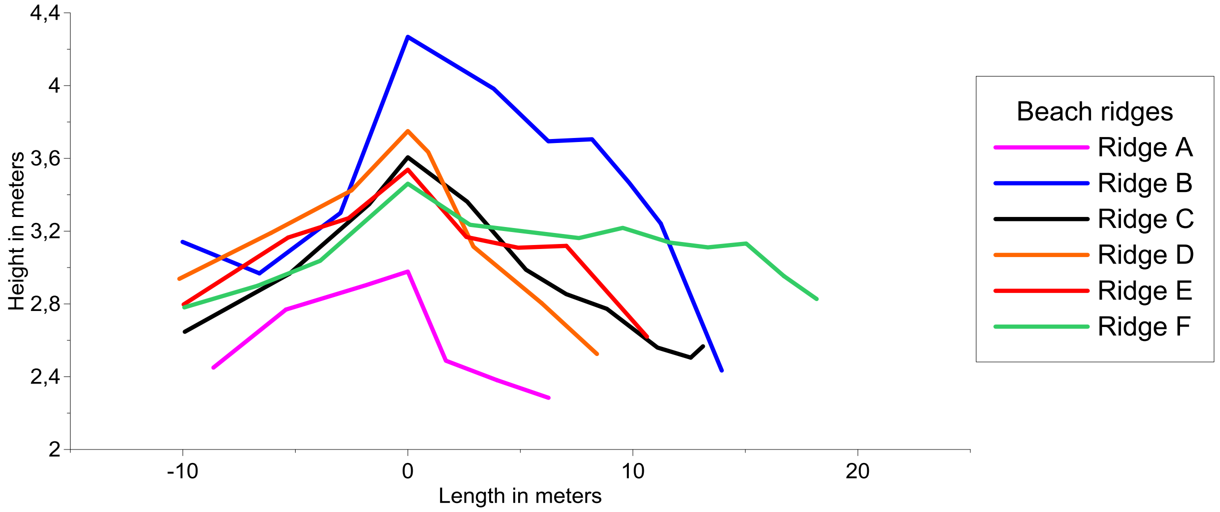

Fig. 3-2 Graph of the 6 profiles of the modern beach ridge, where the three different zones of the beach ridge can be seen. Zone 1 includes Ridge A, Zone 2 includes Ridge B, and Zone 3 includes Ridges C, D, E, and F. There is a difference in height and width between each zone, with Zone 1 having the smallest ridge, Zone 2 the largest and the ridge in Zone 3 the widest. Note the decrease in ridge height in Zone 3, the further away from Zone 2 it gets.

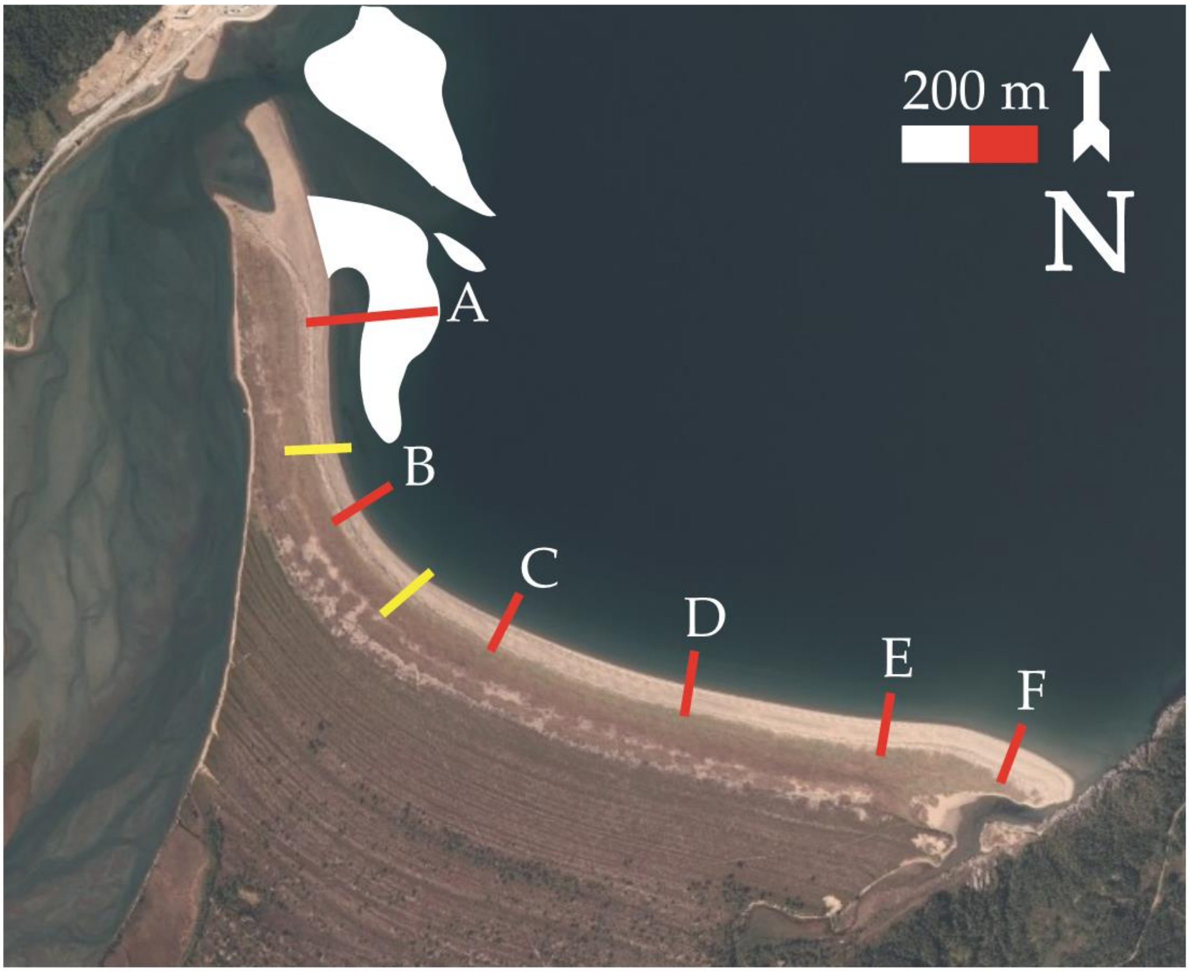

Fig. 3-3 Map showing the location of the three different beach ridge zones at Sandbukt, divided by the yellow lines. The sand bars near Profile A are shown as well, marked by white. The extent of the area of the bars was not measured, but is based on observation and photographs, Modified from norgeibilder.no.

The same morphological features are present in all zones and the features are usually on the sea-ward facing slope or on top of the beach ridge itself. These features are wind ripples, obstruction structures, scratch circles and blowouts (fig. 3.4). During winter time, the ridge is most often completely covered with snow and ice.

Fig. 3-4.The beach ridge between Profile A and B with wind ripples, obstacle marks and scratch circles.

Zone 1 extends from the top of the spit to about 220 meters south of Profile A (fig. 3.3.). The ridge is smaller in this area compared to other two zones of the ridge, and is about 10 m wide and 55 cm high on both the slip face and the sea-ward facing slope at Profile A. The ridge also lies at lower elevation over sea level in this zone than in the others (fig. 3.2). The ridge has a fairly gentle slip face and a steeper sea-ward facing slope connecting it to the berm. There is a small ridge in front of the beach ridge, closer to the tip of the spit. This ridge has some vegetation on top of it, but is not well formed and might be a buildup of aeolian sediment trapped by the vegetation rather than an actual beach ridge. There are multiple ridges behind the modern day beach ridge in this zone, similar to the modern ridge in both size and height, and separated only by small and shallow swales. These ridges are often not in a straight line, and are then rather a collection of small elevated mounds with vegetation on the top and loose sand in between (fig 3.5).

Fig. 3-5 The beach ridge at Profile A, along with two smaller ridges on either side.

Zone 2 extends from the southern end of zone 1 and about 150 south of Profile B (fig. 3.3). At profile B the ridge is 125cm high on the slip face, 185 cm on the sea-ward facing slope, and 21 meter wide, and is by far the highest and widest part of the ridge (fig. 3.2). The ridge has a steep slip face, which is well covered with vegetation, but a more gently sloping sea-ward side with scares vegetation (fig. 3.6). There is a high aeolian activity in this zone and sand is brought to this area when there are strong winds blowing from the north, north-east and south-east.

Fig. 3-6 The beach ridge in zone 2, with a steep slip face that has thick vegetation and the more gently sloping sea-ward facing slope with less vegetation.

Zone 3 extends from about 200 meters north of Profile C to the outlet of Filma Stream, about 80 m south-east of Profile F (fig. 3.3). In this zone the size of the ridge remains similar but its slip face height is gradually decreasing while the sea-ward facing slope and its width varies more. The ridge at Profiles C, D, E and F are 100, 80, 70 and 65 cm high on the slip face, 110, 120, 100 and 65 cm on the sea-ward facing slope, and 23, 18, 21, 28 m wide respectably (fig. 3.2). The ridge has a thick vegetation cover on both sides of the ridge, and the vegetation on the sea-ward facing slope reaches down to the berm during summer times. At profiles E and F, there is a small terrace on the sea-ward side of the ridge with small ridges or mounds that have scarce vegetation on top of them and loose sand in-between (fig. 3.7). These ridges are not unlike the ones seen in Zone 1.

Fig. 3-7 (on the left) The beach ridge at Profile D in zone 3, with dense vegetation cover and fairly gentle sloping sides. The vegetation reaches down to the upper part of the berm during the summer. (on the right) The small terrace, in front of the beach ridge at Profile E in zone 3, with a small ridge where the thin line of vegetation is.

Sandbukt beach has a wide summer berm and a smaller winter berm that is covered with snow and ice for most of the winter. The width of the berm remains similar across the Beach, being between 10 and 20 meters wide depending on the season, but between Profiles A and B the berm starts to get smaller and is only about 3 m wide at Profile A. There is some vegetation on the berm, mostly close to the beach ridge, but in some places there are patches of vegetation that extend as far as the middle of the berm. Patches of seaweed are distributed over the berm that are most likely brought there by winds rather than wave action. Wind ripples are most often present, as are obstacle marks, and in some areas scratch circles.

Fig. 3-8 The berm between profiles B and A, where in the distance the berm starts to get smaller closer to profile A, and the line of beach cusps ends. Wind ripples, some vegetation and scattered seaweed can be seen on the berm, and a tide marker and beach cusps on the boundary of the berm and the beachface.

Fig. 3-9 A beach cusp with erosional scarp near profile E. Nail holes can be seen on the side of the cusp and swash marks below it.

3.1.1.2 The Foreshore

The berm crest is at the boundary between the berm and the beach face, and usually has at least one row of well-formed beach cusps at or just below it. Erosional notches are often formed at the base of the existing beach cusps (fig. 3.9) and when the tidal cycle gets closer to neap tide there is often another line of beach cusp formed, below the exiting beach cusp, on the upper part of the beach face. Beach cusps are formed at the whole length of the beach, except around Profile A, which is usually free of beach cusps (fig. 3.8). The gradient and the width of the beach face are fairly similar over the whole beach. Both tide markers and swash marks are frequent, and the latter often covers the whole of the beach face. Nail holes are frequent as well, and in rare incidents a runnel has formed on it from Profiles C to F (fig. 3.10). From the end of the spit to about the middle of profiles B and C, There are often well defined layers of coarser grained sand than at the rest of the beach face (fig. 3.10). These layers extend from top of the spit to about the middle of profiles B and C, where they either end gradually or have a bend towards the coastline and extend out to the shoreface. The boundary between the beach face and the low tide terrace is separated by a distinct break in the slope, called the step. At the step, or just above it, is most often a thin layer of sand that is coarser than the sand on the beach face (fig. 3.11).

Fig. 3-10 (On the left) Multiple layers of coarser grained sand on the beach face between profile B and A. The lenses can be seen clearly as yellow-brown lenses on top of the gray sand of the beach face. (On the right) A runnel on the middle of the beach face, with a mixture of current- and wave-ripples.

Fig. 3-11 (Top left) A step at the base of the beach face where there is a small layer of coarse sand that is coarser than the sand on the beach face above it and the low tide terrace beneath it. (Top right) A rip current forming after a wave has broken over the swash bar on either side. (Bottom left) Swash bars that have been cut by small rip currents. (bottom right) A runnel with a mixture of current- and wave-ripples at the bottom of the runnel.

3.1.1.3 The Shoreface

A low tide terrace is visible during low tides and is featureless apart from having multiple drainage channels formed by groundwater seeping out and running down the terraces, giving is a glassy appearance since the sand is saturated. The width and the gradient of the low tide terrace are not the same along the beach, being widest and with the lowest gradient from profiles C – F. On the boundary between the beach face and the terrace at these locations is often a runnel and swash bars, which have been cut periodically by small rip currents (fig. 3.11). Around Profile B the terrace is steep and cut by drainage channels with no runnels or bars there. At Profile A, the low tide terrace bridges the gap between the beach face and the sandbar, and serves as a drainage channel as the tide falls (fig. 3.13). Wave ripples are often found present there as well as current ripples. During low tides, the low tide terrace ends in the swash zone where a thin layer of sand, usually coarse sand, is present (fig. 3.12). This layer forms a boundary between the low tide terrace and the sandy ocean bottom, which is covered in wave ripples, that lies beyond the terrace. When the tides starts to rise again, this layer of coarse sand is moved some distance over the low tide terrace and the ripples migrate along behind it.

Fig. 3-12 Part of the low tide terrace can be seen at the bottom of the image, then a layer of coarse sand in the swash zone and behind it a wave rippled sea bottom.

The sand bar in front of Profile A extends from the top of the spit and close to Profile B. This is one of two large sandbars found on the northern side of the spit, the other being further to the north and in front of the outlet of Breivika River (fig. 3.3). The bar in front of Profile A is connected to the beach face about 40 meters north of the profile, and is connected by low tide terrace at profile A. Wave and current ripples and are quite common on the sandbar and are concentrated on both the land-ward and sea-ward facing sides of the sandbar (fig. 3.14), but the highest part of the sand bar is free of them. During low tide, the sandbar is split into two by a large drainage channel (fig. 3.14), and some erosion occurs on the banks of it. Two other sandbars are near Profile A, one small one just north of the profile and another larger one further north. During low tide these sand bars are exposed as well and the river stream is split into two, one on the northern side of the large sandbar, and one in-between the large sand bar and the sand bar at Profile A (fig. 3.3).

Fig. 3-13 (left) A drainage channel cutting through the sand bar at Profile A, leading from the low tide terrace to the shoreline during low tides. (right) Ladder-back ripples at the sea-ward side of the sandbar at Profile A.

3.1.2 Beach profile change during a one year cycle

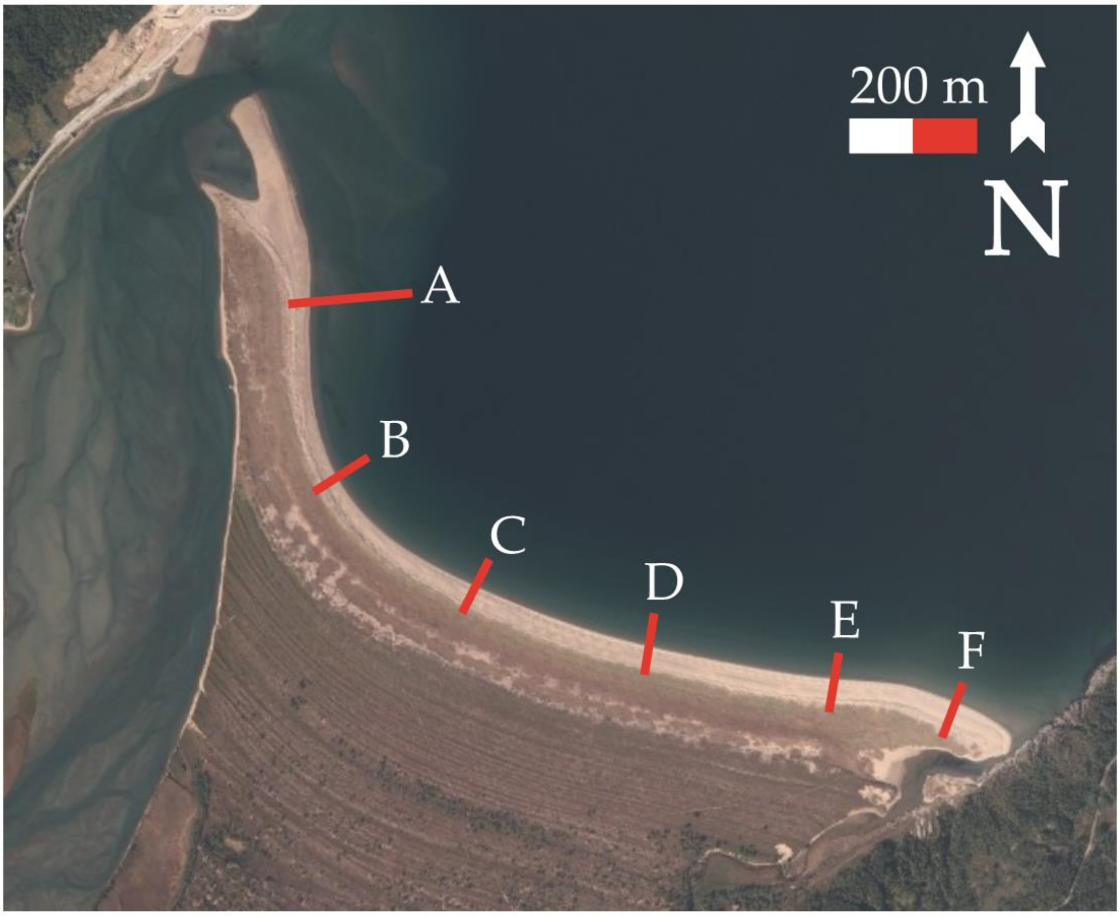

Fig. 3-14 Picture showing the location of the six profiles at Sandbukt Beach. Modified from Norgeibilder.no

The six profiles, A, B, C, D, E, and F, (Fig. 3-14) were measured once a month, from October 2014 to October 2015. The measurements were taken around spring tides, in order to have the profiles extending further offshore. During the winter time, when they day was shorter, the measurements took place during the lowest tide possible that coincided with the time of the day that daylight was present. This meant that some of the profiles measured during the winter time were several days before or after spring tide. There were extensive changes in the beach morphology during the cycle, on the backshore, the foreshore, and the shoreface. Seven main beach responses were observed: 1 berm destruction; 2 berm construction; 3 onshore bar migration; 4 low tide terrace lowering; 5 low tide terrace raising; 6 beach face raising; and 7 beach face lowering. The beach width and gradient fluctuated greatly during the year and they were calculated from the two points at the top of the beach ridge and the mean high water level (MHWL) at each profile. The top of the beach ridge was chosen as a reference point since the traditional point of the beach ridge base (toe) was concealed for extensive period of time due to snow cover. The MHWL was chosen for the endpoint of the beach width calculation due to that not all profile measurements extended down to mean water level or mean low water level, especially during the winter time, and so accurate comparison of beach width using those locations was impossible. In this chapter the changes that occurred on each profile between each month are described, along with a description of secondary morphological features. In chapter 3.1.3, the seasonal changes at each profile are analyzed and in chapter 3.1.4, the annual changes on Sandbukt Beach are discussed.

Between 3rd of October and 12th of November there was erosion on all six profiles, and accretion on the lower beach face at four profiles (Fig. 3-15). Profile A experienced erosion on the berm and on the beach face. The sandbar could not be measured on October the 3rd since tide height was too great at the time of measuring, and therefore the changes of the sandbar for this period are unknown. At profiles B, C, D, and E there was erosion on the berm and upper beach face, while accretion on the lower part of the beach face and the low tide terrace. At profile F there was erosion on the berm and the upper beach face, while the lower beach face and low tide terrace remained stable. The first snow had fallen in the days leading up to the profile measurement on the 12th of November. The snow cover was thin but covered the back shore and due to newly fallen snow it extended beneath the last high tide line in the foreshore. The changes of the profiles will be discussed in greater detail in chapter 4.1.5 where the impact of the northern storm that occurred in early November is analyzed. The storm was the cause for the extensive erosion that happened between the months and greatly changed the morphology of the beach, a change that was still present months later.

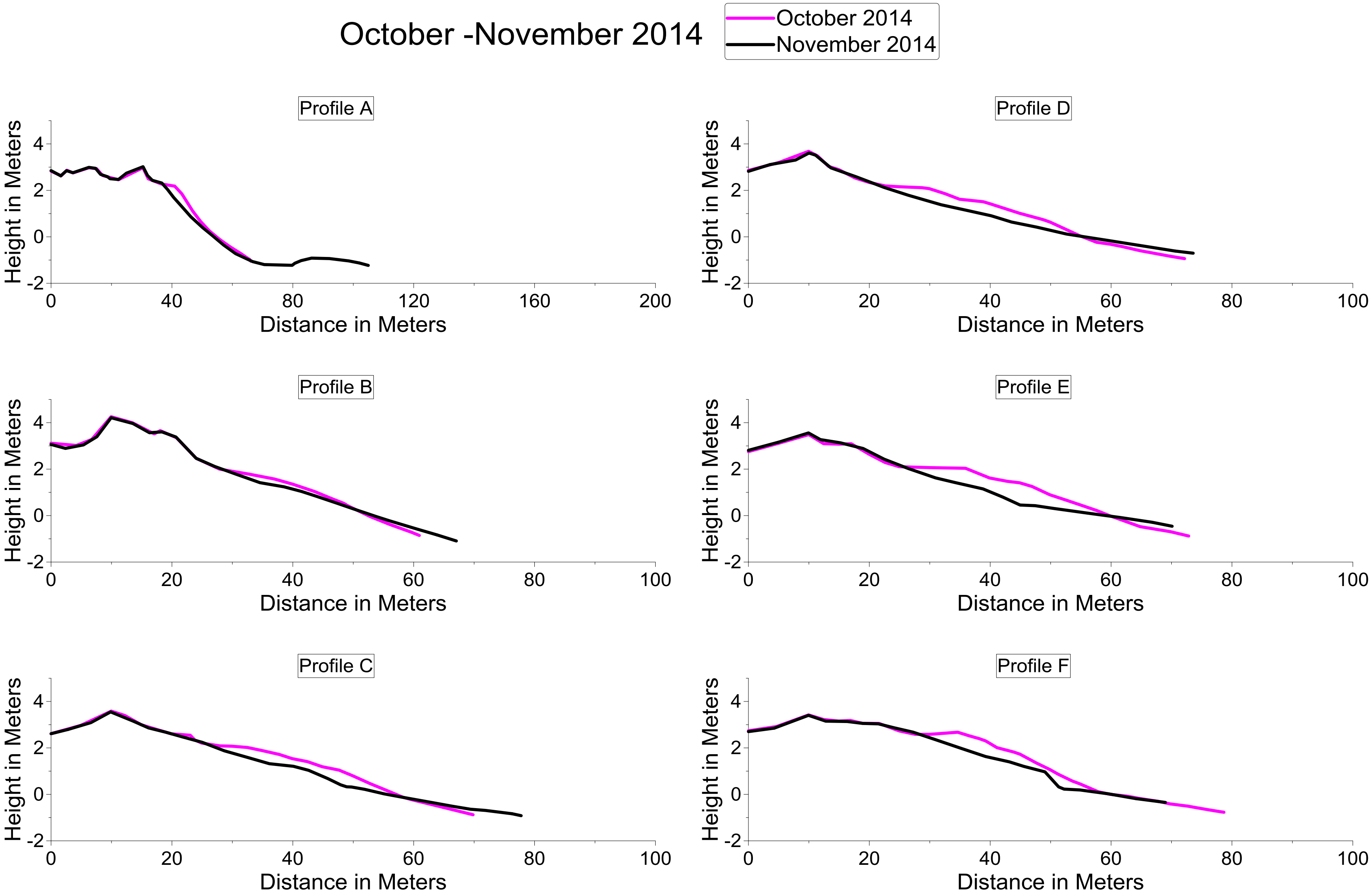

Fig. 3-15 Profile changes between 3rd of October and 12th of November 2014. The profile lines measured in November are black, while the lines from December are orange.

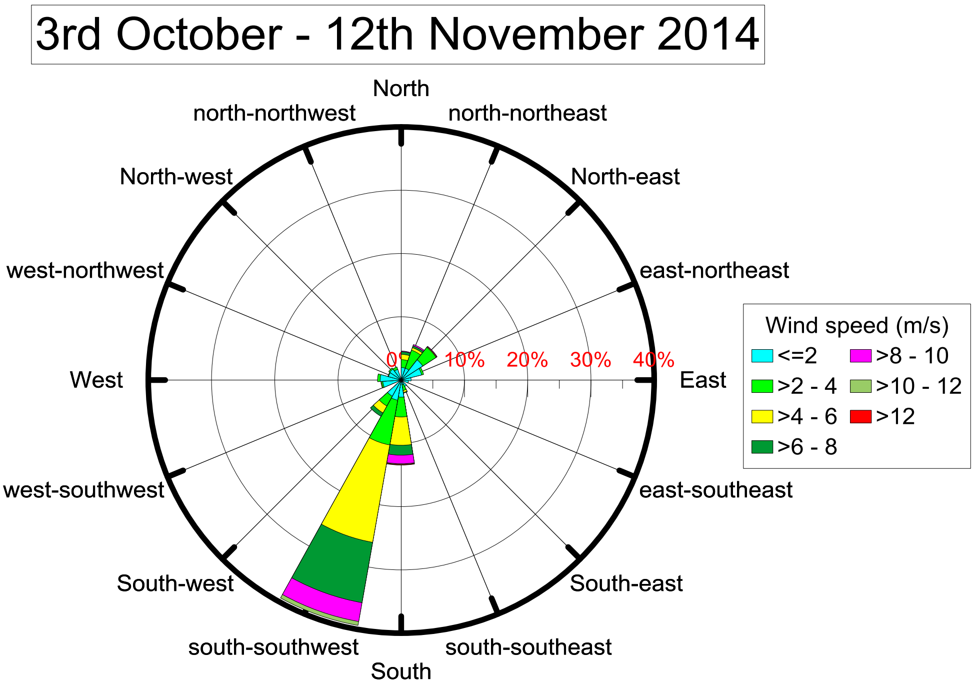

Fig. 3-16 Wind rose diagram for the period between the 3rd of October and the 12th of November 2014. South-southwest was the prevailing wind direction. Data from yr.no.

South-southwest was the dominating wind direction during the period in between the two measurements, with 40% of the wind coming from that direction (Fig. 3-16) Winds form the south were frequent as well, or about 13% of the time, and winds from the south-west, north-east and north-northeast around 5% of the time. Wind strength varied considerably during the period, with winds from the south having the highest wind speed during the period, or 12,6 m/s. The mean wind speed for the period was 3,6 m/s. There were seven periods where wind speed reached 8 m/s or higher, six of those periods had wind from the south or south-southwest and one from the north to north-northeast (fig. 3-17)

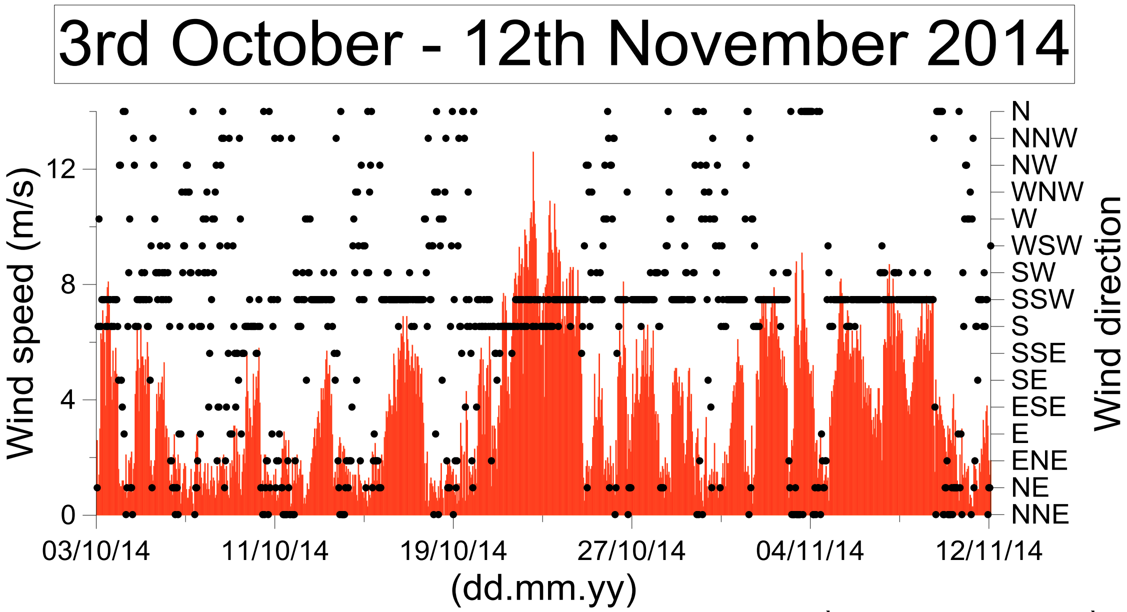

Fig. 3-17. A wind speed and direction diagram for the period between the 3rd of October and the 12th of November 2014. The red columns represent the wind speed during the period, while the black dots show the wind direction. Every dot represents an hour. Data from yr.no.

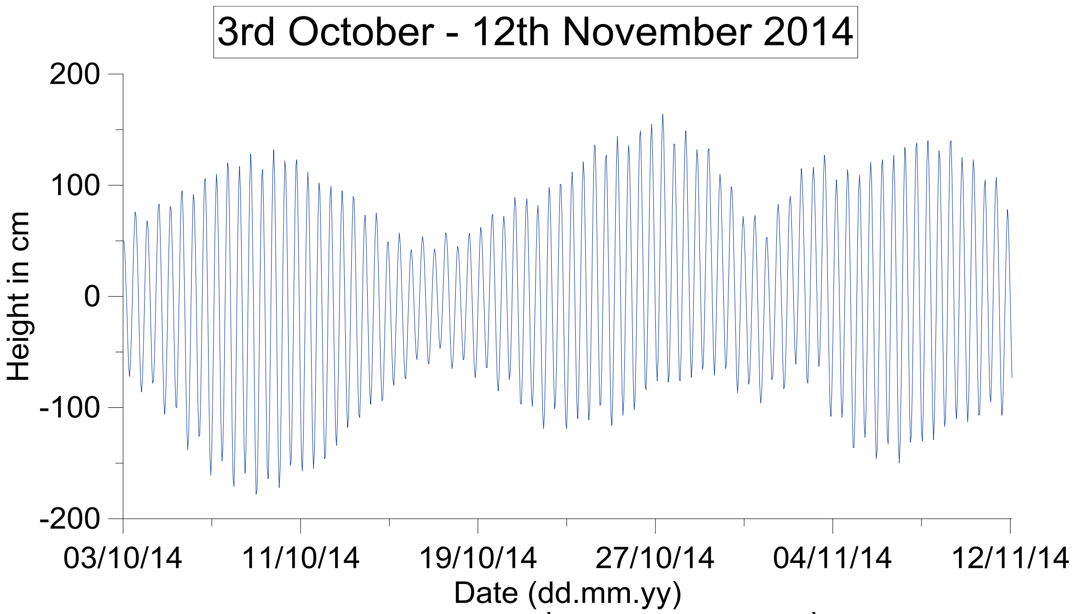

Fig. 3-18. Tidal diagram for the period between the 3rd of October and the 12th of November 2014. Data from http://kartverket.no/sehavniva/.

There were three spring tides and two neap tides during the period between the measurements in October and November (fig. 3-18), and the mean tide height was -0,6 cm. The mean high tide height for the period was 103 cm, with the highest high tide at 164 cm, while the mean low tide height was -105 cm where the lowest low tide was at -178. The storm on the 3rd and 4th of November caused an increase in high tide height during those two days, as well as a decrease in the low tide height.

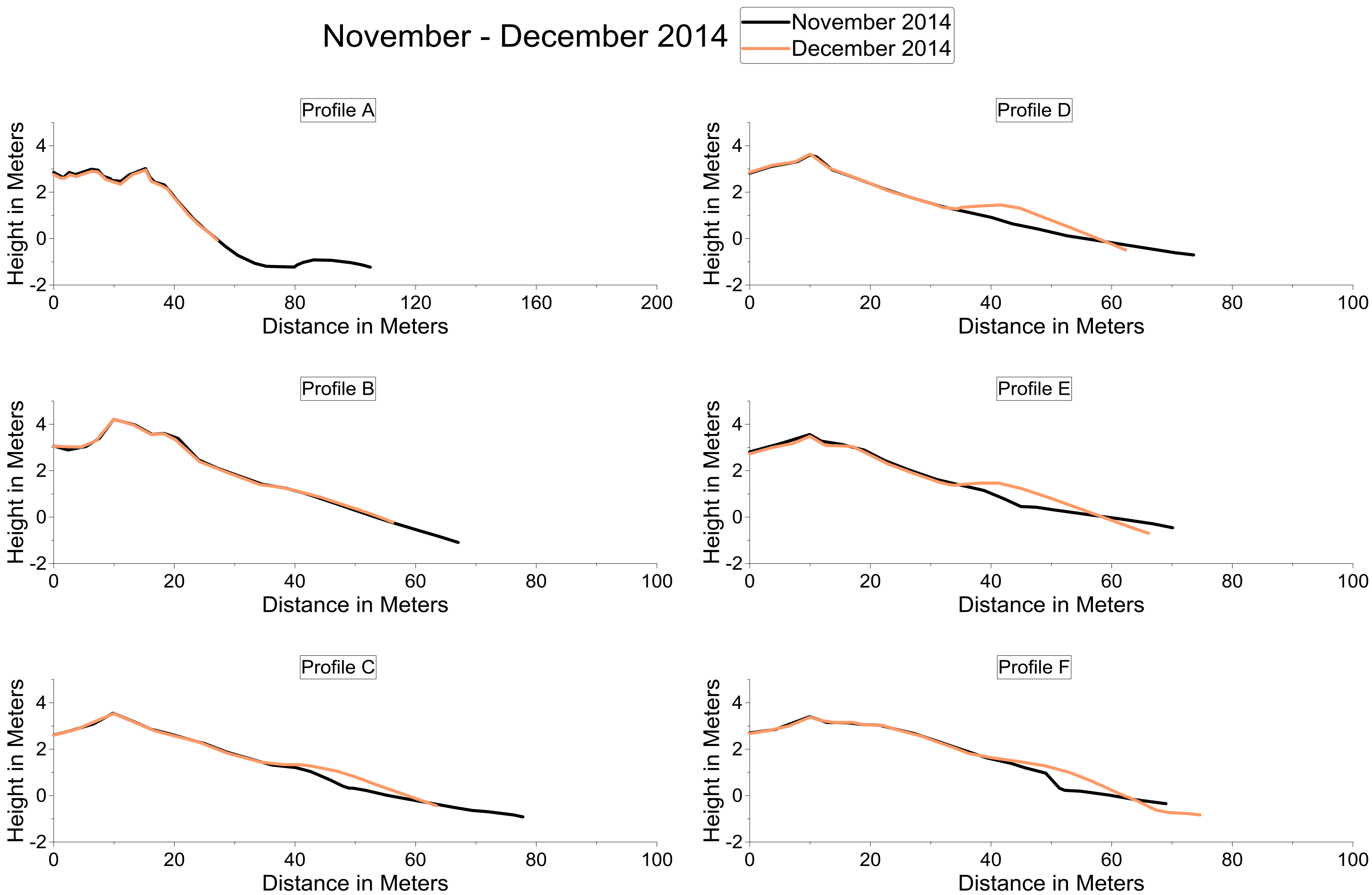

Fig. 3-19. Profile changes between 12th of November and 9th of December 2014. The profile lines measured in November are black, while the lines from December are orange.

Between 12th of November and 9th of December the beach started to recover from the erosion caused by the northern storm in early November. The lower backshore and the upper foreshore started being built up again by forming low lying berms and steeper beach face, but the lower foreshore eroded when the buildup of material in the month before was moved up the foreshore to create the berms. The snow cover increased in thickness in the period and extended down to the berm crest (fig. 3-19).

Profile A remained stable with no changes in the backshore or the upper foreshore. The profile measured at 9th of December did however not reach down to the low tide terrace or the sandbar as the tide had gotten to high. The beach width decreased by 0,3 m, from 36,45 m to 36,15 m, and the beach gradient increased by 0,03°, from 3,45° to 3,48°.

Profile B remained stable as well with no changes in the backshore or the upper foreshore, and like Profile A the measurement did not reach down to the lower foreshore. The beach width increased by 0,7 m, from 33,83 m to 34,53 m, and the beach gradient decreased by 0,1°, from 5,06° to 4,96°.

Fig. 3-20. Pictures from profiles C and E. Beach cusps in the snow at profile C (on the left) and a runnel in front of the ice front at profile E (on the right)

At Profile C the backshore remained stable, but there was accretion on the upper foreshore and erosion on the lower foreshore. Small berm was formed, with beach cusps on the berm crest and the beach face gradient increased from the month before. The lower foreshore likely experienced erosion, as the profile for 9th of Decembers dips slightly below that of the profile of 12th of November on the lower foreshore, but measurements did not reach far enough down the foreshore to confirm that or to see how wide the eroded area was. The beach width increased by 5,28 m, from 40,76 m to 46,04 m, and the beach gradient decreased by 0,45°, from 3,88° to 3,43°.

Profile D, E, and F show similar changes as Profile C and extensive erosion of the lower shoreface as well, making it likely that Profile C had erosion occurring there as well. At Profile E, there was small erosion right in front of the beach ridge, most likely caused by aeolian erosion, and another patch of minor erosion at the upper shoreface, in front of the newly formed berm. There were beach cusps at Profile D, but none at profiles E and F where there was a runnel in front of the ice front, with wave ripples in it. The beach width at Profile D increased by 8,49 m, from 31,04 m to 39,53 m, and the beach gradient decreased by 1,12°, from 5,23° to 4,11°. The beach width at Profile E increased by 7,88 m, from 31,71 m to 39,59 m, and the beach gradient decreased by 0,95°, from 4,77° to 3,82°. The beach width at Profile F increased by 5,06 m, from 39,58 m to 44,64 m, and the beach gradient decreased by 0,41°, from 3,7° to 3,29°.

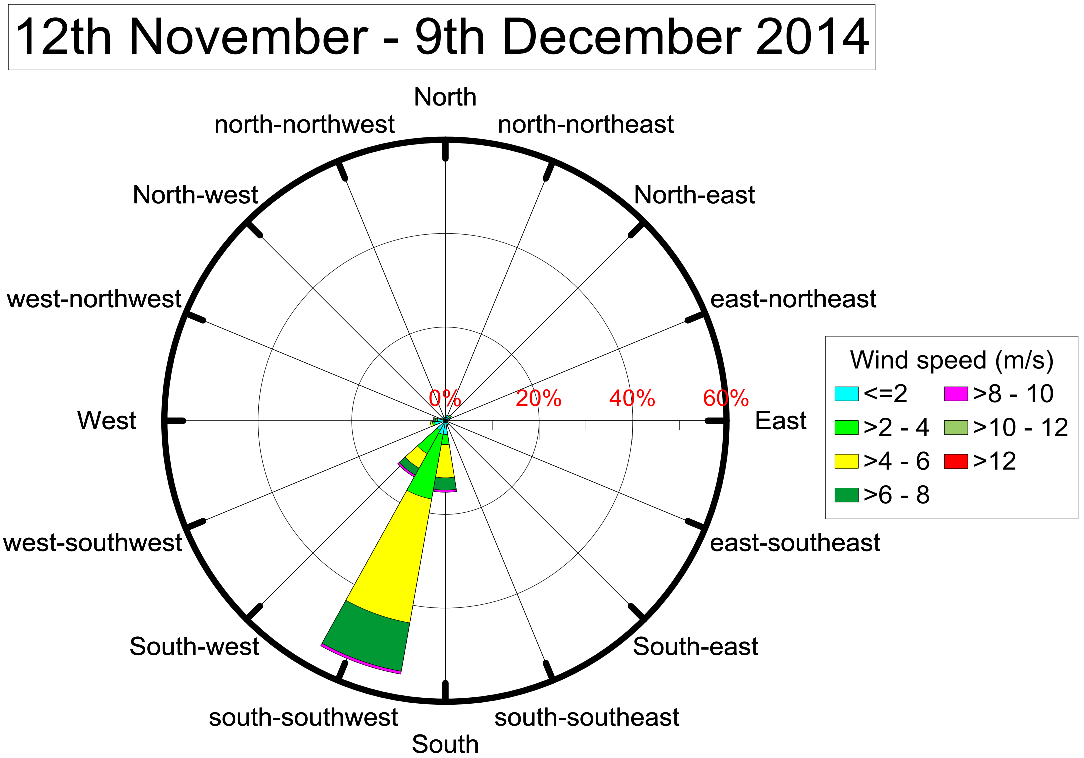

Fig. 3-21. Wind rose diagram for the period between the 12th of November and the 9th of December 2014. The prevailing wind direction for the period was south-southwest. Data from yr.no.

The dominating wind direction from 12th of November and 9th of December was south-southwest, with wind coming from that direction during 55% of the time (fig. 3-21). Winds from the south and the south-west were frequent as well, with 16% and 14% of the time respectively. Winds from other directions were not frequent during the period, and were almost absent. Wind was calm during this period with the highest hourly average wind speed of 9,5 m/s, from the south, and a mean wind speed of 4,1 m/s. Three minor storms occurred during the period, all with south-southwest wind direction and highest wind speed of about 8 m/s (fig. 3-22).

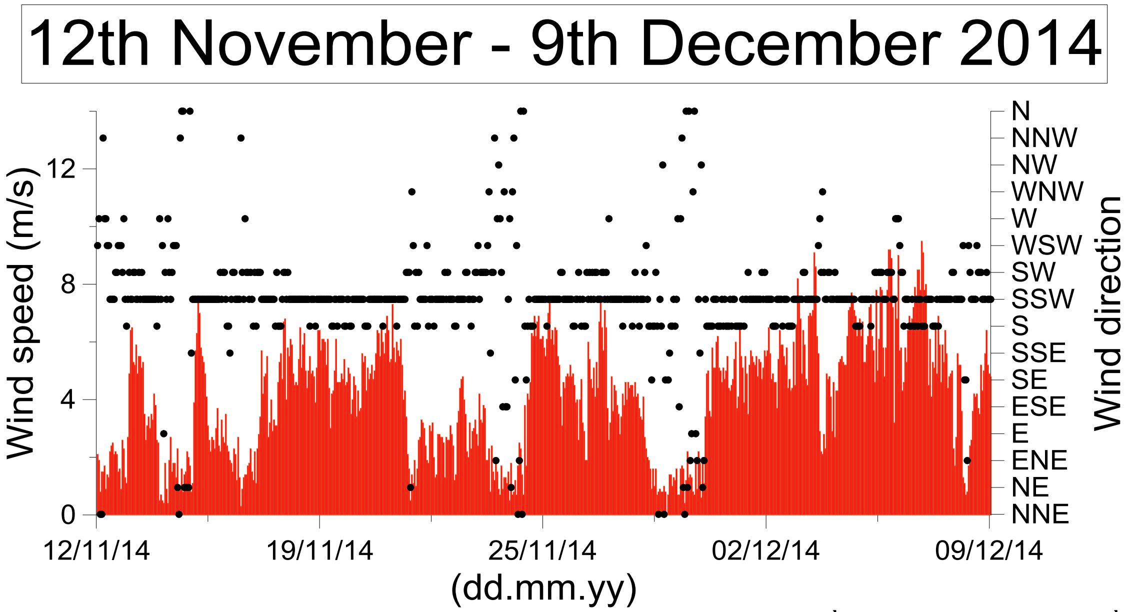

Fig. 3-22. A wind speed and direction diagram for the period between the 12th of November and the 9th of December 2014. The red columns represent the wind speed during the period, while the black dots show the wind direction. Every dot represents an hour. Data from yr.no.

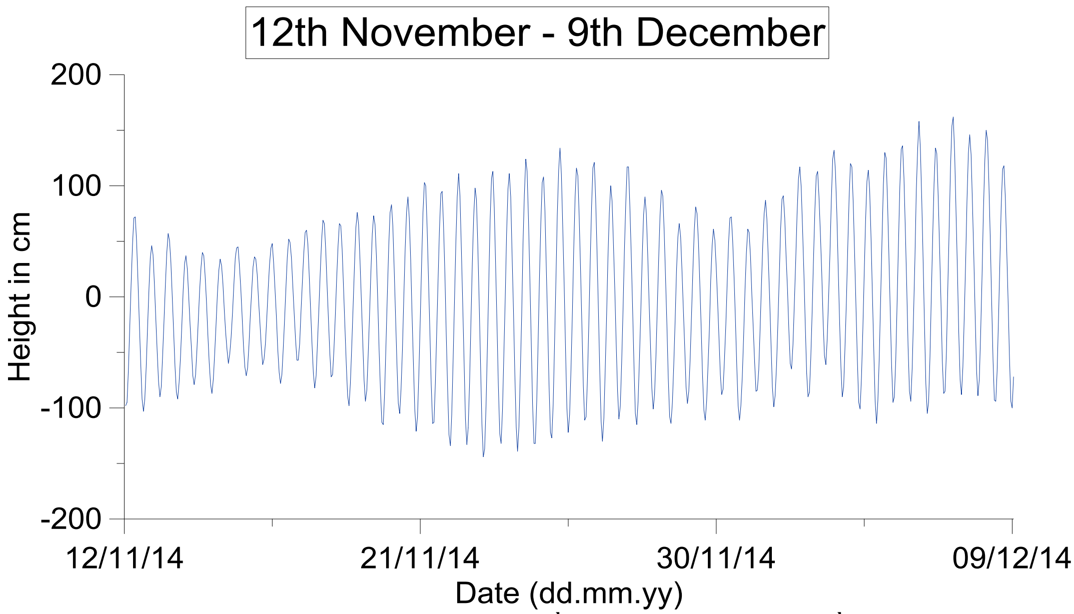

Fig. 3-23. Tidal diagram for the period between the 12th of November and the 9th of December 2014. Data from http://kartverket.no/sehavniva/.

There were two spring tides and two neap tides during the period between the measurements in October and November (fig. 3-22) and the mean tide height was -2,7 cm. The mean high tide height for the period was 94 cm, with the highest high tide at 162 cm, while the mean low tide height was -100 cm where the lowest low tide was at -144. In the early days of

December, the tide cycle is somewhat irregular and is most likely caused by the minor storm in early December.

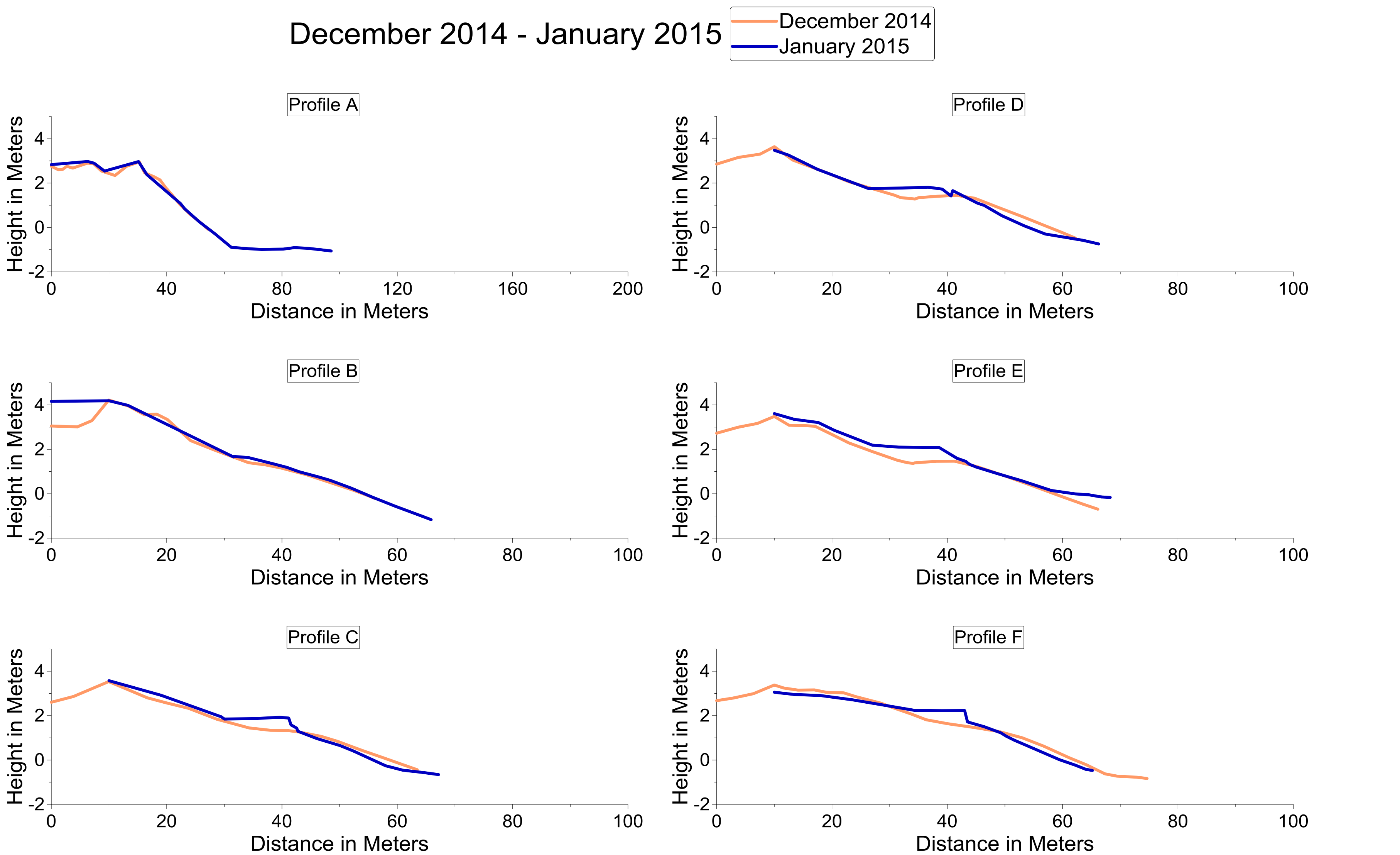

Fig. 3-24. Profile changes between 9th of December 2014 and 26th of January 2015. The profile lines measured in December are orange, while the lines from January are blue.

Between the 9th of December and 26th of January a thicker snow and ice cover started to form in the backshore and the upper foreshore, reaching down to the berm crest (fig. 3-24). By January 26th the snow and ice cover had gained considerable thickness on the berm of profiles C, D, E, and F, while profiles A and B had thinner layers there. The beach ridge had only thinn layer of snow on its top at all profiles, except at profile E where it was a few cm thick. At profiles A and B, there were no points measured on the snow and ice cover, extending from the base of the beach ridge down to the berm. Therefore, the erosion on the berm and the beach ridge on profiles A and B did not occurred but represent overlying snow and ice cover. On profiles C, D, E, and F the changes in the gradient on the snow and ice were measured.

At Profile A there was no change in the profile lines between December and January, apart for a minor accretion on the beach face, but the profile line from December did not reach down to neither the low tide terrace or the sand bar, and therefore comparison of those zones cannot be made. If the profile line of these zones from January and November is compared, it can be seen that the low tide terrace had extensive accretion during the period and was raised by about 30 cm from November to January (fig. 3-25). The beach width increased by 0,12 m, from 36,15 m to 36,27 m, and the beach gradient decreased by 0,01°, from 3,48° to 3,47°. Snow cover extended over the whole of the backshore and ended abruptly on the berm crest, with a thinner snow cover extending about a meter further down the beach face (fig. 3-26). The beach face was made up of fine sand with several thin lines of coarse sand on top of it. The thickest line with the coarsest sand was just above the break between the beach face and the low tide terrace. The low tide terrace and the sand bar were almost the same height, and there were wave ripples both on the low tide terrace (fig. 3-26), that were periodically cut by drainage channels, and on the seaward slope of the sand bar.

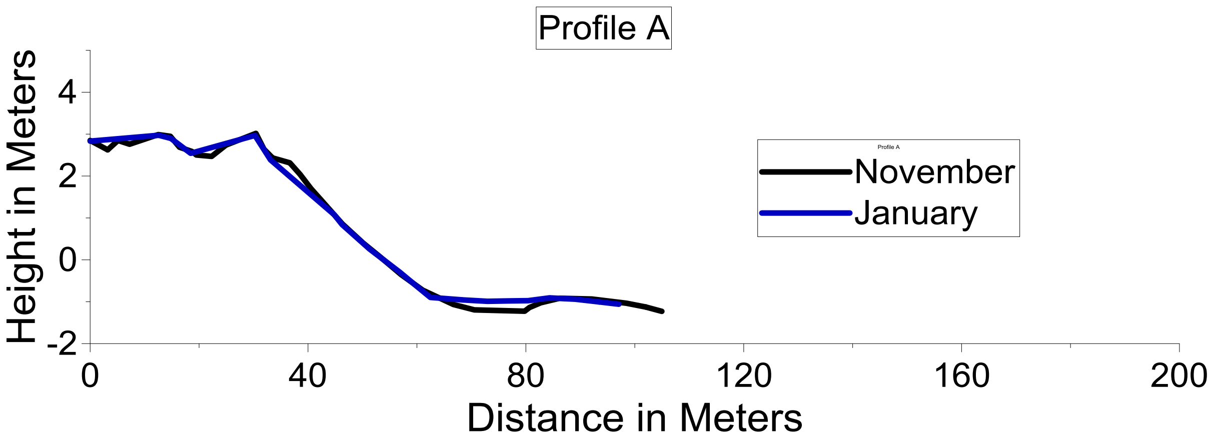

Fig. 3-25. Profile lines from November and January compared. The low tide terrace in between the beach face and the sand bar had experienced extensive accumulation and was raised by about 30 cm.

 

Fig. 3-26. The low tide terrace and the sand bar in front of profile A (on the left) and the end of the snow and ice cover on the berm (on the right).

At Profile B the backshore was covered by snow and ice cover, which extended down to the berm crest, and accretion occurred on the beach face, filling up the area where the runnel had formed the month before. The beach face and the low tide terrace did not have any lines of coarse sand. The low tide terrace was cut by multiple drainage channels and there was a layer of coarse sand in the surf zone. The beach width increased by 0,64 m, from 34,53 m to 35,17 m, and the beach gradient decreased by 0,09°, from 4,96° to 4,87°.

At Profile C the backshore was covered with a ice and snow cover, that was at its thickest on the berm. A small erosional scarp had been formed on the end of the ice, and fresh snowfall was in front of the scarp and on top of the ice (fig. 3-27). The beach face had been eroded, shortening the beach face and bringing the low tide terrace closer to the foreshore. There was a thin line of coarse sand at the boundary between the beach face and the low tide terrace and a small swash bar, a few cm in height and about 2 meters wide, on the low tide terrace (fig. 3-27). The height of the bar was only a few cm The beach width decreased by 1,98 m, from 46,04 m to 44,06 m, and the beach gradient increased by 0,16°, from 3,43° to 3,59°.

 

Fig. 3-27. Pictures showing the „cliff“ of ice on profile C (on the left) and the swash bar on the low tide terrace (on the right)

At Profile D the changes were similar to that of Profile C. Thick snow and ice cover on the berm with erosion of the ice on the berm crest that formed an erosional scarp, and a fresh snow cover in front of the ice and on top of it. The beach face was eroded, which shortened the beach face and brought the low tide terrace closer to the foreshore. There was a thin line of coarse sand at the boundary between the beach face and the low tide terrace. The beach width decreased by 2,07 m, from 39,53 m to 37,46 m, and the beach gradient increased by 0,23°, from 4,11° to 4,34°.

At Profile E the backshore was covered with a snow and ice layer, but the erosion of the ice on the berm crest was not as much as on profiles C and D, and therefore the scarp was not as steep. The upper beach face remained the same in between the months, but accretion occurred on the lower beach face, extending it further out. The beach width and the beach gradient remained the same during the period, 39,59 m and 3,82°,

Profile F underwent the same changes as profiles C and D, with ice cover on the berm, steep ice scarp on the berm crest and erosion on the beach face (fig. 3-28). There was a row of beach cusps, made up of ice, on the berm crest. The „beach cusps“ had been undercut and a new row of beach cusps had been formed in the more recently fallen, thinner snow, in between the older row of „beach cusps“ (fig. 3-28). There were two lines of coarse sand on the low tide terrace, but none on the beach face. The beach width decreased by 2,5 m, from 44,64 m to 42,14 m, and the beach gradient increased by 0,2°, from 3,28° to 3,48°.

Fig. 3-28. Pictures from Profile F. On the right the „cliff“ of the ice can be seen on the berm crest, and on the left the cliff can be seen on the far right with beach cusps formed in the snow and ice layers in front of the thicker one on the berm.

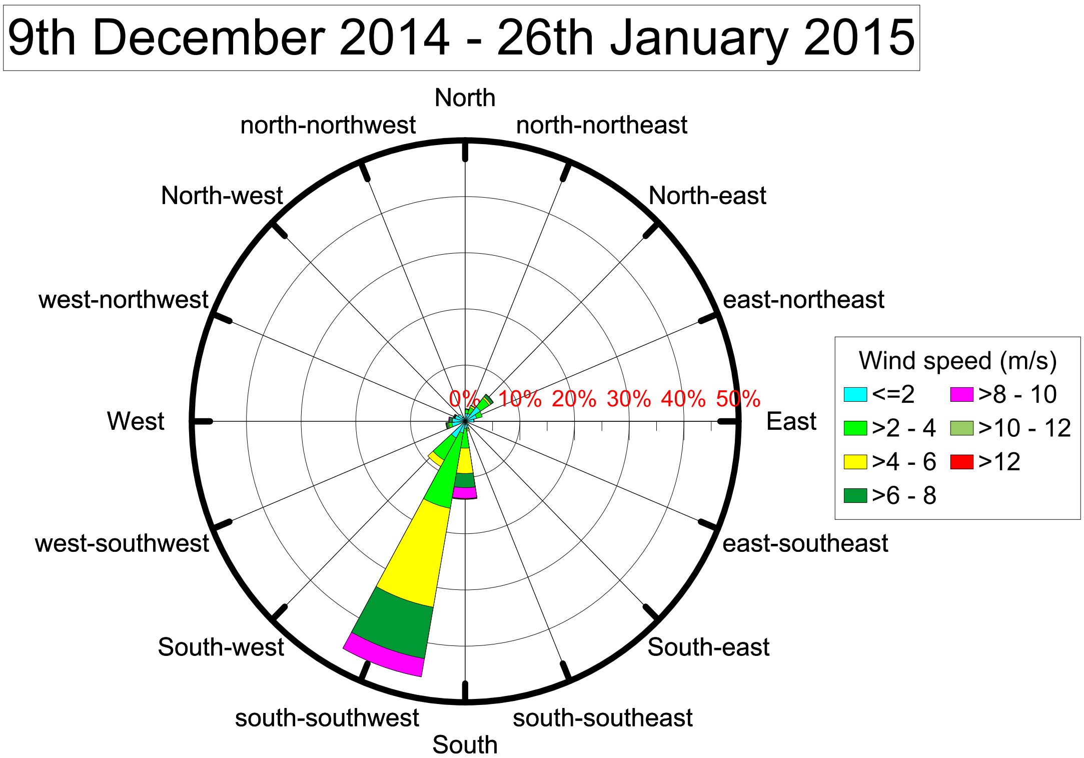

Fig. 3-29. Wind rose diagram for the period between the 9th of December 2014 and 26th of January 2015. The prevailing wind direction was from the south-southwest. Data from yr.no.

The dominating wind direction from 9th of December to 26th of January was south-southwest, with wind coming from that direction during 46% of the time (fig. 3-29). Winds from the south and the south-west were frequent as well, with 14% and 9% of the time respectively. Winds from other directions were not frequent during the period. Wind speed during this period fluctuated, with the highest hourly average wind speed of 12,1 m/s, from the south, and a mean wind speed of 3,9 m/s. The wind reached 8 m/s several times during the period, in most cases when the wind was blowing in from the south and south-southwest, but once when the wind direction was from the east-northeast to north-east (fig. 3-30). These small storms were all short in duration with lower wind speed in between them.

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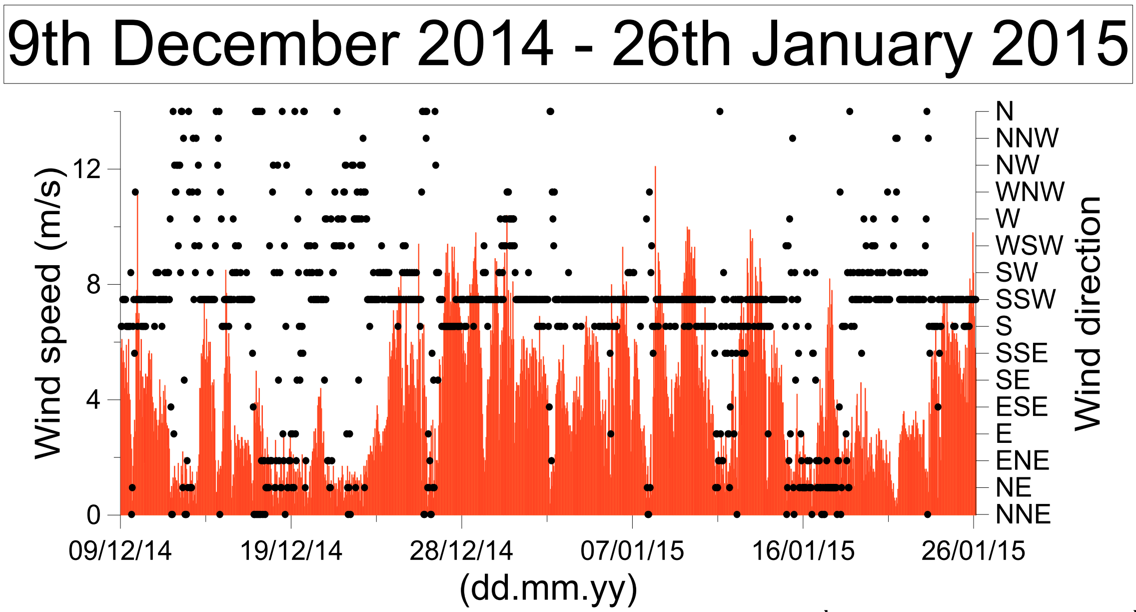

Fig. 3-30. A wind speed and direction diagram for the period between the 9th of December 2014 and 26th of January 2015. The red columns represent the wind speed during the period, while the black dots show the wind direction. Every dot represents an hour. Data from yr.no.

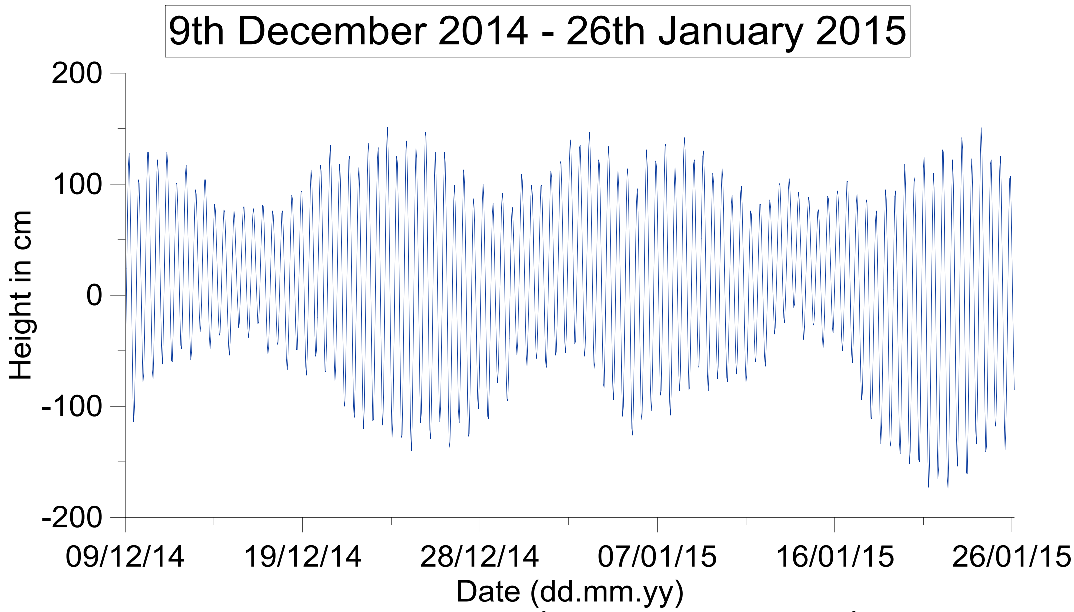

Fig. 3-40. Tidal diagram for the period between the 9th of December 2014 and 26th of January 2015. Data from http://kartverket.no/sehavniva/.

There were three spring tides and three neap tides during the period between the measurements in December and January (fig. 3-40), and the change between spring tide and neap tide around 9th of December is also recorded. The mean tide height during the period was 11,2 cm, while the mean high tide height was 94 cm and the mean low tide height was -100 cm. The highest tide was 151 cm and the lowest tide was -174 cm. The tidal cycles during the period were highly irregular, with double peaks in tide height during one of the spring tide and one of the neap tide. The cause for the irregularity is likely the high winds during the frequent small storms in the period.

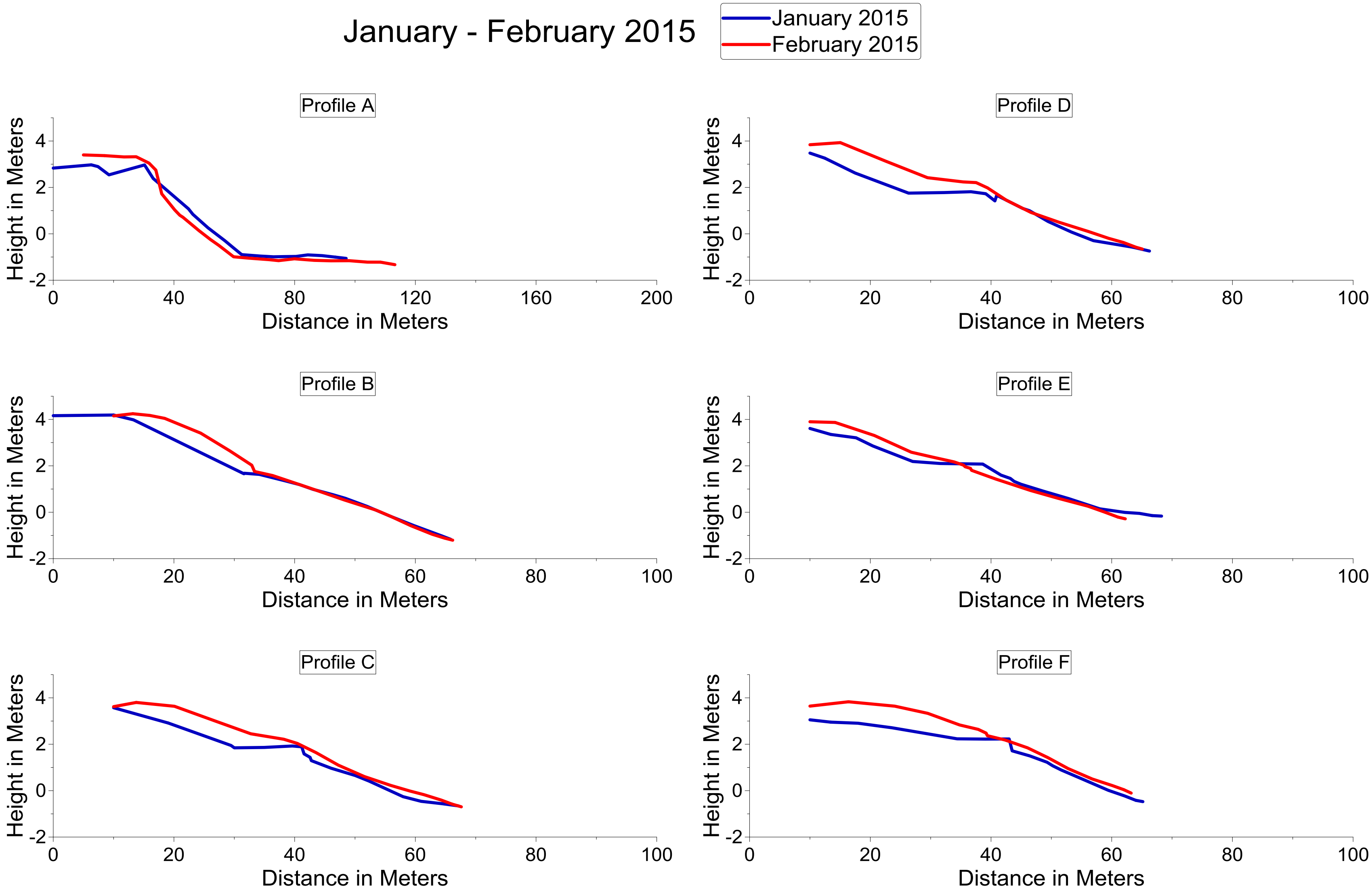

Fig. 3-41. Profile changes between 26th of January and 23rd of February 2015. The profile lines measured in January are blue, while the lines from February are red.

Between 26th of January and 23rd of February snow and ice accumulation continued on the backshore and the upper foreshore and accretion occurred on the beach face at most profiles (fig. 3-41). Due to deep snow neither peg 1 nor peg 2 could be located at Profile A and peg 1 at the other five profiles. The profile line measured at Profile A that month is therefore not correct and lies about 15 m further to the south than it should. The measured profile line also lies in a more west-northwest to east-southeast direction than it should. The line is not usable as a direct measurement, but gives some indications of changes occurring there between January and February. The deviation on the other five profiles is not as high, as peg 2 was located on them, and the GPS coordinates were used for the location of peg 1.

At Profile A the snow and ice covered reach the berm crest, where it ended abruptly with erosional scarp on its end (fig. 3-42). There was no sand deposited on top of the snow, or in front of the scarp. The beach face was uniform in grain size, with no lines of coarser material, and had a gentle slope onto the low tide terrace. The surface of the low tide terrace was frozen, with about 1 cm thick ice covering it, and no ripples. The sand bar had wave ripples and combination of wave and current ripples on most of its surface area. Some areas on the berm had a thin ice covering it like on the low tide terrace.


Fig. 3-42. Pictures from Profile A (on the left) and Profile B (on the right), where the snow and ice cover at Profile A can be seen, reaching down to the berm crest with erosional scarp on the ice front, and the small beach cusps ridges at Profile B with a patch of coarse sand in between.

At Profile B there was a minor accretion on the berm crest, and erosion on two areas of the beach face. The beach width decreased by 0,38 m, from 35,17 m to 34,79 m, and the beach gradient increased by 0,03°, from 4,89° to 4,92°. The thickness and extent of the snow and ice cover had increased, reaching down to the berm crest and had a small erosional scarp on its end. In front of the scarp there was a layer of ice, about half a meter wide, which had been partially covered with sand. There were no beach cusps formed in the ice like in January, but instead the upper part of the beach face had small beach cusps that only had one horn and a ridge extending up to the berm crest, ending at the scarp of the snow and ice cover. On some occasions there was a small patch of coarse sand between two of the cusps (fig. 3-42). The low tide terrace had a thin layer of ice on its surface, much like at Profile A.

Fig. 3-43. Beach cusps ridges at Profile C. The cusps were largest at profiles C, D, and E, while they were both shorter and not as high at profiles B and F. There were no cusps at Profile A.

At Profile C the snow thickness on the ridge and the berm had increased greatly and the beach face and the low tide terrace had been raised since January. Some of the increase height on the upper beach face is likely due to ice forming there, and then being overlaid by sand when the tide rose. The beach width increased by 1,85 m, from 44,06 m to 45,91 m, and the beach gradient decreased by 0,15°, from 3,59° to 3,44°. There was a large erosional scarp in the snow and ice cover, with a small terrace in the ice that had been cut by the tide and the waves (fig. 3-44). On this terrace sand had been deposited on top of the ice, much like at Profile B. There were beach cusp ridges on the profile as well that were larger in size and more visible than at Profile B (fig. 3-43), but there were no patches of coarse sand in between the ridges. The low tide terrace was covered in ice as well, with only a few, small drainage channels that were not frozen.

At Profile D the snow and ice cover had increased as well, and the lower part of the beach face and the low tide terrace had been raised. A new berm crest was formed, at an higher elevation that it had been in January, out of ice overlaid by sand. The beach width increased by 0,09 m, from 37,46 m to 37,55 m, and the beach gradient decreased by 0,01°, from 4,34° to 4,33°. There was little to no visible erosional scarp in the ice front here, but rather the tide and the waves had smoothed out the ice front and deposited sand on top of about 3 m wide area on the ice front, with ice sticking out periodically. There were beach cusps ridges on the beach face below the ice, with no patches of coarse sand, and the low tide terrace was frozen.

Fig. 3-44. Pictures of the ice front at profiles D (on the left) and C (on the right). At both profiles sand had been deposited in front of the ice front, but at Profile C the scarp was visible while at Profile D there was either no scarp or it was concealed under sand.

At Profile E The snow and ice cover increased in thickness on the berm, but the a large portion of the ice front in January had been eroded, pushing the ice front further up the beach, and the low tide terrace had been lowered considerably. The beach width decreased by 1,69 m, from 39,59 m to 37,9 m, and the beach gradient increased by 0,17°, from 3,82° to 3,99°. A new erosional scarp had been formed in the ice front (fig. 3-45), as it was pushed back up the beach, and had a small terrace on it that divided the upper part and the lower part of the scarp. Only small quantities of sand had been deposited on top of the terrace, but there was sand on the ice in front of the lower terrace. The rest of the profile was the same as the others, with beach cusps ridges on the beach face and the low tide terrace was frozen.

At Profile F similar changes had occurred as at Profile E. The ice front from January had been pushed back on the berm where a new scarp had formed and the whole beach face been raised. The beach width increased by 1,69 m, from 42,14 m to 43,83 m, and the beach gradient decreased by 0,13°, from 3,48° to 3,35°. Sand had been deposited in front of the erosional scarp, smoothing out the surface and sand was also deposited on top of the snow behind the scarp. The beach cusps ridges were present there as well (fig. 3-45), but had diminished in both height and length, being similar in size as the cusps at Profile B. The upper part of the low tide terrace was frozen, but the tide had started to rise and the ice was being broken up by the sea. During the rise of the tide, there was mild erosion on the beach terrace, as the ice broke up and seawater undercut the ice.

Fig.3-45. Beach cusps ridges at Profile F (on the left) and erosional scarps and terrace in the ice front at Profile E (on the right). The cusps were smaller at Profile F than at profiles C, D, and E, and about the same size as Profile B. The ice front had two scarps at Profile E, with a small terrace between them, and sand deposited in front of the lower scarp.

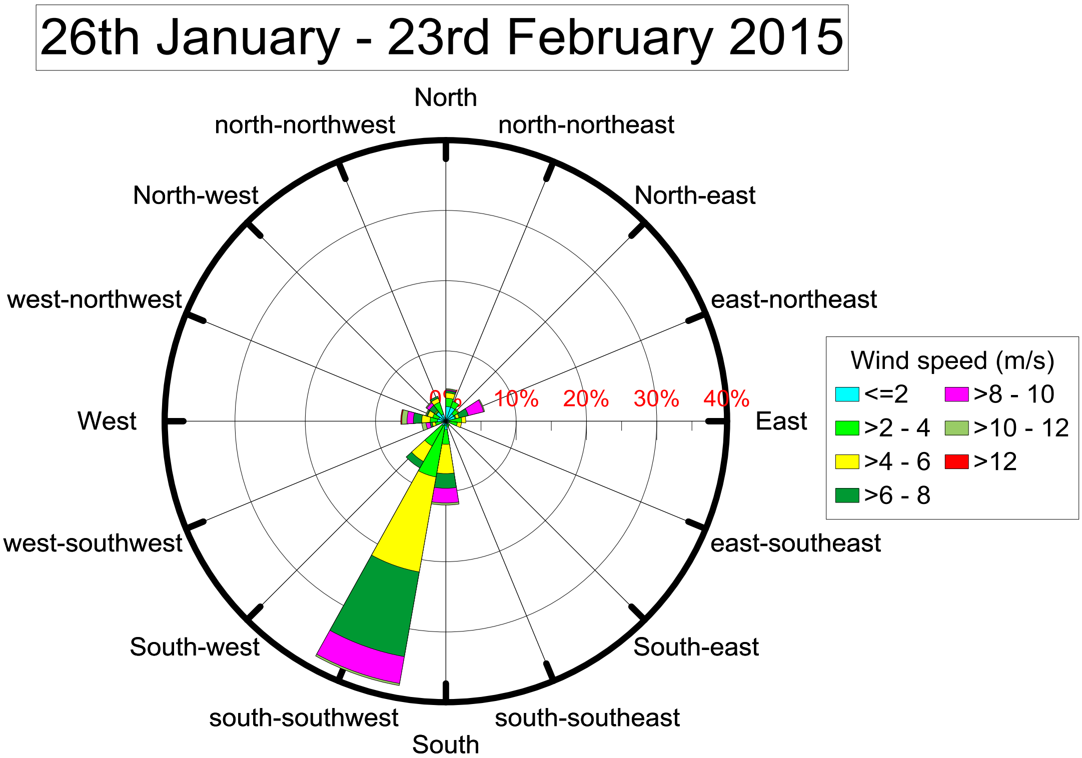

Fig. 3-46. Wind rose diagram for the period between 26th of January and 23rd of February 2015. The prevailing wind direction was south-southwest.Data from yr.no.

The dominating wind direction from 26th of January to 23rd of February was south-southwest, with wind coming from that direction during 39% of the time (fig. 3-46). Winds from the south and the south-west were frequent as well, with 13% and 7% of the time respectively. Winds from other directions were not frequent during the period. Wind was fairly high during this period with the highest hourly average wind speed of 12,3 m/s, from the west, and a mean wind speed of 4,9 m/s. The wind reached 8 m/s several times during the period, in most cases when the wind was blowing in from the south and south-southwest, but once when the wind direction was from the East to east-northeast (fig. 3-47). These small storms were all short in duration, apart from the small storm around the 16th of February which lasted for a few days.

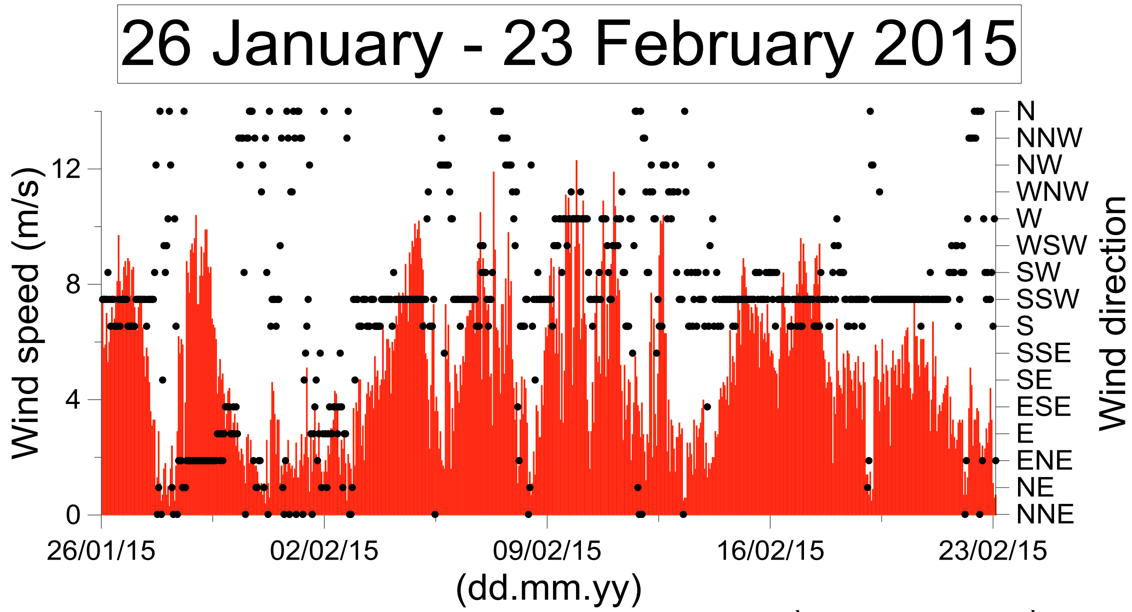

Fig. 3-47. A wind speed and direction diagram for the period between 26th of January and 23rd of February 2015. The red columns represent the wind speed during the period, while the black dots show the wind direction. Every dot represents an hour. Data from yr.no.

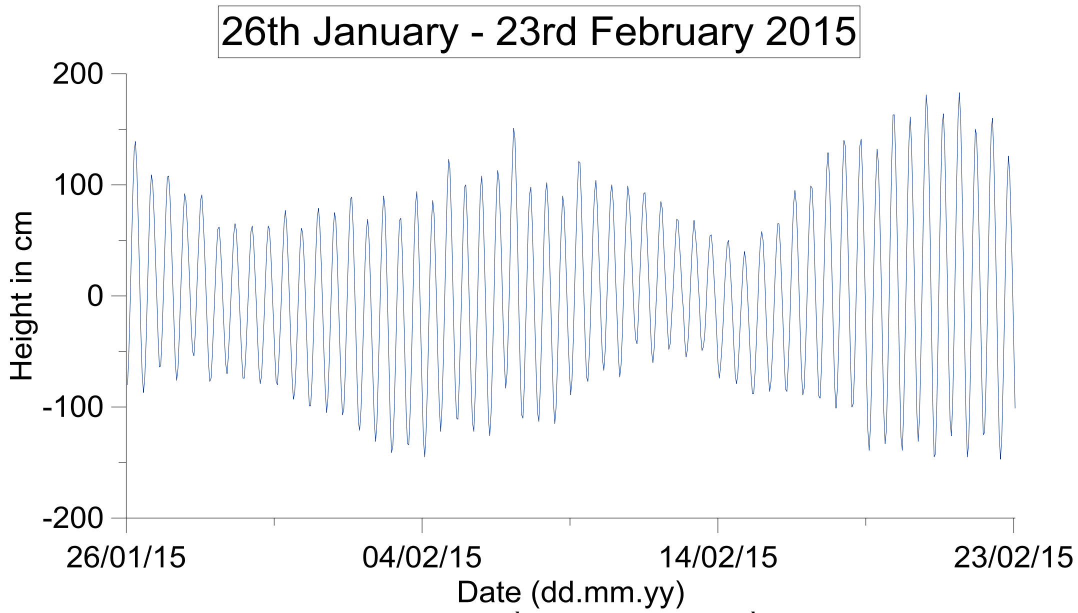

Fig. 3-48. Tidal diagram for the period between 26th of January and 23rd of February 2015. Data from http://kartverket.no/sehavniva/.

There were two spring tides and two neap tides during the period between the measurements in January and February (fig. 3-48). The mean tide height during the period was 2,3 cm, while the mean high tide height was 102 cm and the mean low tide height was -98 cm. The highest tide was 183 cm and the lowest tide was -147 cm. The tidal cycles during the period are highly irregular, likely due to the high number of small storms in the period.

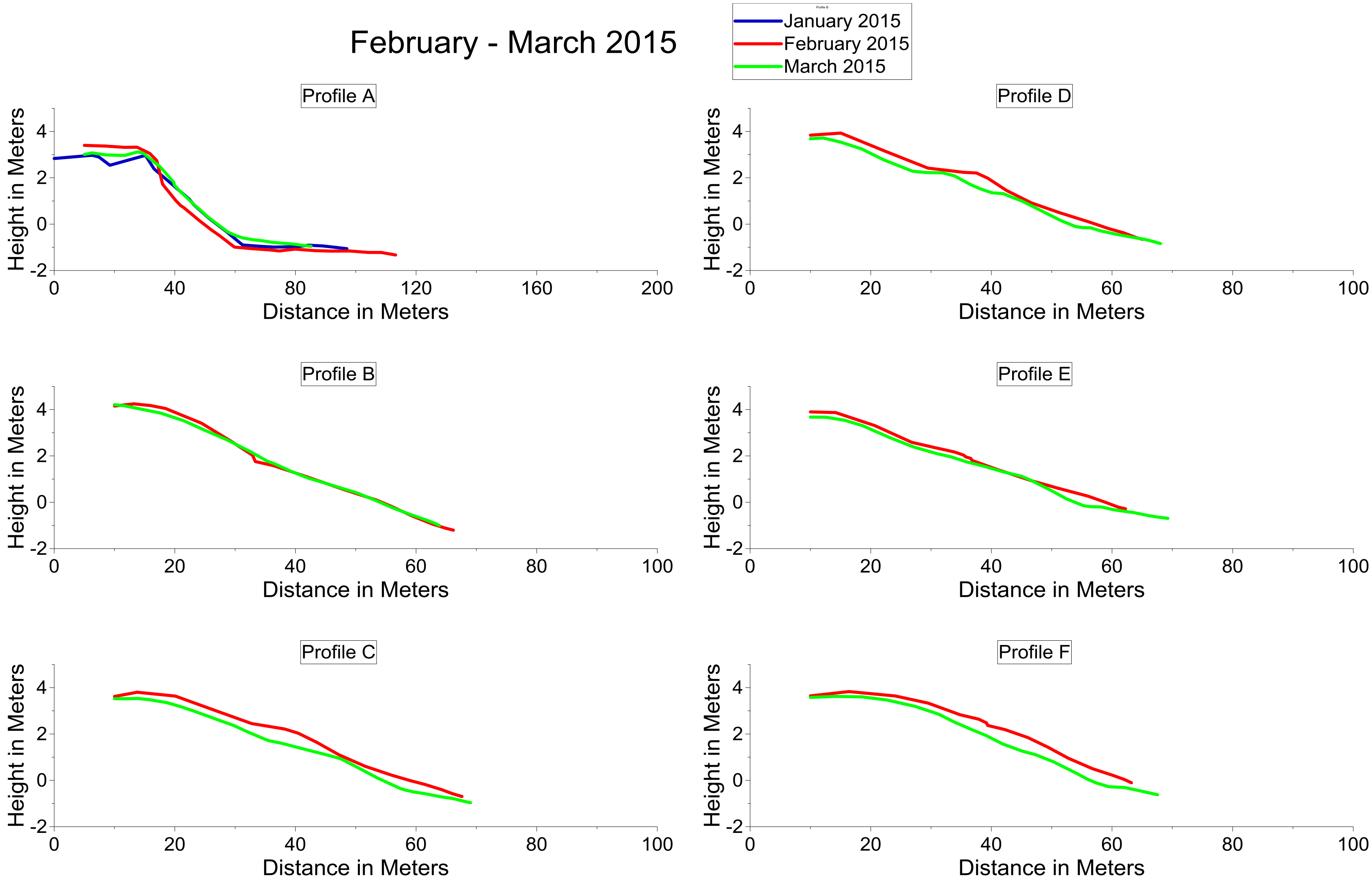

Fig. 3-49. Profile changes between 23rd of February and 31st of March 2015. The profile line at Profile A for January 2015 is shown as well, since the profile line for February at that profile is incorrect. The profile lines measured in January is blue, the line from February is red, and the line from March is green.

During the period between February 23rd and March 31st the snow and ice covered started to decrease and erosion occurred on the beach face and the low tide terrace at most of the profiles (fig. 3-49). Due to the measuring error at Profile A in February, comparison from February to March was not made, but instead the profile line from January is compared to the March profile line.

At Profile A the low tide terrace had been raised significantly (fig. 3-50), decreasing the length of the beach face, but the beach face profile remained stable. The beach width increased by 0,14 m, from 36,27 m to 36,41 m, and the beach gradient decreased by 0,01°, from 3,47° to 4,46°. There was still snow on the beach ridge, but the berm had become mostly snow free and there was an erosional scarp on the berm crest (fig. 3-50), not unlike the one in February, but it was made out of sand, not ice. Due to the increase in the height of the low tide terrace, the boundary of the beach face and the terrace had a low angle and the terrace and the bar were at the same height and there were wave ripples on the inner part of the sandbar. There were no lines of coarse sand on the beach face or the boundary of the beach face and the terrace.

Fig. 3-50. Pictures from profile A. (on the left) The beach face, the low tide terrace and the sandbar can be seen, where the height of the terrace had reached the same height as most of the sandbar. (On the right) Erosional scarp on the berm crest, similar to the one on the crest in February, but with no ice on it.

At Profile B there were no changes in the profile, apart from the erosional scarp from the month before was smoothed out. The beach width decreased by 0,03 m, from 34,79 m to 34,76 m, and the beach gradient increased by 0,01°, from 4,92° to 4,93°. The backshore was still covered with snow and on the berm crest there was a small erosional notch on the ice front mostly covered by sand. Below the notch was a row of small beach cusps and there were no lines of coarse sand on the beach face.

At Profile C and D, the entire length of the profile had been lowered, with the greatest reduction on the berm crest, due to decreased snow, and on the boundary of the beach face and the low tide terrace, where a runnel was formed. The beach width at Profile C decreased by 1,31 m, from 45,91 m to 44,6 m, and the beach gradient increased by 0,1°, from 3,44° to 3,54°. The beach width at Profile D decreased by 1,23 m, from 37,55 m to 36,32 m, and the beach gradient increased by 0,14°, from 4,33° to 4,47°.

At Profile E there was decrease in the thickness of the snow and ice cover, and the boundary of the beach face and the low tide terrace was lowered, and a runnel was formed in the depression. The upper part of the beach face however had been raise d slightly. The beach width decreased by 0,48 m, from 37,9 m to 37,42 m, and the beach gradient increased by 0,05°, from 3,99° to 4,04°.

At Profile F the entire length of the profile had been lowered much like at profiles C and D, but the lowering of the profile was fairly even throughout. The beach width decreased by 3,85 m, from 43,83 m to 39,98 m, and the beach gradient increased by 0,32°, from 3,35° to 3,67°.

Profiles C, D, E, and F all had similar changes during the period. The snow and ice cover had diminished greatly and the erosional scarps in the ice front had mostly disappeared (fig. 3-51), but the ice front still reached down to the berm crest. There was a row of beach cusps on the berm crest, with snow on the top. A small and shallow runnel was formed on the boundary between the beach face and the low tide terrace, with a line of coarse sand just above the runnel. In some areas of the runnel there was a mixture of wave and current ripples, but large areas of the runnel had been filled in with sand (fig. 3-51).

Fig. 3-51. Pictures from Profile F and Profile E, showing the runnel on Profile F (on the right) with ripples in it and a bar in front of it, and a sand covered erosional scarp in the ice front. At Profile E

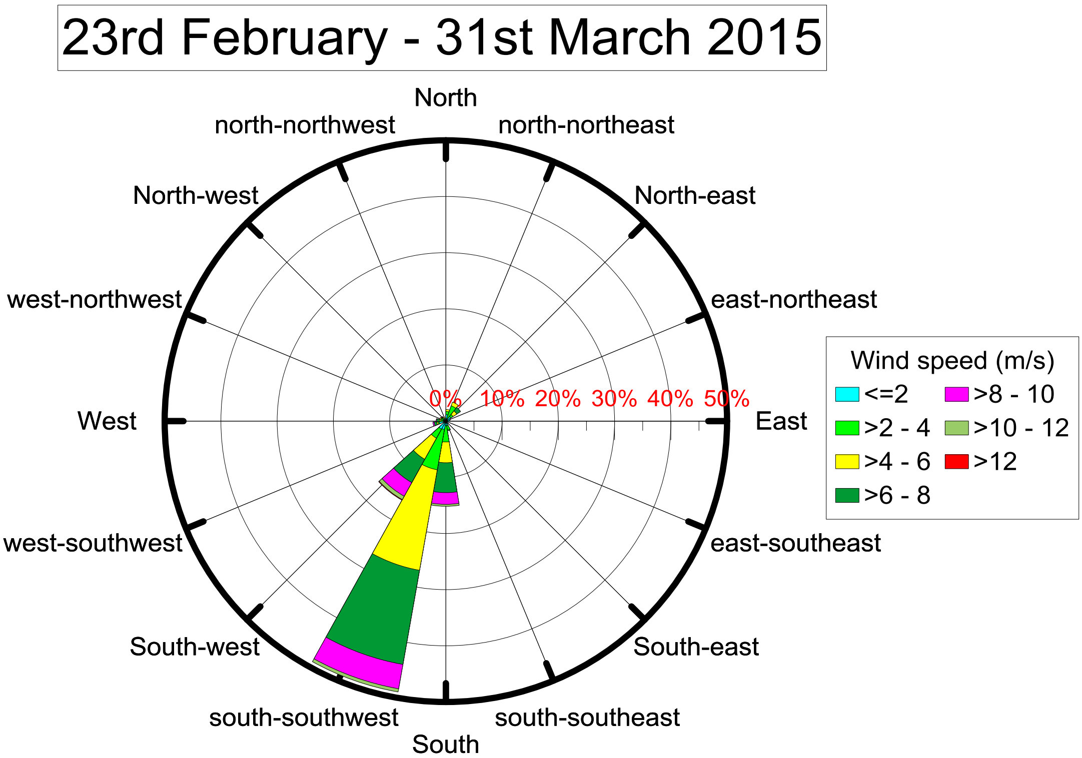

Fig. 3-52. Wind rose diagram for the period between 23rd of February to 31st of March 2015. The prevailing wind direction was south-southwest. Data from yr.no.

The dominating wind direction from 26th of January to 23rd of February was south-southwest, with wind coming from that direction during 49% of the time (fig. 3-52). Winds from the south and the south-west were frequent as well, with 15% and 16% of the time respectively. Winds from other directions were not frequent during the period. Wind was fairly high during this period with the highest hourly average wind speed of 12,8 m/s, from the south-west, and a mean wind speed of 5,3 m/s, which was the highest mean wind speed during the one year cycle. The wind reached 8 m/s several times during the period, in most cases when the wind was blowing in from the south, south-southwest and south-west (fig. 3-53). There was however one small storm from the north-west, but it lasted for only about four hours.

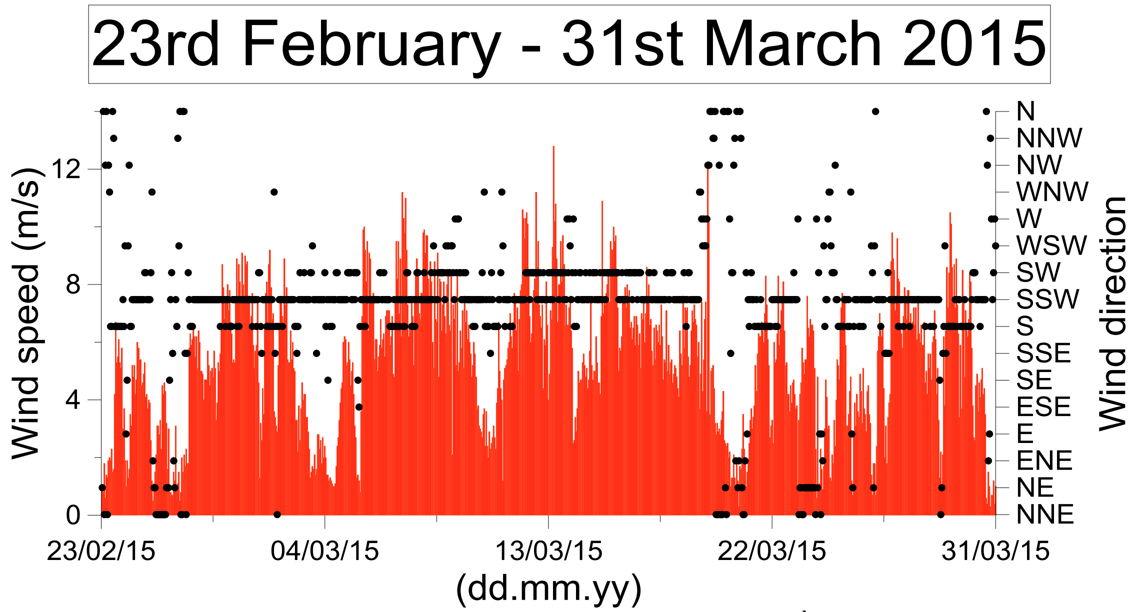

Fig. 3-53. A wind speed and direction diagram for the period between 23rd of February to 31st of March 2015. The red columns represent the wind speed during the period, while the black dots show the wind direction. Every dot represents an hour. Data from yr.no.

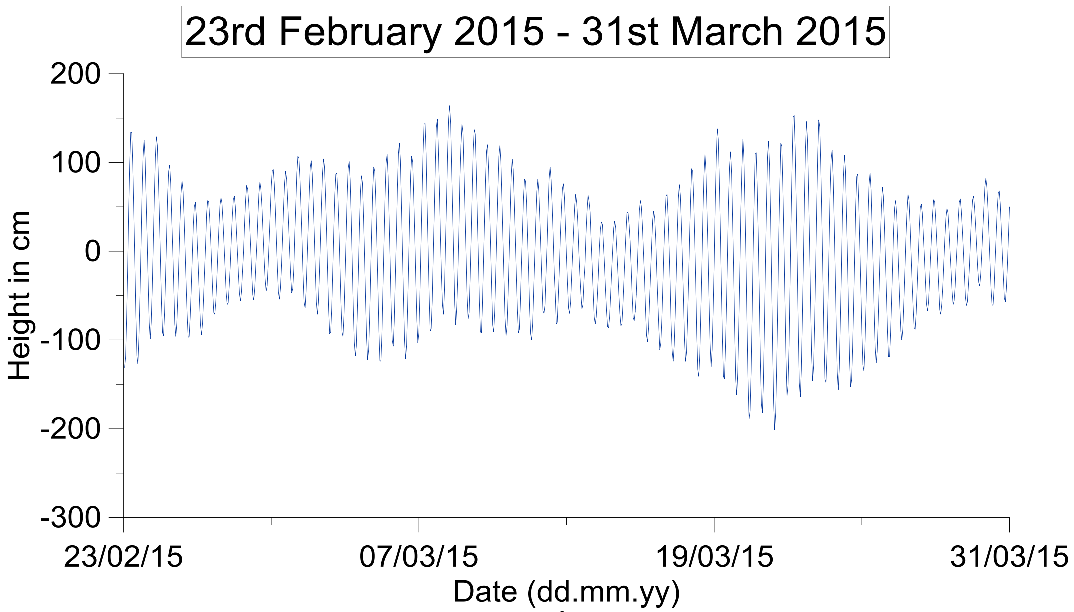

Fig. 3-54. Tidal diagram for the period between the 23rd of February and the 31st of March 2015. Data from http://kartverket.no/sehavniva/.

There were two spring tides and three neap tides during the period between the measurements in February and March (fig. 3-54). The mean tide height during the period was -3,5 cm, while the mean high tide height was 93 cm and the mean low tide height was -101 cm. The highest tide was 164 cm and the lowest tide was -201 cm. The tidal cycles continued to be irregular in response to the high frequency of storms in the period.

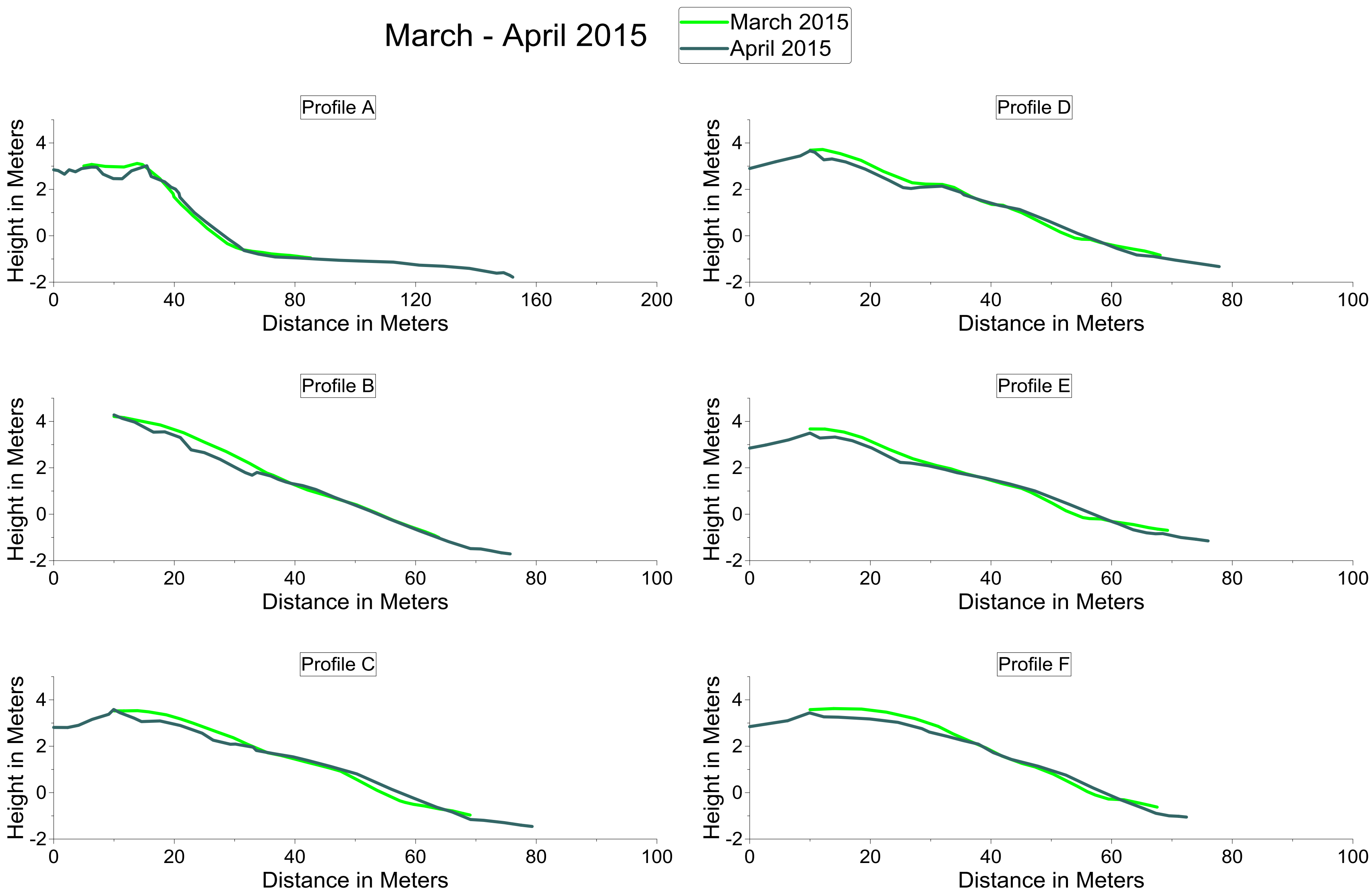

Fig. 3-55. Profile changes between the 31st of March and 21st of April 2015. The profile lines measured in March are green, while the lines from April are dark green.

Between 31st of March and 21st of April most of the remaining snow disappeared from the beach, but there was a snow and ice cover still present on the berm (fig. 3-55).

At Profile A the profile became snow free and mostly ice free, with some ice still present underneath the sand on the upper part of the berm. There was accretion on the berm and the whole beach face, while there was erosion on the low tide terrace, reducing the height of it. The accretion extended the width of the berm by about 3 m but it had not jet fully recovered from the erosion in November 2014. The beach width increased by 1,73 m, from 36,41 m to 38,14 m, and the beach gradient decreased by 0,16°, from 3,46° to 3,3°. The same erosional scarp on the berm crest from March was still present on the berm crest, but the edges of it had been eroded and some sand deposited in front of it (fig. 3-56). The beach face had no lines of coarse sand and no beach cusps, and the low tide terrace had both wave ripples and drainage channels. The sandbar was split into two by a large drainage channel, and was covered with wave ripples on the landward facing side, while it had a combination of wave and current ripples on the seaward facing side.

Fig. 3-56. Pictures from profiles A (on the left) and B (on the right), showing the erosional scarp on the berm crest at Profile A and the berm at Profile B with the snow and ice cover with sand on top, the collapsed sand and a beach cusp below that.

At Profile B most of the back shore became snow free, but the berm was still covered with snow and ice. There was small accretion on the upper beach face, with slight erosion on the rest of it. The beach width increased by 0,78 m, from 34,76 m to 35,54 m, and the beach gradient decreased by 0,11°, from 4,93° to 4,82°. The snow and ice still on the berm was covered in sand (fig. 3-56) and in front of the snow cover there was a small area where sand had collapsed when the underlying ice had melted. There was a row of beach cusps just beneath that area and there were no lines of coarse sand on the beach face. The low tide terrace had a small runnel on it, with a small longshore bar at its base. There were two lines of coarse sand on the low tide terrace, one just above the runnel on the other on top of the bar.

At Profile C the beach ridge had become clear of the snow and ice cover, but there was still a substantial amount of snow on the berm. There was extensive accretion on the beach profile, but erosion on the low tide terrace where a runnel had formed. The beach width increased by 1,62 m, from 44,6 m to 46,22 m, and the beach gradient decreased by 0,12°, from 3,54° to 3,42°. The snow and ice cover on the berm was not covered by sand as at Profile B, but had a small area right in front of the ice front where a thin layer of sand overlaid some ice that was melting. The sand was however not collapsing in like at Profile B, but formed rather small mounds on the surface as the ice melted. A row of beach cusps was on the upper part of the beach face, just below the ice front, and no lines of coarse sand were present. There was a runnel with a large longshore bar on the low tide terrace, and the bar was cut periodically by rip current channels and had no line of coarse sand. In the runnel there was a mixture of wave and current ripples.

At Profile D the berm had been built up to the same height as it was before the storm in November 2014, and was wider than then. There was accretion on the beach face, but erosion on the low tide terrace where the runnel was formed. The beach width increased by 1,29 m, from 36,32 m to 37,61 m, and the beach gradient decreased by 0,15°, from 4,47° to 4,32°. Profile D had the same morphology as Profile C, apart from the runnel being slightly wider.

At Profile E the berm height had increased to similar heights as it had before the storm in November 2014, but was not as wide as it had been. There was accretion on the beach face, but erosion on the low tide terrace, where the runnel had formed. The beach width increased by 1,49 m, from 37,42 m to 38,91 m, and the beach gradient decreased by 0,15°, from 4,04° to 3,89°.

Profiles D and E had the same morphology as Profile C, but the runnel increased in width the closer it got to Profile E (fig. 3-57). The runnel had wave and current ripples at the bottom, but most of them had been cut by drainage channels. The size of the longshore bar also increased the closer it got to Profile E, and was cut periodically by rip current channels.

At Profile F small parts of the berm had been exposed, but it had not been repaired since the storm in November. There was accretion on the beach face, and erosion on the low tide terrace that decreased the height of it. The beach width increased by 1,49 m, from 39,98 m to 41,47 m, and the beach gradient decreased by 0,13°, from 3,67° to 3,54°. The morphology at Profile F was the same as at profiles C, D, and E, apart from the runnel and the longshore bar not reaching the profile, but ending about 10 meters north of it (fig. 3-57).

Fig. 3-57. Pictures from Profile E (on the left) and F (on the right). The runnel at Profile E can be seen, with cut ripples on the bottom of the runnel and a longshore bar with channels through it. The low tide terrace at Profile F did not have a runnel and a bar, as they stopped just north of the profile.

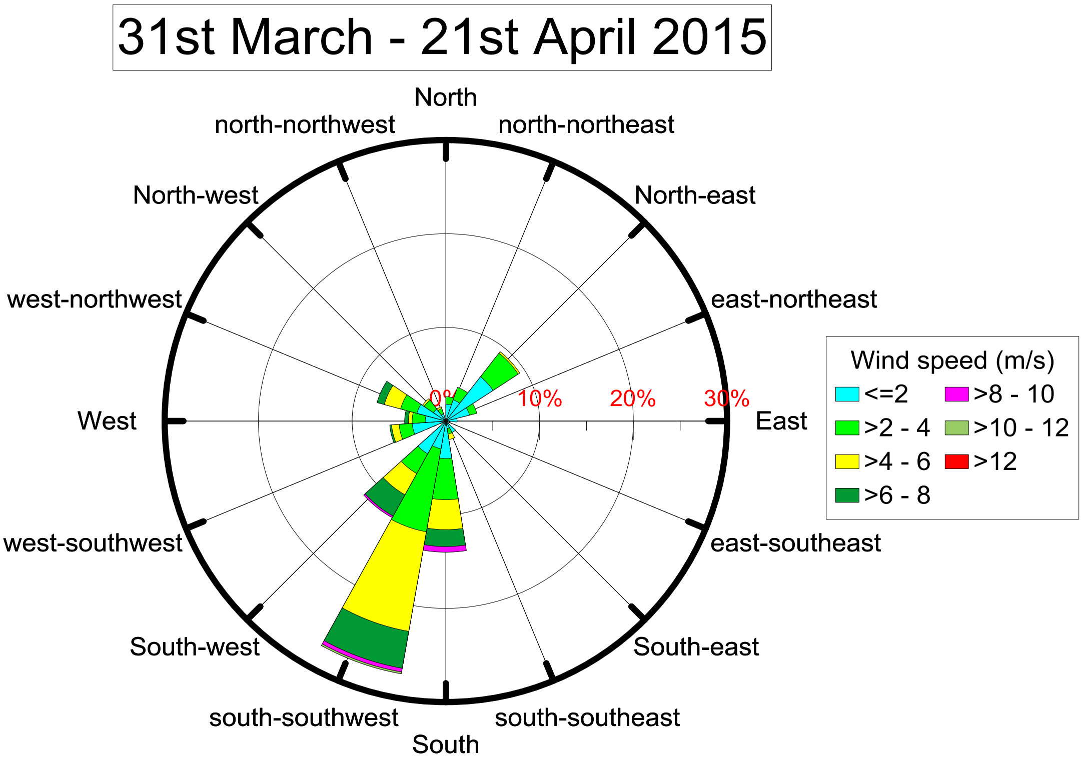

Fig. 3-58. Wind rose diagram for the period between 31st of March and 21st of April 2015. The prevailing wind direction was south-southwest. Data from yr.no.

The dominating wind direction from 31st of March to 21st of April was south-southwest, with wind coming from that direction during 28% of the time (fig. 3-58) Winds from the south and the south-west were frequent as well, with 14% and 12% of the time respectively. Winds from other directions were not as frequent during the period, but winds from the west-southwest, west-northwest and north-east were in the duration of between 5 and 9% of the time. Wind was calm during this period with the highest hourly average wind speed of 10,7 m/s, from the south-southwest, and a mean wind speed of 3,2 m/s. There were no major storms during the period and wind speed only reached 8 m/s once during the period, during winds from the south-southwest (fig. 3-59).

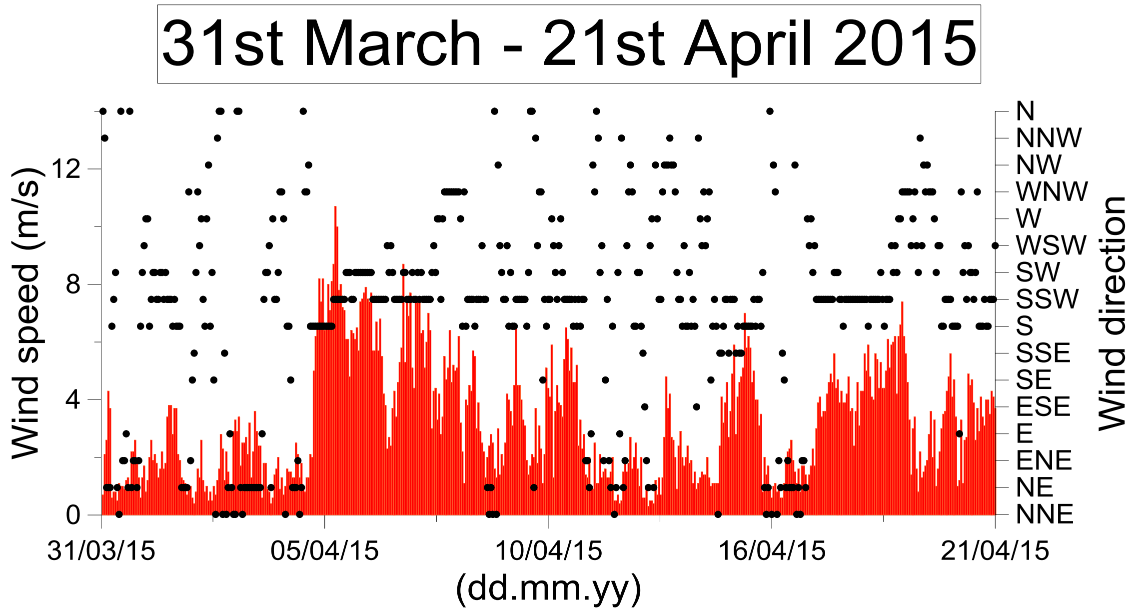

Fig. 3-59. A wind speed and direction diagram for the period between the 31st of March and the 21st of April 2015. The red columns represent the wind speed during the period, while the black dots show the wind direction. Every dot represents an hour. Data from yr.no.

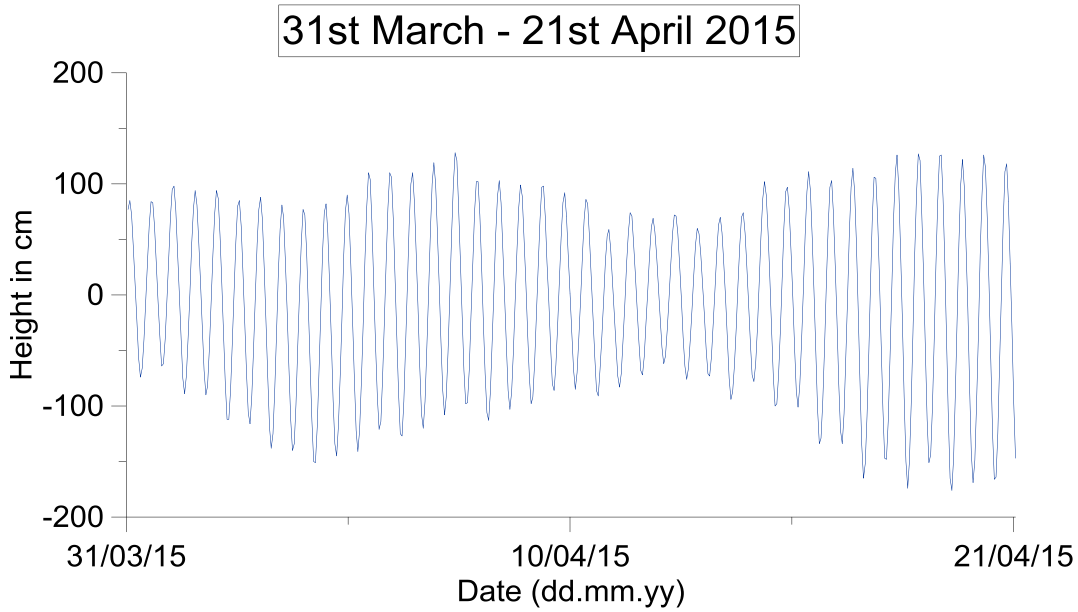

Fig. 3-60. Tidal diagram for the period between the 31st of March and the 21st of April 2015. Data from http://kartverket.no/sehavniva/.

There were two spring tides and one neap tide during the period between the measurements in March and April (fig. 3-60). The mean tide height during the period was -7,6 cm, while the mean high tide height was 97 cm and the mean low tide height was -114 cm. The highest tide was 128 cm and the lowest tide was -176 cm. The tidal cycles were more regular than in the months prior, but a slight decrease in the high tide occurred during the spring tide, most likely caused by the small storm.

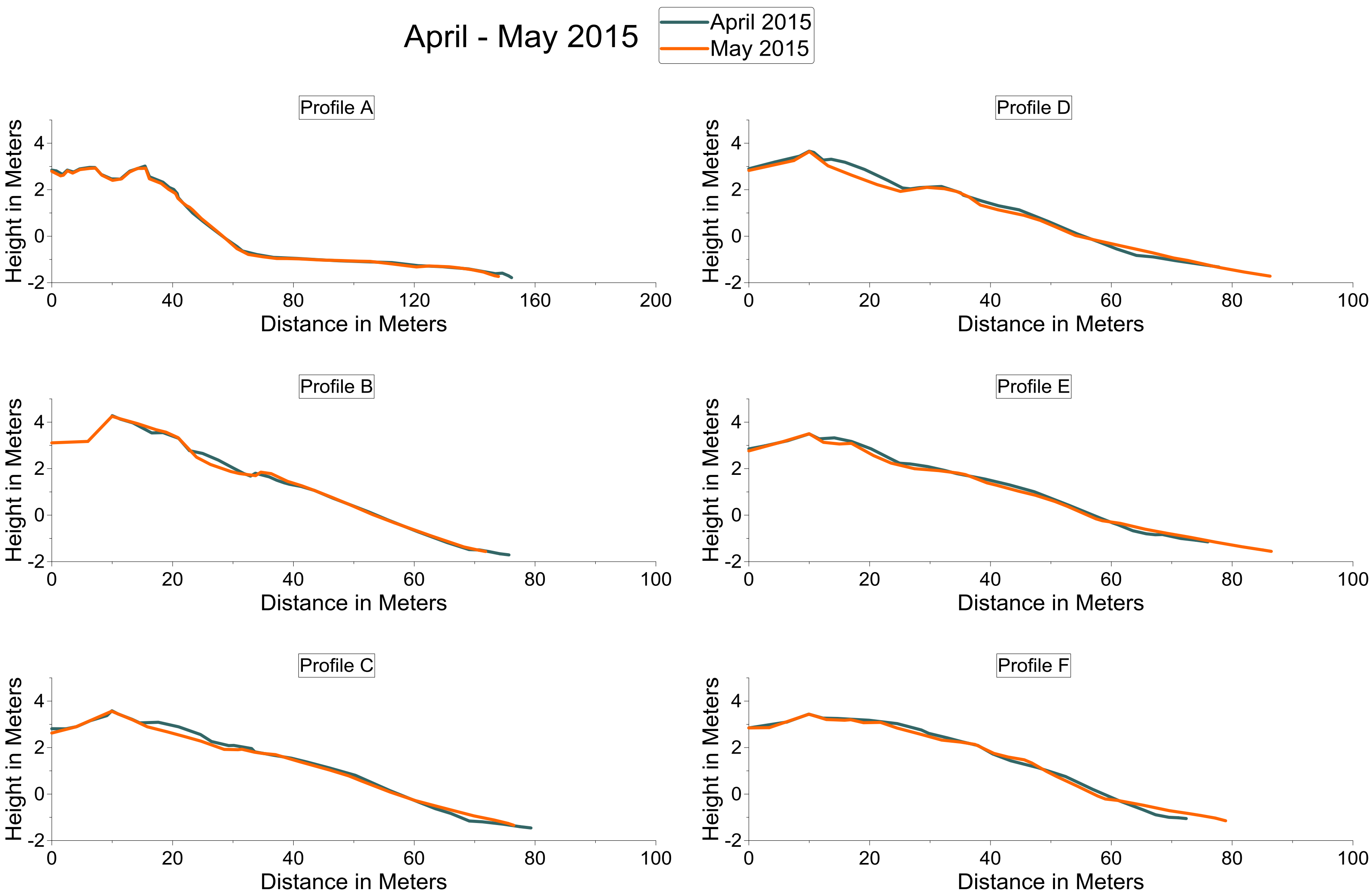

Fig. 3-61. Profile changes between 21st of April and 18th of May 2015. The profile lines measured in April are dark green, while the lines from December are light orange.

Between April 21st and May 18th, the lasts snow and ice disappeared from the berm at Sandbukt Beach. The profiles remained fairly stable with some accretion on the low tide terrace at most of the profiles (fig. 3-61).
At Profile A there was small erosion on the berm, where the berm height decreased from the ridge toe to the berm crest. This erosion is most likely to have been caused either by aeolian erosion or that ice melted underneath the surface, collapsing the sand above it. The profile had also some accretion on the upper beach face but the rest of the profile remained almost identical in between the periods. The beach width increased by 0,76 m, from 38,14 m to 38,9 m, and the beach gradient decreased by 0,06°, from 3,3° to 3,24°. The erosional scarp that had been on the berm crest had been smoothed and was no longer visible and there were no lines of coarse sand on the beach face, only multiple swash marks marked by lines made out of seaweed. The low tide terrace had no ripples on it and was cut by drainage channels. The sandbar was also cut by a large drainage channel and had wave ripples covering most of its surface.
At Profile B small accretion occurred on the beach ridge, filling in a small depression that had been there since at least October 2014. The last snow and ice cover was also removed from the berm and the berm crest increased in height, producing a landward slope from the berm crest down onto the berm. The beach face and the low tide terrace remained stable. The beach width increased by 0,13 m, from 35,54 m to 35,67 m, and the beach gradient decreased by 0,02°, from 4,82° to 4,8°. The collapsed part of the berm from the previous month had mostly been smoothed out, but a number of small mounds had formed around Profile B. These small mounds, about 2 m thick, 4 m wide and 30 cm in height, were spaced rather evenly along the berm, about 8-10 meters apart. These mounds were only formed around Profile B and did not extend to profiles A or C. Neither the beach face nor the low tide terrace had line of coarse sand on it, and there was no runnel or bar present on either of them.
At profile C the rest of the snow and ice cover was removed from the berm and a small berm emerged from underneath the snow. There was small erosion on the upper beach face, but a large accretion on where the boundary of the beach face and the low tide terrace had been in April, that caused the beach face to extend further out in March than it did in April. Other parts of the profile remained stable. The beach width decreased by 1,38 m, from 46,22 m to 44,84 m, and the beach gradient increased by 0,1°, from 3,42° to 3,52°.
At Profile D the rest of the snow and ice cover was removed. There was a small erosion and accretion on the berm crest, resulting in smoother edges of the crest. There was extensive erosion on the upper beach face that caused accretion on where the boundary of the beach

face and the low tide terrace had been in April. The accretion caused the beach face to extend further out in March than it did in April. The beach width decreased by 1,31 m, from 37,61 m to 36,3 m, and the beach gradient increased by 0,16°, from 4,32° to 4,48°.

At Profile E the remaining snow and ice cover was removed, uncovering a small berm there. There was extensive erosion on the upper part of the beach face, making it steeper and shorter than it was in April. The erosion caused accretion on the low tide terrace and it was moved closer landward as a result and had higher elevation at its most upper part. The beach width decreased by 1,26 m, from 38,91 m to 37,65 m, and the beach gradient increased by 0,13°, from 3,89° to 4,02°.

At Profile F the remaining snow and ice cover was removed which revealed a small berm. Accretion occurred on the upper beach face which formed another small berm below the existing one. Erosion took place on the middle- and lower beach face, steepening and shortening the beach face. Accretion occurred on the low tide terrace and like at Profile E that caused the low tide terrace to move further inland and having higher elevation at its upper part, moving it to similar position as it had been in March and countering the erosion that had occurred prior to the measurement in April. The beach width decreased by 1,1 m, from 41,47 m to 40,37 m, and the beach gradient increased by 0,09°, from 3,54° to 3,63°.

Profiles C, D, E, and F all had similar morphology. There was a row of beach cusps on the berm crest and no lines of coarse sand on either the beach face or the low tide terrace. There was a small runnel on the boundary of the beach face and the low tide terrace, with small longshore bar in front of it. The runnel and the bar extended from just north of Profile F to just south of Profile D.

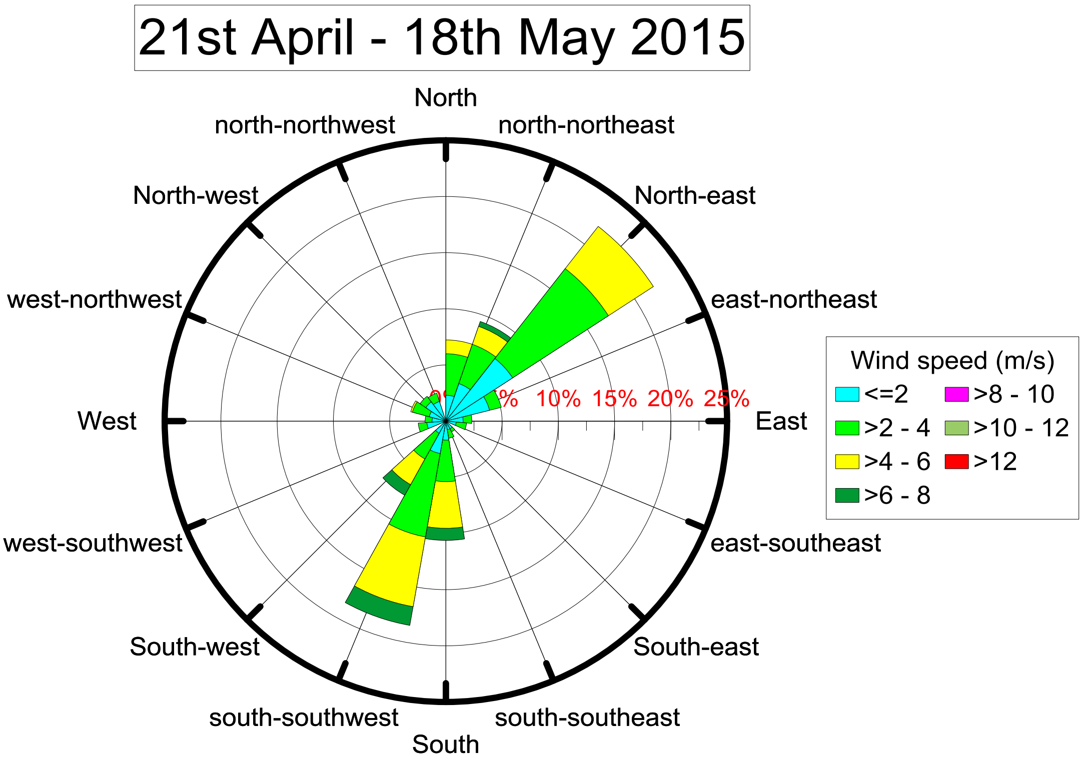

Fig. 3-62. Wind rose diagram for the period between the 21st of April and the 18th of May 2015. The prevailing wind direction was north-east. Data from yr.no.

The dominating wind direction from 21st of April to 18th of May was north-east, with wind coming from that direction during 22% of the time (fig. 3-62). South-southwest followed closely with winds coming in for 18% of the time. Winds from the south and the north-northeast were frequent as well, with 11% and 9% of the time respectively. Winds from other directions were less frequent during the period. Wind was calm during this period with the highest hourly average wind speed of 8 m/s, from the south-west, and a mean wind speed of 3 m/s. There were no storms during the period and wind speed only reached 8 m/s once during the period (fig. 3-63).

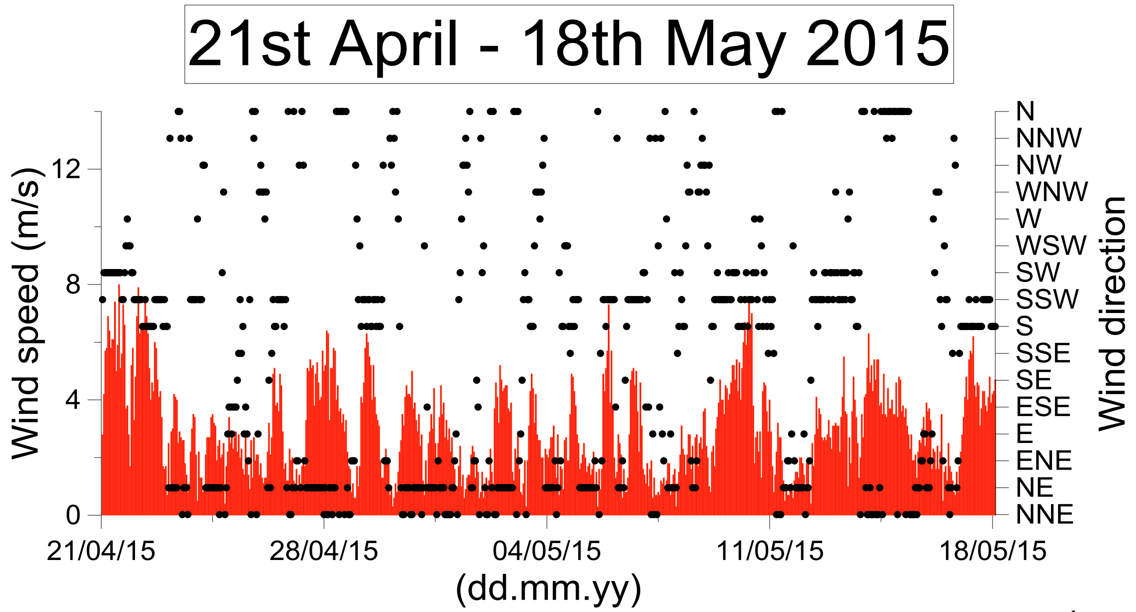

Fig. 3-63. A wind speed and direction diagram for the period between the 21st of April and the 18th of May 2015. The red columns represent the wind speed during the period, while the black dots show the wind direction. Every dot represents an hour. Data from yr.no.

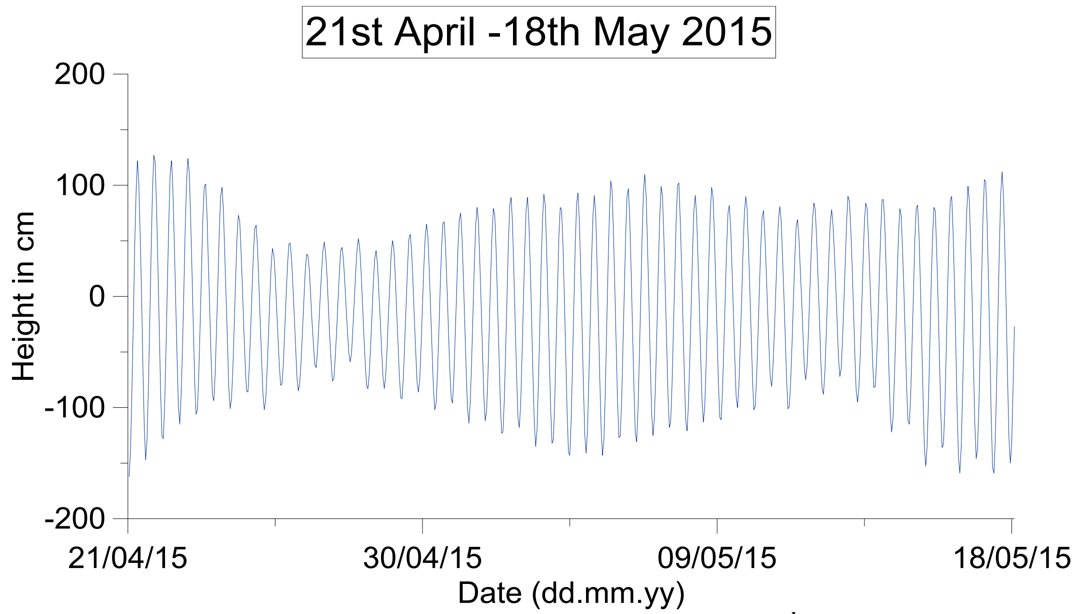

Fig. 3-64. Tidal diagram for the period between the 21st of April and the 18th of May 2015. Data from http://kartverket.no/sehavniva/.

There were two spring tides and two neap tides during the period between the measurements in April and May (fig. 3-64). The mean tide height during the period was -13,4 cm, while the mean high tide height was 82 cm and the mean low tide height was -110 cm. The highest tide was 127 cm and the lowest tide was -162 cm. The tidal cycles were regular during the period, with only a small increase in the tidal height during the latter neap tide. This irregularity coincides with a short period of time where there were northerly winds.

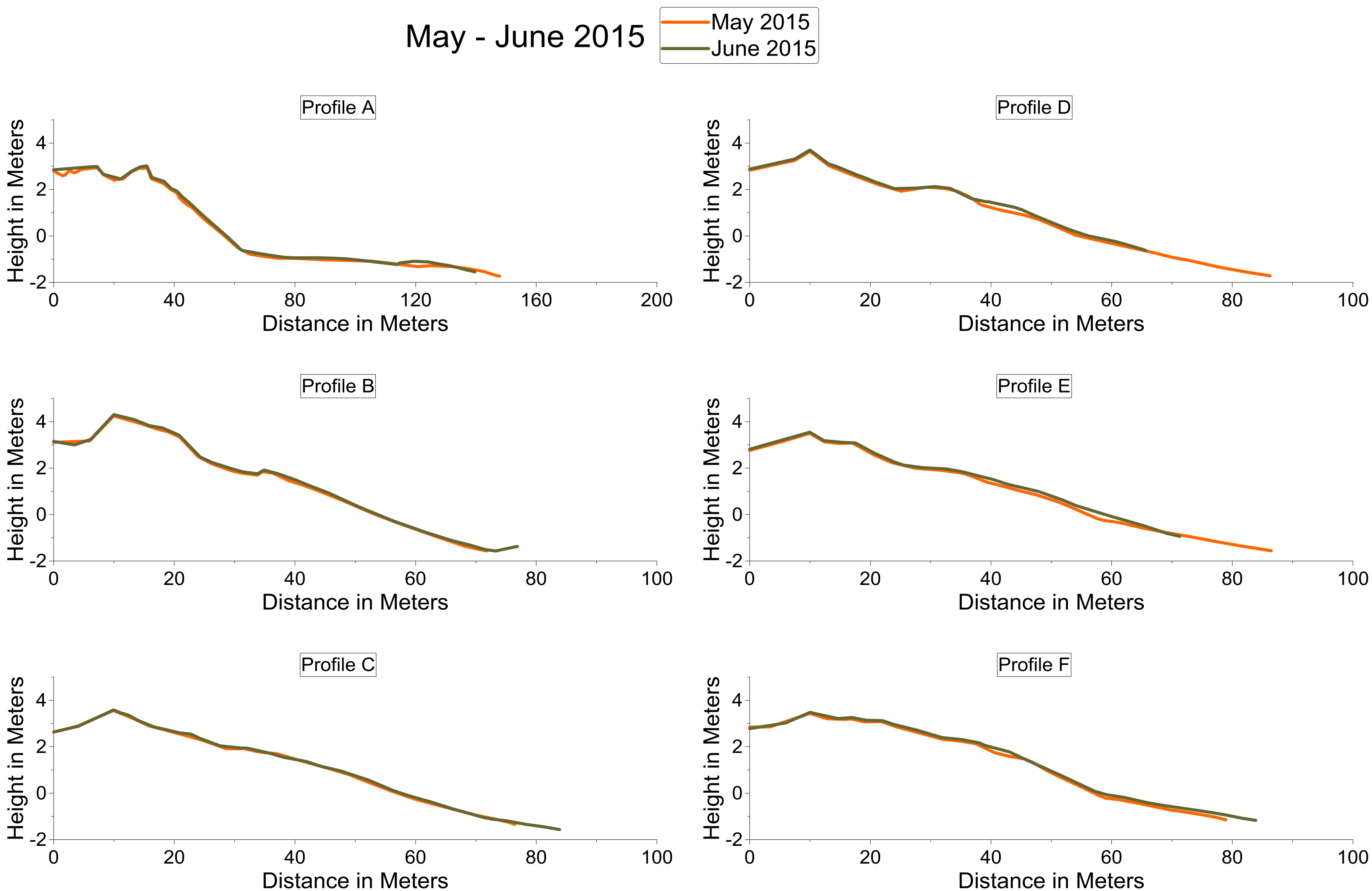

Fig. 3-65. Profile changes between 18th of May and 6th of June 2015. The profile lines measured in May are light orange, while the lines from June are gray.

Between 18th of May and June 6th there were no major changes between the profiles, and mostly accretion occurred on the beach face and the low tide terrace (fig. 3-65).

At profile A there was a small accretion on the upper beach face, and the sandbar moved closer to the beach face, resulting in accretion and erosion as the top of the bar moved. The beach width increased by 0,99 m, from 38,9 m to 39,89 m, and the beach gradient decreased by 0,08°, from 3,24° to 3,16°. There were wind ripples on the base of the beach ridge and the berm, with the direction north to south. There were no lines of coarse sand on the beach face, but there was a thin layer of coarse sand on the boundary of the beach face and the low tide terrace. The terrace was covered in seaweed that was split periodically by drainage channels. The sandbar was covered with wave ripples over most of its surface and cut in half by a large drainage channel.

At Profile B there were no changes, apart from very small accretion on the upper beach face and just above the step. The beach width increased by 0,7 m, from 35,67 m to 36,37 m, and the beach gradient decreased by 0,09°, from 4,8° to 4,71°. There were wind ripples on the beach ridge base and the berm, with north to south direction, and a row of beach cusps on the berm crest. There were no lines of coarse sand on the beach face or the low tide terrace, but a number of small pebbles were scattered across the terrace.

At Profile C there were very small accretions on the berm, most likely caused by increased vegetation there during the spring that trapped aeolian born sand. There was small erosion as well on the berm crest, likely caused by movement of beach cusps. There seems to have been some accretion on the low tide terrace, but the profile from May does not extend far enough to compare it with the one from June at that part. The beach width increased by 0,53 m, from 44,84 m to 45,37 m, and the beach gradient decreased by 0,04°, from 3,52° to 3,48°. There was a row of beach cusps on the berm crest and no lines of coarse sand were present on the beach face or the low tide terrace. There was a small runnel and a swash bar on the middle of the low tide terrace (fig. 3-66). There were no ripples in the runnel and the bar was cut periodically by drainage channels.

Fig. 3-66. Pictures from profiles C and F. (on the left) A runnel fronted by a large swash bar that was cut periodically by drainage channels. (on the right) The beach face at Profile F and the end of the runnel can be seen in the distance.

At profile D there was accretion both on the berm and the beach face. A small area was filled in at the berm, causing the landward dip from the beach crest to decrease. Almost the whole beach face experienced accretion during the period, but the profile from June does not extend to the low tide terrace, and therefore it cannot be said whether accretion occurred there. The beach width increased by 1,36 m, from 36,3 m to 37,66 m, and the beach gradient decreased by 0,16°, from 4,48° to 4,32°.

At Profile E there was accretion on the beach face, extending it seaward, and what seems to be erosion on the low tide terrace but the profile line for June does not extend far enough to see how extensive the erosion was. The accretion on the lower beach face fills up the erosion that occurred there from April to May. The beach width increased by 1,92 m, from 37,65 m to 39,57 m, and the beach gradient decreased by 0,19°, from 4,02° to 3,83°.

At Profile F there was accretion on the upper beach face and the low tide terrace. The beach width increased by 0,65 m, from 40,37 m to 41,02 m, and the beach gradient decreased by 0,06°, from 3,63° to 3,57°.

The morphology at profiles D, E, and F was similar to that of Profile C, but at profiles D and E the rising tide had obscured the runnel and the runnel ended just north of Profile F (fig. 3-66). There were some minor wind ripples on the base of the beach ridge and the berm at the three profiles, with direction from north-west to south-west. There was a row of beach cusps on the berm crest and there were no lines of coarse material on the beach face or the low tide terrace.

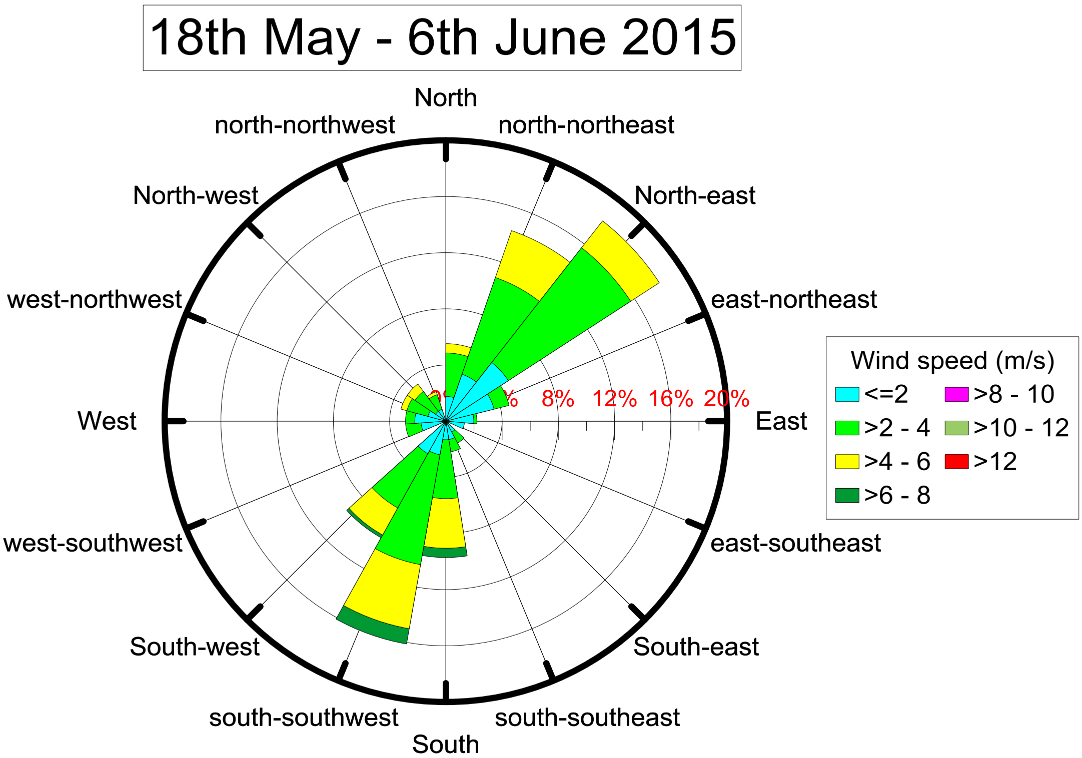

Fig. 3-67. Wind rose diagram for the period between the 18th of May and the 6th of June 2015. The prevailing wind direction was north-east. Data from yr.no.

The dominating wind direction from 18th of May to 6th of June was north-east, with wind coming from that direction during 18% of the time (fig. 3-67). South-southwest followed closely with winds coming in for 16% of the time. Winds from the south, south-west and the north-northeast were frequent as well, with 10%, 9 and 14% of the time respectively. Winds from other directions were less frequent during the period. Wind was calm during this period with the highest hourly average wind speed of 8 m/s, from the south, and a mean wind speed of 2,8 m/s. There were no storms during the period and wind speed only reached 8 m/s once during the period (fig. 3-68).

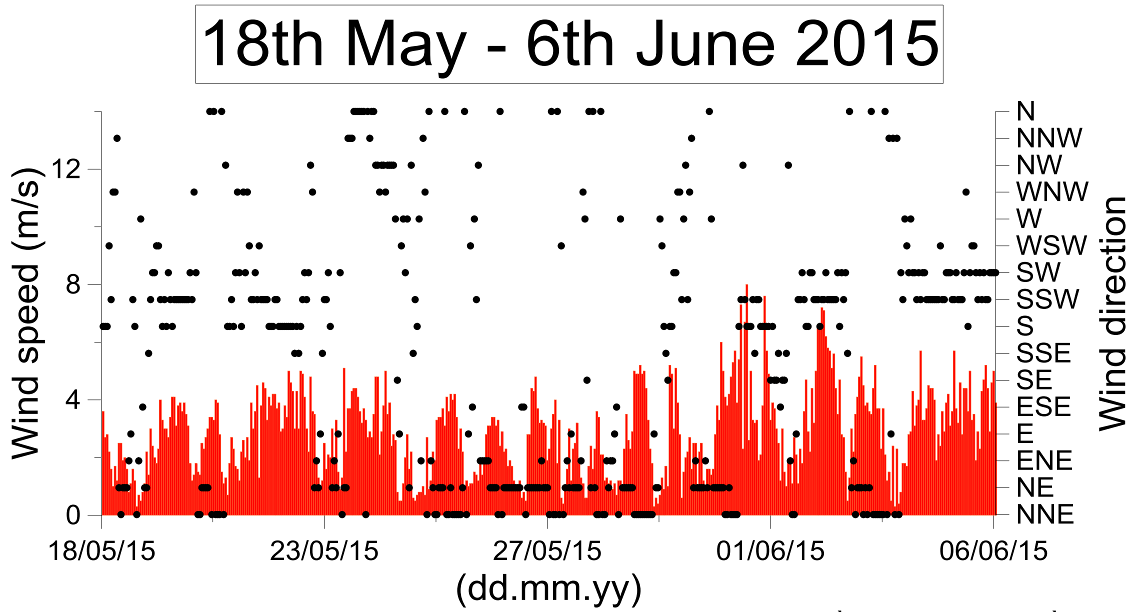

Fig. 3-68. A wind speed and direction diagram for the period between the 18th of May and the 6th of June 2015. The red columns represent the wind speed during the period, while the black dots show the wind direction. Every dot represents an hour. Data from yr.no.

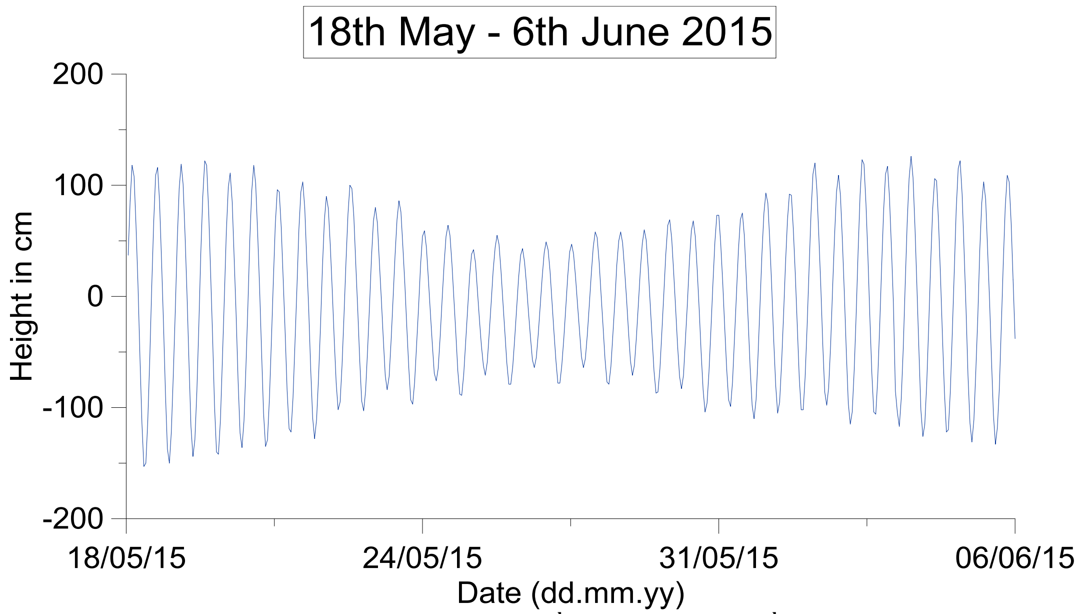

Fig. 3-69. Tidal diagram for the period between the 18th of May and the 6th of June 2015. Data from http://kartverket.no/sehavniva/.

There were two spring tides and one neap tide during the period between the measurements in May and June (fig. 3-69). The mean tide height during the period was -7,4 cm, while the mean high tide height was 88 cm and the mean low tide height was -104 cm. The highest tide was 126 cm and the lowest tide was -153 cm. The tidal cycle was regular during the period, with no visible changes to the tides.

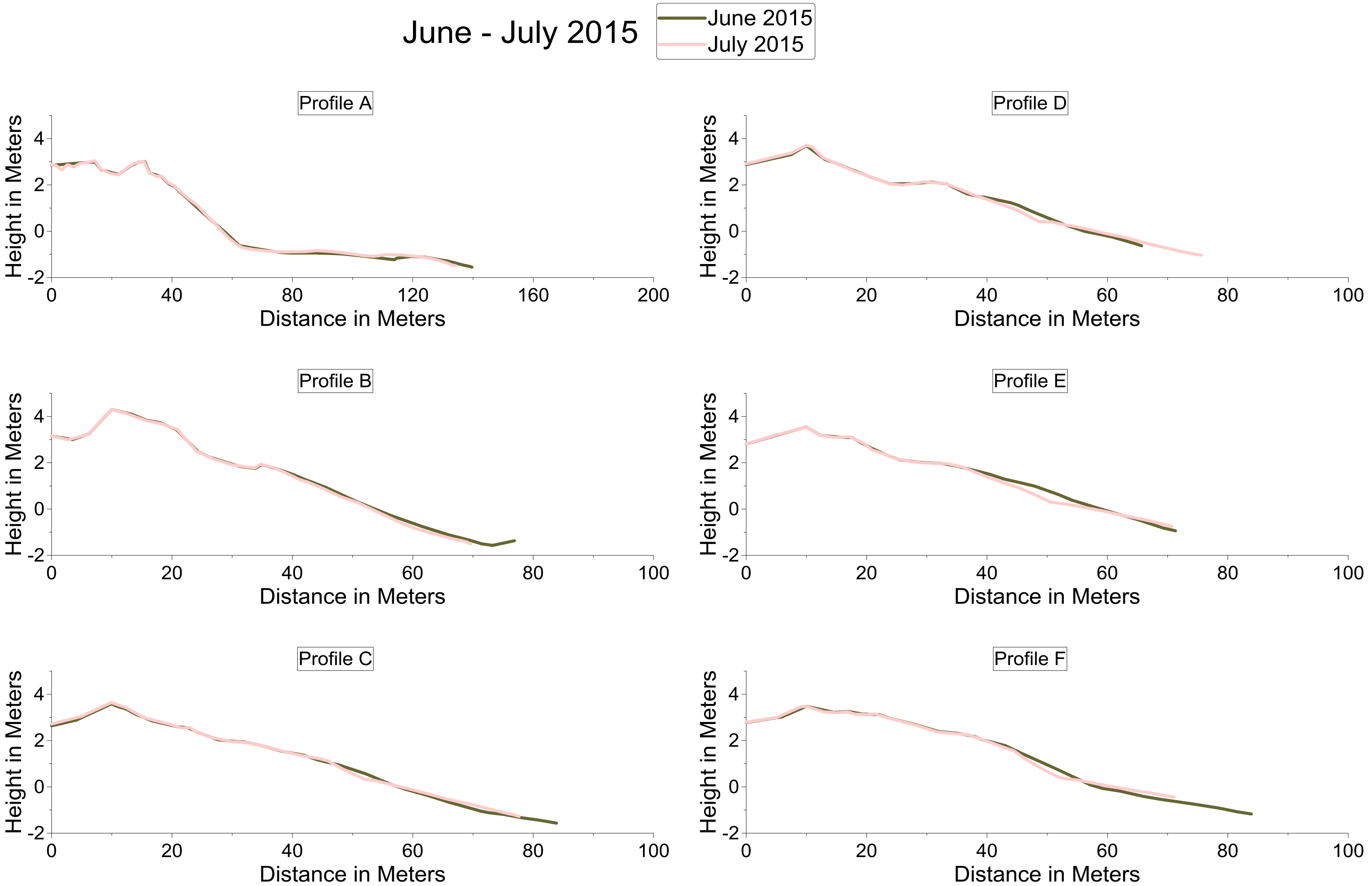

Fig. 3-70. Profile changes between 6th of June and 17th of July 2015. The profile lines measured in June are grey, while the lines from July are light pink.

Between 6th of June and 17th of July there were no changes on the upper part of the profiles, but there was some erosion on the beach face of all of the profiles and accretion on the lower part of the beach face and/or the low tide terrace (fig. 3-70)

At Profile A there was a small accretion at the middle of the beach face and erosion on the lower beach face and the low tide terrace. There was considerable accretion on the sandbar and it continued to migrate closer to the beach face, causing erosion on the outer part of the sand bar. The cut by the drainage channel in between the inner and outer part of the sand bar was not as deep, and that counts for some of the accretion. The beach width increased by 0,48 m, from 39,89 m to 40,37 m and the angle decreased by 0,04°, from 3,16° to 3,12°. At the base of the beach ridge and the upper part of the berm there were wind ripples, with the direction north-northeast to south-southwest. The wind ripples were formed by fine, gray sand that was on top of red garnet sand. The upper part of the beach face had fine sand on its surface, but lower on the beach face it was covered in lines of coarser sand (fig. 3-71). The lines were a few cm wide and made up by coarse sand and small gravel, which laid on top of finer sand that was underneath and in between those lines. These lines extended down to the boundary of the beach face and the low tide terrace. The low tide terrace had some small drainage channels and wave ripples near the sand bar. The sandbar was covered by wave ripples, with east to west direction, and was cut by a large drainage channel, splitting the bar almost in two (fig. 3-71). The outer part of the sand bar, and the lowermost part of the drainage channel, had two lines of coarser sand like the ones on the beach face, but were thinner and more confined.


Fig. 3-71. Pictures from Profile A. On the right the beach face can be seen with multiple lines of coarse sand on top of it. On the left the shoreward facing side of the sand bar, with wave ripples on it, and the low tide terrace can be seen.

At Profile B there was erosion of the whole of the beach face and the low tide terrace, but no changes to the upper beach. The beach width decreased by 0,86 m, from 36,37 m to 35,51 m, and the beach gradient increased by 0,11°, from 4,71° to 4,82°. On the berm there were wind ripples, with the direction north-northeast to south-southwest, and were formed from fine gray sand, with red garnet sand in between each ripple (fig. 3-72). The red garnet sand was visible on the surface on the middle of the berm, extending close to the base of the beach ridge. There were two tide markers on the berm crest, the upper reaching up onto the berm between beach cusps and leaving a line of sea-weed and coarse sand there. The lower tide marker was on the berm crest, where well-formed beach cusps were present, and was made up of small pieces of sea-weed and fine sand. The beach face had fine sand on the most upper part, near the berm crest, but the rest of the beach face had multiple thin lines of coarser sand on it (fig. 3-72). The lines were not as thick as at Profile A, but covered similar area of the beach face and extended down onto the low tide terrace. The low tide terrace was cut by multiple small drainage channels, with most of the finer material having been removed and the surface was covered with coarser sand, similar in grain size as that of the lines.

Fig. 3-72. Pictures from Profile B. On the left, the lines of coarse sand can be seen on the beach face, with finer sand on the upper part of the beach face. On the right, the berm with wind ripples, red garnet sand, two tide markers and a row of beach cusps can be seen.

At Profile C erosion occurred on the upper beach face, while accretion occurred on the lower part of the beach face and the low tide terrace. The beach width decreased by 1,1 m, from 45,37 m to 44,27 m, and the angle 0,09°, from 3,48° to 3,57°. There were wind ripples at the base of the beach ridge and the upper part of the berm, with same direction as on profiles A and B. The ripples were made up of fine, gray sand, but unlike at profiles A and B, the ripples were on top of gray sand. There was a tide marker on the berm crest, made up of small pieces of sea-weed and a row of beach cusps. The beach face was split into two by a large runnel, almost in the center of the beach face where the erosion had occurred. On the beach face above the runnel, there were two lines of coarse sand like at profiles A and B, but none below the runnel (fig. 3-73). In the runnel there was a mixture of wave and current ripples that had been partially infilled. A small longshore bar was at the base of the runnel, and the bar had been periodically cut. The low tide terrace had multiple small drainage channels, but featureless.

Fig. 3-73. Pictures from Profile C (left) and D (right), showing the runnel on the beach face and the lines of coarse sand above it. A small longshore bar can be seen below the runnel and a mixture of wave and current ripples in the runnel itself.

At Profile D there was no change on the upper part of the profile. The upper beach face experienced some erosion, while the lower beach face and the low tide terrace had accretion. The beach width decreased by 2,06 m, from 37,66 m to 35,6 m, and the angle of the beach increased by 0,24°, from 4,32° to 4,56°. Profile D had the same features as found at Profile C, but there was only one line of coarse sand on the beach face there. Like before, the line was above the runnel on the beach face, just above the runnel. The ripples in the runnel at Profile D where larger than the ripples found at Profile C, and covered larger area within the runnel (fig. 3-73).

At Profile E there was no change on the upper part of the profile, but large area of the beach face had been eroded and accretion occurred on the low tide terrace. The beach width decreased by 3,54 m, from 39,57 m to 36,03 m, and the beach gradient had increased by 0,37°, from 3,83° to 4,2°. Unlike the previous four profiles, there were almost no wind ripples on the berm and they were not as well developed as on the other profiles. There were large and well developed beach cusps and multiple swash marks on the upper part of the beach face (fig. 3-74). A runnel was present there as well, at the middle of the beach face, and a line of coarse sand just above it. The runnel had mostly been filled in with sand, and only occasional ripples were on the surface. The beach face below the runnel and the low tide terrace were featureless.

Fig. 3-74. Pictures from profiles E (left) and F (right). The berm crest on profile E can be seen with a row of beach cusp, multiple swash lines, and the runnel can be seen just below the berm crest. The line of coarser sand at Profile F, the grain size scale on the image is about 15 cm long.

Profile F was similar to that of Profile E, with erosion on its beach face and accretion on the low tide terrace. The beach width decreased by 2,19 m, from 41,02 m to 38,83 m, and the beach gradient increased by 0,2°, from 3,57° to 3,77°. The profile had identical features as Profile E, with few patches of wind ripples on the berm and a filled in runnel on the beach face. The line of coarse sand was still present, but had become thinner at this point (fig. 3-74).

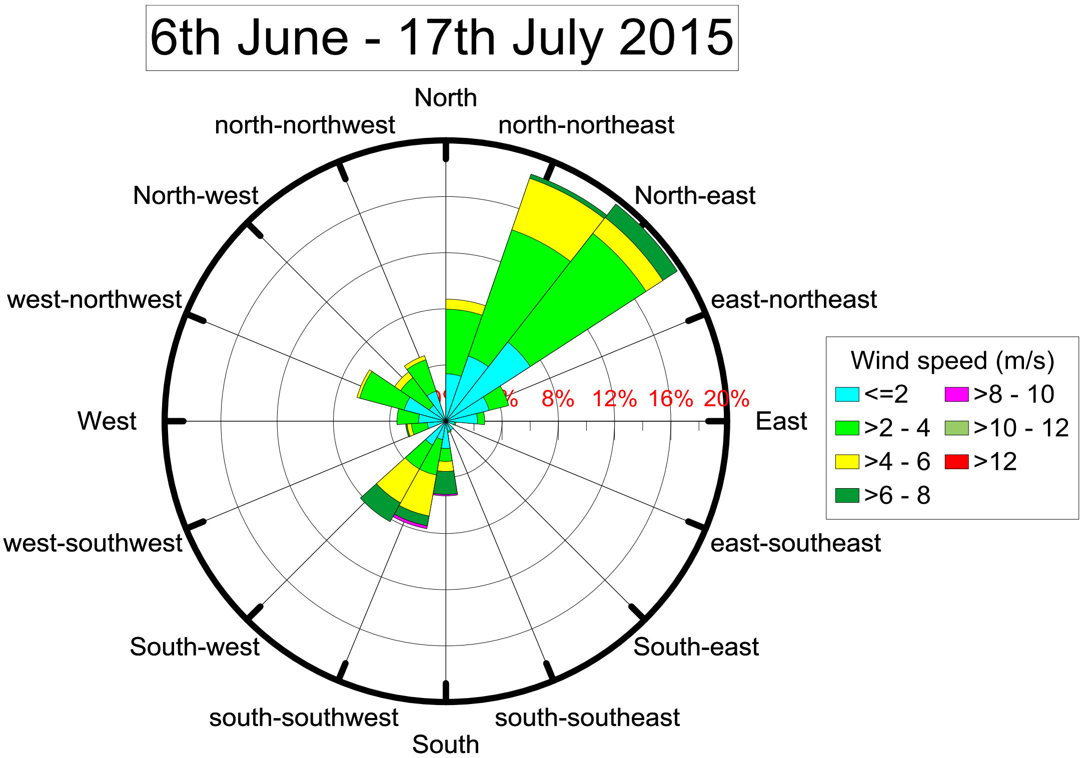

Fig. 3-75. Wind rose diagram for the period between 6th of June and 17th of July. The most common wind direction was from the north-east, followed closely by north-northeast, and the highest wind speed from south-southwest. Data from yr.no.

During the period between 6th of June and 17th of July, the most common wind direction was from the north-east, followed closely by north-northeast (fig. 3-75). The wind came in from these two directions about 20% and 18% of the time during the period. North, south-west and south-southwest directions were common as well, all at around 8% of the time. Other wind directions were less frequent. Wind speed during the period was mild, with mean wind strength of 2,8 $^{m/s}$ and strongest winds at 8,3 $^{m/s}$ from the south-southwest. There were two periods with high winds coming in from the south to south-west during the period (fig. 3-76.) These two small storms occurred in early June, with more northerly winds dominating the latter half of the period. Apart from a small storm in early July, the northerly winds were not strong, usually less than 6 $^{m/s}$, but had a long duration from some directions, allowing wave energy to build up.

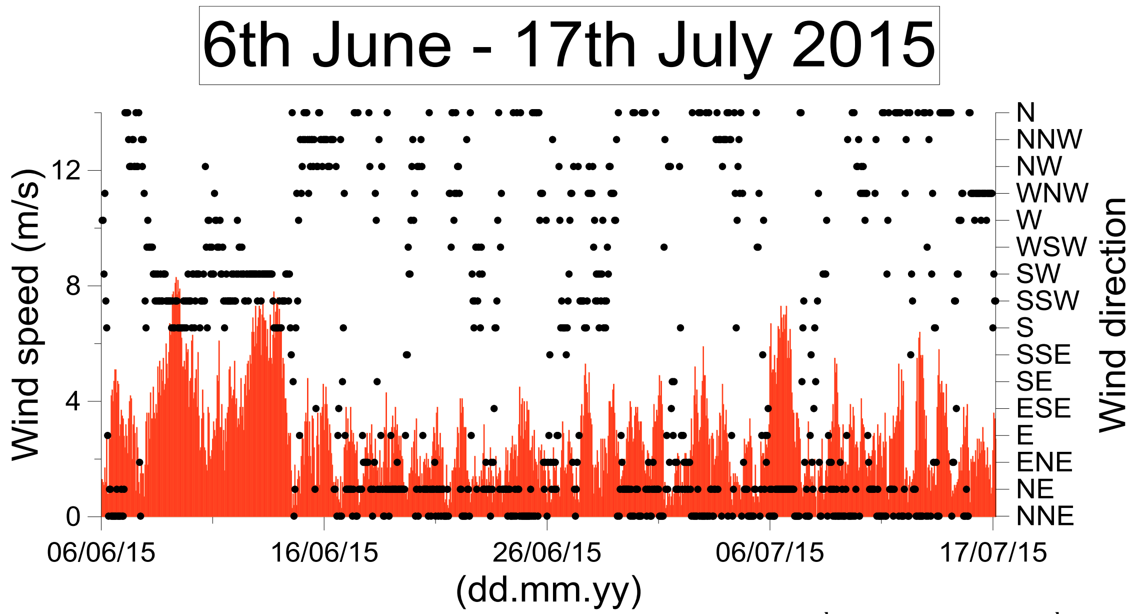

Fig. 3-76. A wind speed and direction diagram for the period between the 6th of June and the 17th of July 2015. The red columns represent the wind speed during the period, while the black dots show the wind direction. Every dot represents an hour. Data from yr.no.

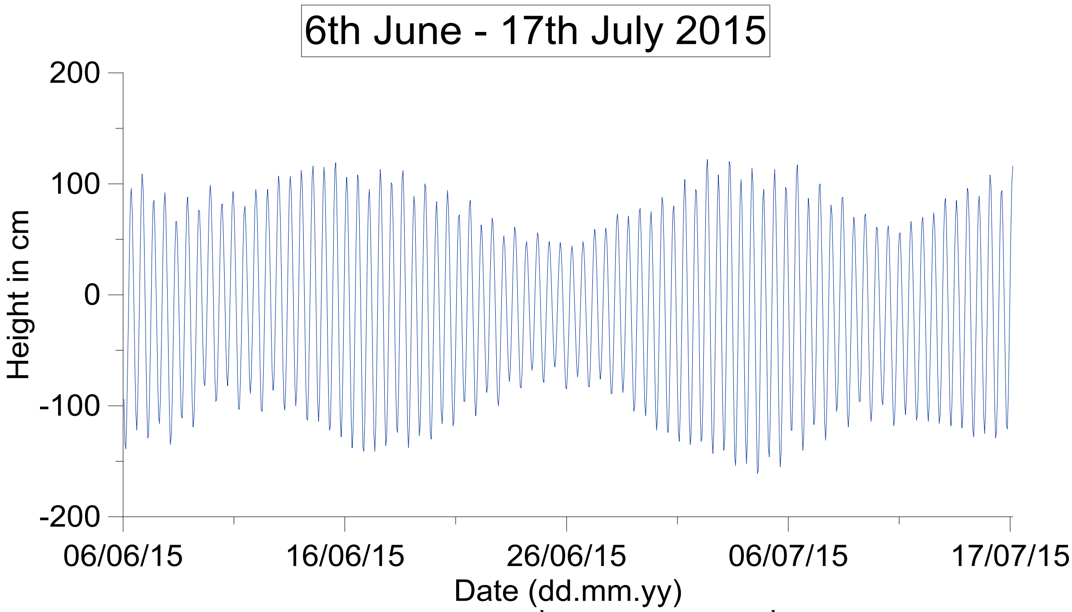

Fig. 3-77. Tidal diagram for the period between the 6th of June and the 17th of July 2015. Data from http://kartverket.no/sehavniva/.

There were two spring tides and three neap tides during the period between the measurements in June and July (fig. 3-77). The mean tide height during the period was -13,1 cm, while the mean high tide height was 87 cm and the mean low tide height was -114 cm. The highest tide was 122 cm and the lowest tide was -161 cm. The tidal cycles were mostly regular, apart from the neap tide in the beginning of the month, which was likely influenced by the two small storms in early June. The small storm from the north had also small effects on the tide during the storm, with slightly higher high tides and low tides occurring.

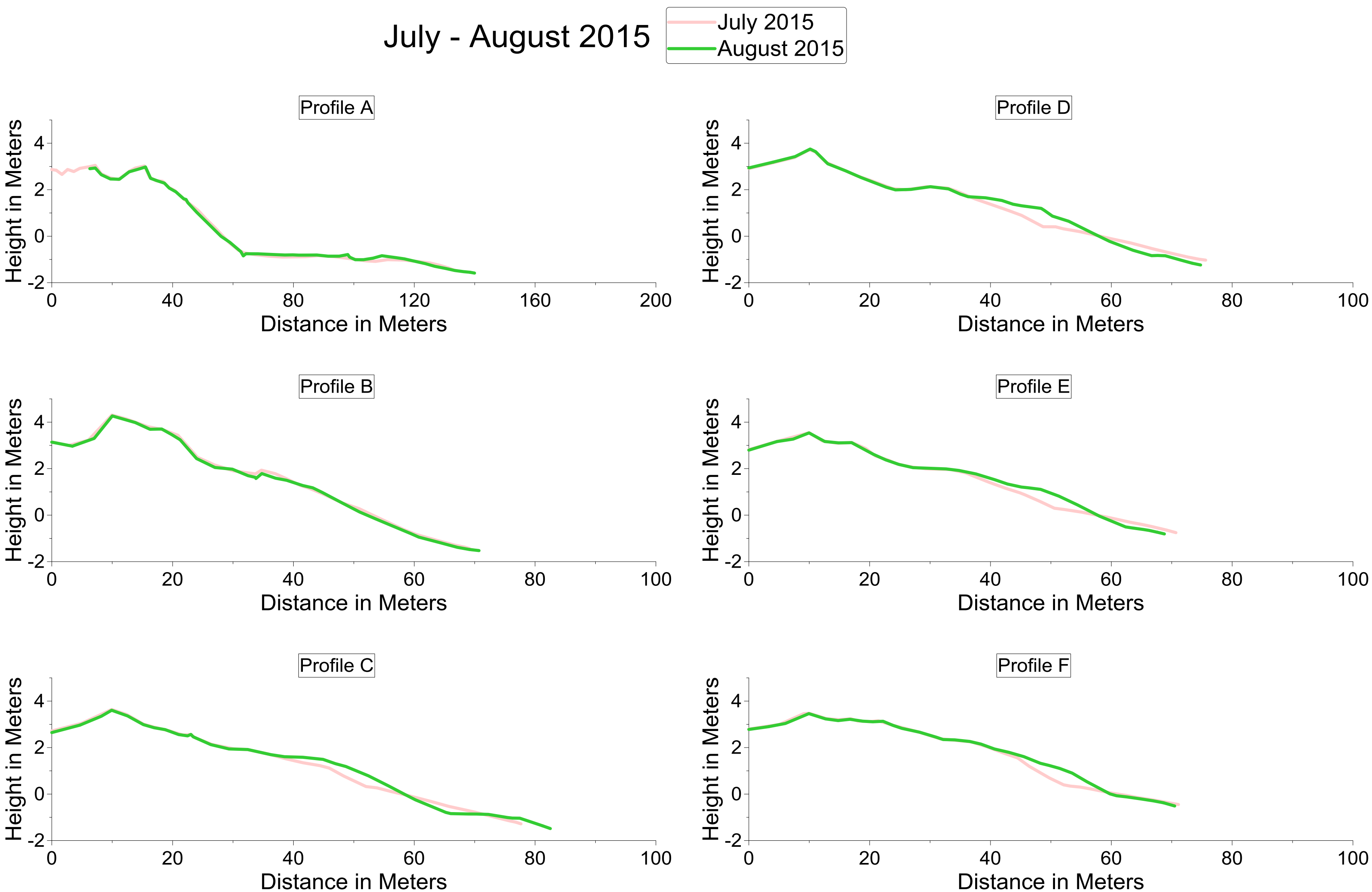

Fig. 3-78. Profile changes between 17th of July and 16th of August 2015. The profile lines measured in July are light pink, while the lines from August are green.

In the period between 17th of July and 16th of August the areas that had been eroded between June and July were filled back in, and the areas on the lower part of the beach face and the low tide terrace were eroded where accretion had occurred the month before. There continued to be no change on the profiles on the backshore but the berm at most profiles was extended (fig. 3-78)

At Profile A there was small erosion on the middle of the beach face and at the boundary of the beach face and the low tide terrace, where a small step had been formed. There was accretion on the rest of the low tide terrace and on most of the sandbar, there was however a slight erosion on the seaward facing slope of the bar as the bar continued to migrate closer to the beach face. The beach width decreased by 0,92 m, from 40,37 m to 39,45 m, and the beach gradient increased by 0,07°, from 3,12° to 3,19°. At Profile A there were some wind ripples on the berm, but not as well developed as in July, and formed by both red garnet sand and fine, gray sand. The directions of the ripples were formed by wind from a north to north-northeast direction. There were no beach cusps present as before and the beach face had no lines of coarse material, apart from one present on the beach step. The landward facing side and the seaward facing side of the sand bar had wave ripples on it, with wave direction from north-east, but the middle part of the bar had none. The sand bar was cut by a large drainage channel as before and there were no lines of coarse sand on it.

At Profile B the profile line measured for August shows erosion on the berm. This was caused by to much deviation to the south of the profile line during measurements of the berm. This becomes clear when the profile lines for Profile B from June, July and September are compared to each other and show that the berm did not go under any change during the period between July and August. The area in question is a small mound that was created from April to May, and did not change between May and September. There was however small accretions on the berm crest and erosion on the beach face and the low tide terrace. The beach width increased by 0,28 m, from 35,51 m to 35,79 m, and the beach slope decreased by 0,03°, from 4,82° to 4,79°. There were wind ripples on the berm, with the direction from south-east to north-west and a row of beach cusps on the berm crest. The beach face did not have any lines of coarse sand, but there was a line on the boundary of the beach face and the low tide terrace and scattered gravel on the terrace itself. There was also a large field on the beach face, between profiles A and B, that had coarse sand and gravel on the surface, but this patch did not reach either profile A or B (fig. 3-79).

Fig. 3-79. A field of yellow, coarse sand and gravel on the beach face between profiles A and B. The field did not extend to either profiles, but scattered gravel was present on the low tide terrace at profile B

At Profile C there was extensive accretion on the upper part of the berm, which increased the berm width and raised the berm crest. There was erosion on the lower beach face with accretion on the low tide terrace. The beach width increased by 4,04 m, from 44,27 m to 48,31 m, and the beach gradient decreased by 0,3°, from 3,57° to 3,27°.

At Profile D there was extensive accretion on the upper part of the beach face, similar to that of Profile C, which created a new berm lying below the existing one. There was erosion on the lower beach face and the low tide terrace. The beach width increased by 4,99 m, from 35,6 m to 40,59 m, and the beach gradient decreased by 0,56°, from 4,56° to 4°.

Profile E underwent the same changes as Profile D, which was accretion on the upper beach face, constructing a new, lower lying berm, and erosion on the lower beach face and the low tide terrace. The beach width increased by 5,09 m, from 36,03 m to 41,12 m, and the beach gradient decreased by 0,52°, from 4,2° to 3,68°.

Profile F had similar changes as profiles C, D, and E, but the accretion on the upper part of the beach face did not create a new berm, rather it extended the width of the beach face and decreased its angle. The erosion on the low tide terrace was also considerably less than at the other three. The beach width increased by 5,17 m, from 38,83 m to 44 m, and the beach gradient decreased by 0,45°, from 3,78° to 3,33°. Profiles C, D, E, and F all had the same morphology on the profiles, where there were no wind ripples on the berm, but there was a row of beach cusps on the berm crest. There was a small runnel and a longshore sandbar on the boundary of the beach face and the low tide terrace, and there were drainage channels in the runnel that cut the bar periodically. Just above the runnel there was a line of coarse sand, but the beach face and the rest of the terrace had none.

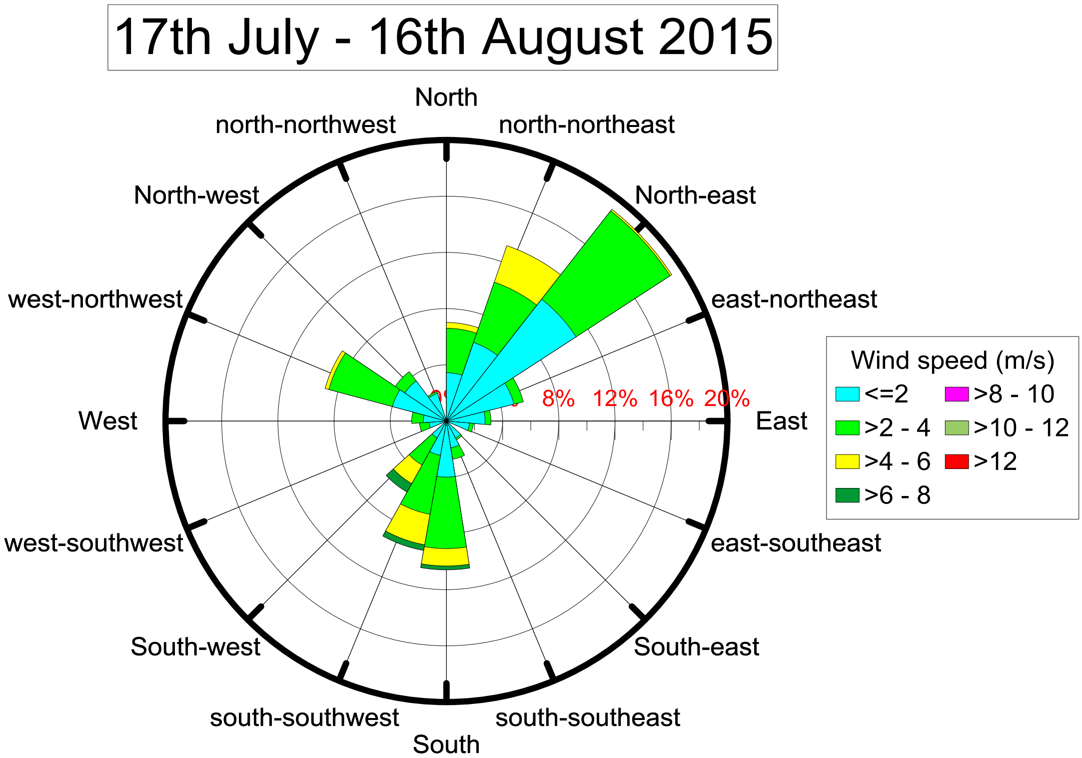

Fig. 3-80. Wind rose diagram for the period between the 17th of July and the 16th of August 2015. The prevailing wind direction was north-east. Data from yr.no.

The period between 17th of July and 16th of August had multiple wind directions for extensive period of time. The wind direction was dominated by north-east wind direction, where wind came from that direction about 19% of the time during the period (fig. 3-80). Other major wind directions were north-northeast, south, and south-southwest, with between 13% and 8% of wind duration, and for the first and only time the west-northwest direction had a large percentage of the overall wind direction. The dominating wind direction of north-east never had wind speed exceeding 4 m/s, and had wind speed below 2 $^{m/s}$ most of the time. This is evident in the mean wind strength, which was only 2,3 $^{m/s}$ during the period, with highest wind speed at 7,7 $^{m/s}$ coming in from the south-west. The wind directions changed considerably during the time between 17th of July and 16th of August (fig. 3-81). There was only one period where wind direction remained fairly stable, with wind coming in from the north-east to north at end of July. Wind speed only exceeded 6 m/s twice between July and August, both times for short intervals and from south and south-southwest direction.

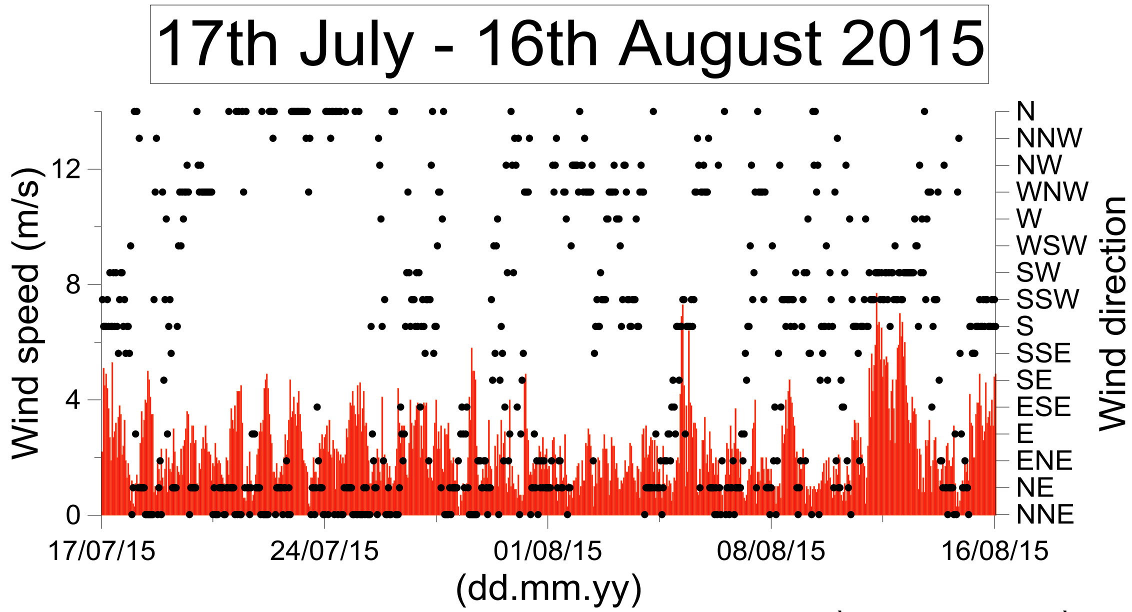

Fig. 3-81. A wind speed and direction diagram for the period between the 17th of July and the 16th of August 2015. The red columns represent the wind speed during the period, while the black dots show the wind direction. Every dot represents an hour. Data from yr.no.

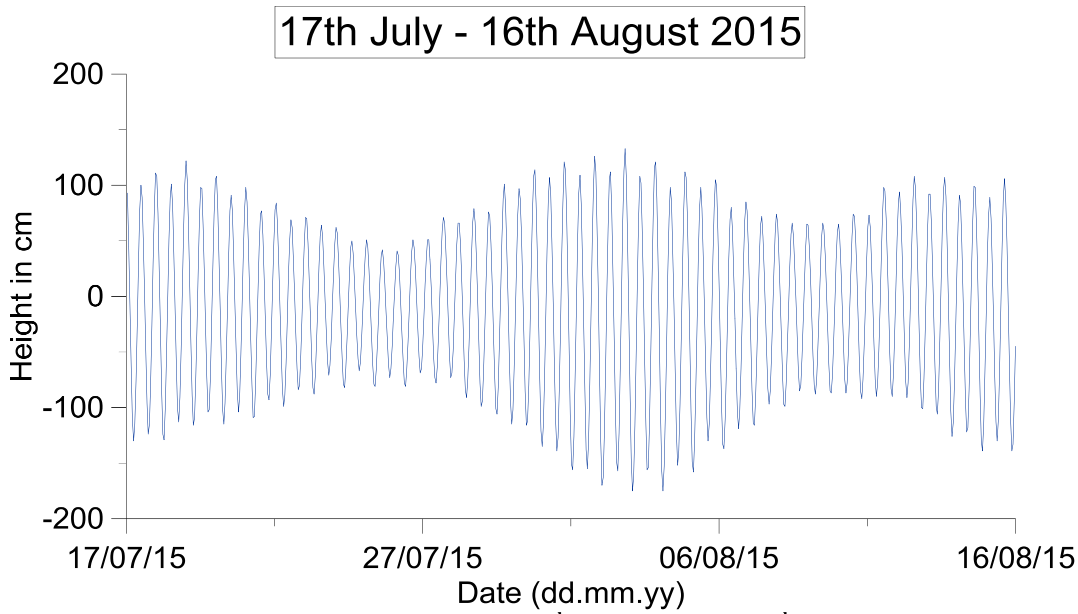

Fig. 3-82. Tidal diagram for the period between the 17th of July and the 16th of August 2015. Data from http://kartverket.no/sehavniva/.

There were two spring tides and two neap tides during the period between the measurements in July and August (fig. 3-82). The mean tide height during the period was -11,6 cm, while the mean high tide height was 88 cm and the mean low tide height was -111 cm. The highest tide was 133 cm and the lowest tide was -175 cm. The tidal cycles were regular in the period, but a slight decrease in the tide height can be seen at the spring tide in middle of August.

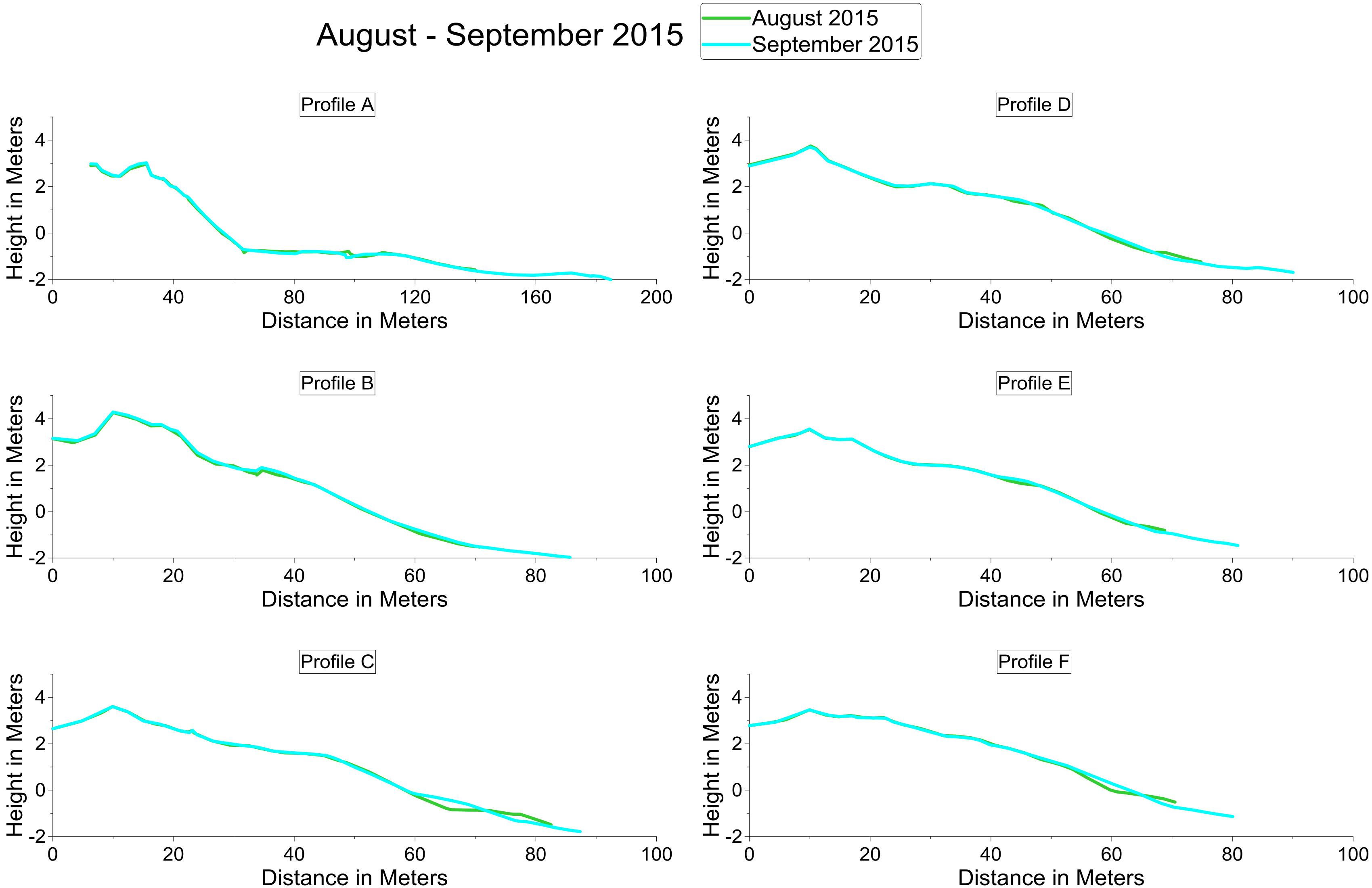

Fig. 3-83. Profile changes between 16th of August and 1st of September 2015. The profile lines measured in August are green, while the lines from September are light blue.

Between the 16th of August and 1st of September were no major changes on the profiles. Some accretion occurred on the low tide terrace and the sandbar continued to be moved closer to the beach face at Profile A (fig. 3-83)

At Profile A there was a minor accretion on the beach face and the step that had formed between the beach face and the low tide terrace the month before was filled in. There was minor erosion on the rest of the low tide terrace, especially adjacent to the sand bar. The sand bar continued to migrate closer to the beach face, but some erosion occurred at two areas on the middle of the bar and the seaward side of the bar erodes slightly as well. There was however a small area where accretion occurred, in between the two eroded areas on the middle of the bar. The beach width increased by 0,25 m, from 39,45 m to 39,7 m, and the beach gradient decreased by 0,02°, from 3,19° to 3,17°. There were small wind ripples on the berm, with the direction south-southeast to west-northwest.

At Profile B, the error measurement, from August, of the mound on the berm was corrected, showing now accretion or erosion between July and September, while there was some accretion on the beach face and the low tide terrace. The beach width decreased by 0,09 m, from 35,79 m to 35,7 m, and the beach gradient 0,01°, from 4,79° to 4,8°.

At Profile C there was a large accretion on the upper part of the low tide terrace, while there was erosion on the lower part of it. The rest of the profile remained the same between the months. The beach width decreased by 0,64 m, from 48,31 m to 47,79 m, and the beach gradient increased by 0,04°, from 3,27° to 3,31°.

At Profile D there areas with accretion and erosion on both the berm crest and the beach face, where in both cases the eroded area was just beneath the accreted area. Erosion occurred on the low tide terrace, but the extent of the erosion cannot be seen as the profile line from August does not cut the profile line from September before it ends. The beach width increased by 0,14 m, from 40,59 m to 40,73 m, and the beach gradient decreased by 0,01°, from 4° to 3,99°.

At Profile E there was accretion on the berm crest, erosion on the beach face and accretion on the bottom of the beach face and the low tide terrace. The beach width decreased by 0,3 m, from 41,12 m to 40,82 m, and the beach gradient increased by 0,03°, from 3,68° to 3,71°.

At Profile F there was extensive accretion on the lower part of the beach face, which extended the beach face and caused erosion on the low tide terrace. The beach width increased by 0,7 m, from 44 m to 44,7 m, and the beach gradient decreased by 0,05°, from 3,33° to 3,28°.

The morphology at profiles C, D, E, and F were the same, were there were wind ripples on the berm, with the direction east to west. A row of beach cusps was at the berm crest and a runnel and longshore bar on the boundary of the beach face and the low tide terrace. At profiles C and D there was another runnel on the middle of the terrace (fig. 3-84), with a large longshore bar on it, but it did not reach profile E (fig. 3-84). The upper runnel did not have any ripples in it as did the lower one apart from a small area at the end of it near profile E, where wave ripples were present from the inner side of the outer bar until the outer side of the upper bar.

Fig.3-84. (on the left) A double row of runnel and longshore bar at Profile C and (on the right) the lower runnel just north of Profile E with wave ripples on the surface between the two bars.

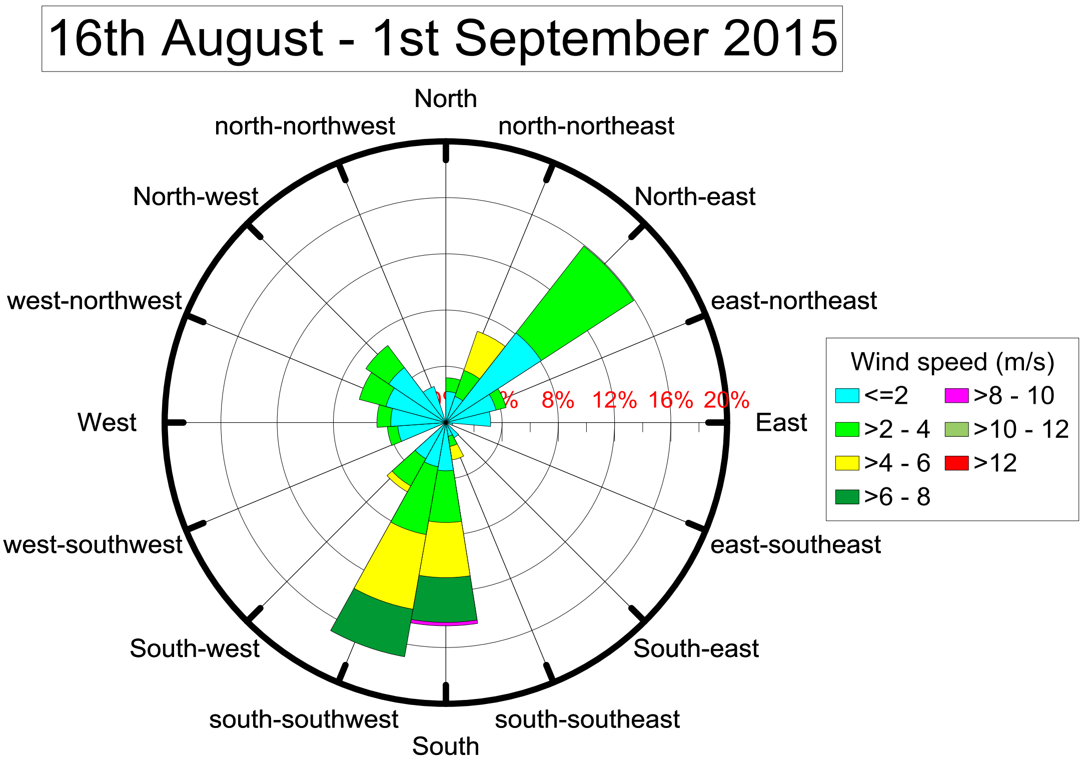

Fig. 3-85. Wind rose diagram for the period between the 16th of August and the 1st of September 2015. The prevailing wind direction was south-southwest, followed closely by north-east. Data from yr.no.

The dominating wind direction from 16th of August and 1st of September was south-southwest, with wind coming from that direction during 17% of the time (fig. 3-85). The north-east direction followed closely with winds coming in for 16% of the time. Winds from the south were frequent as well, with 15% of the time. Winds from other directions were less frequent during the period. Wind was calm during this period with the highest hourly average wind speed of 8,3 $^{m/s}$, from the south, and a mean wind speed of 2,6 $^{m/s}$. There were no storms during the period and wind speed only reached 8 $^{m/s}$ once during the period, during a small storm in late August (fig. 3-86).

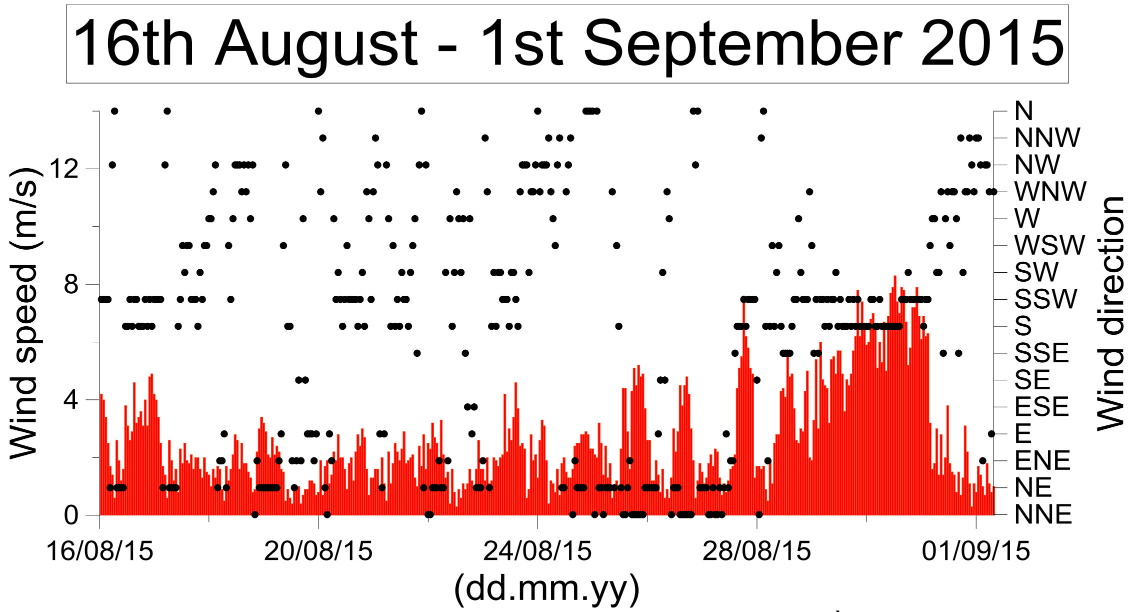

Fig. 3-86. A wind speed and direction diagram for the period between the 16th of August and the 1st of September 2015. The red columns represent the wind speed during the period, while the black dots show the wind direction. Every dot represents an hour. Data from yr.no.

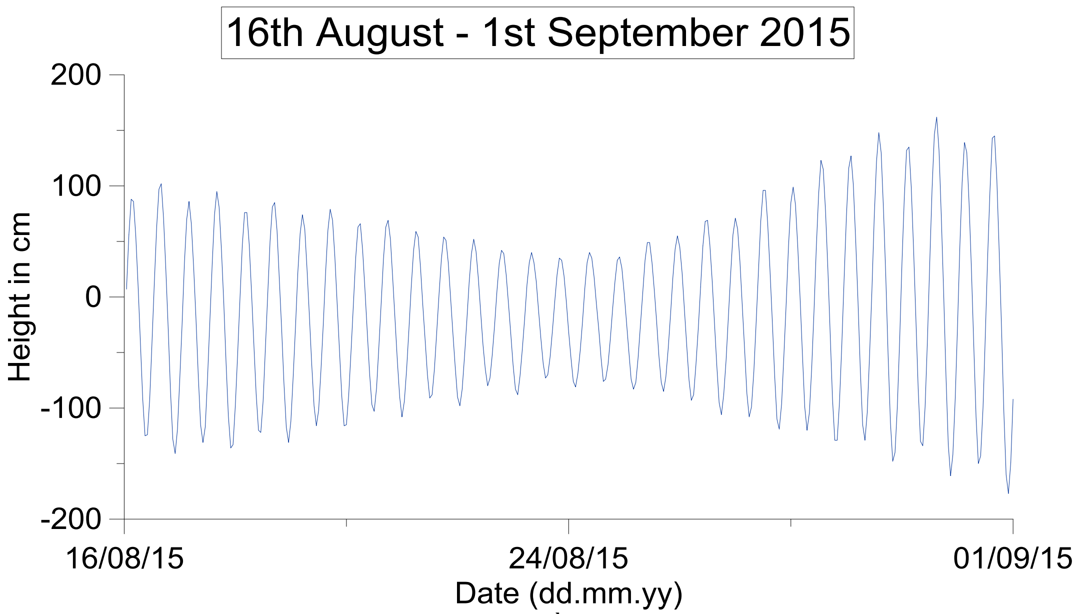

Fig. 3-87. Tidal diagram for the period between the 16th of August and the 1st of September 2015. Data from http://kartverket.no/sehavniva/.

There were two spring tides and one neap tide during the period between the measurements in August and September (fig. 3-87). The mean tide height during the period was -14,6 cm, while the mean high tide height was 84 cm and the mean low tide height was -115 cm. The highest tide was 162 cm and the lowest tide was -177 cm. The tidal cycle was regular during the period.

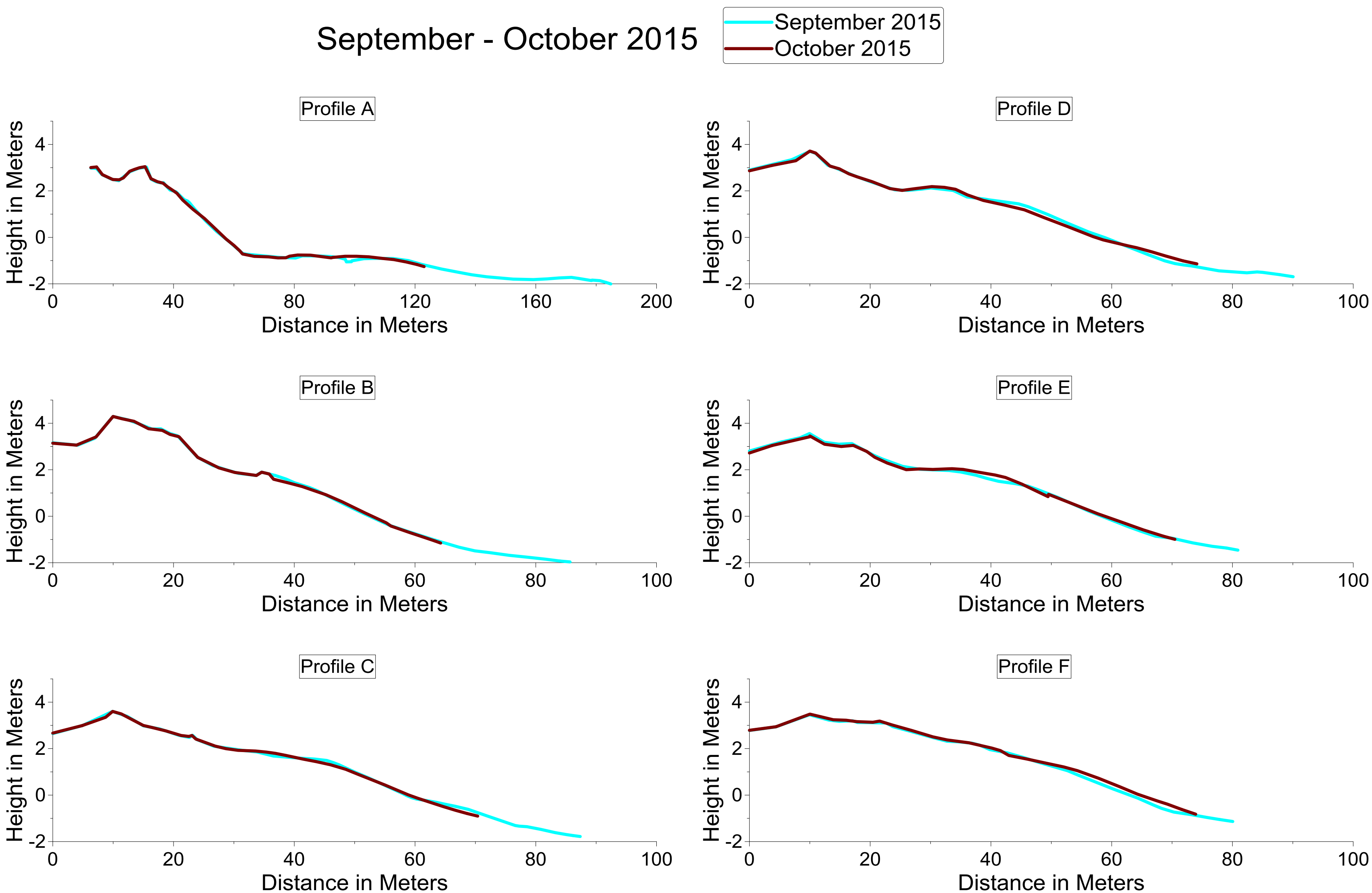

Fig. 3-88. Profile changes between 1st of September and 2nd of October 2015. The profile lines measured in September are light blue, while the lines from December are dark red.

During the period between 1st of September and 2nd of October there were no major changes on the profiles (fig. 3-88). The sand bar in front of Profile A continued to be moved closer to the beach face while other parts of Profile A remained fairly stable. Profiles B, C, and D experienced some erosion while profiles E and F mostly had accretion. The changes on the profiles is discussed at greater length in chapter 4.1.5.2, where the effects of the storm in late September, early October, are discussed in detail.

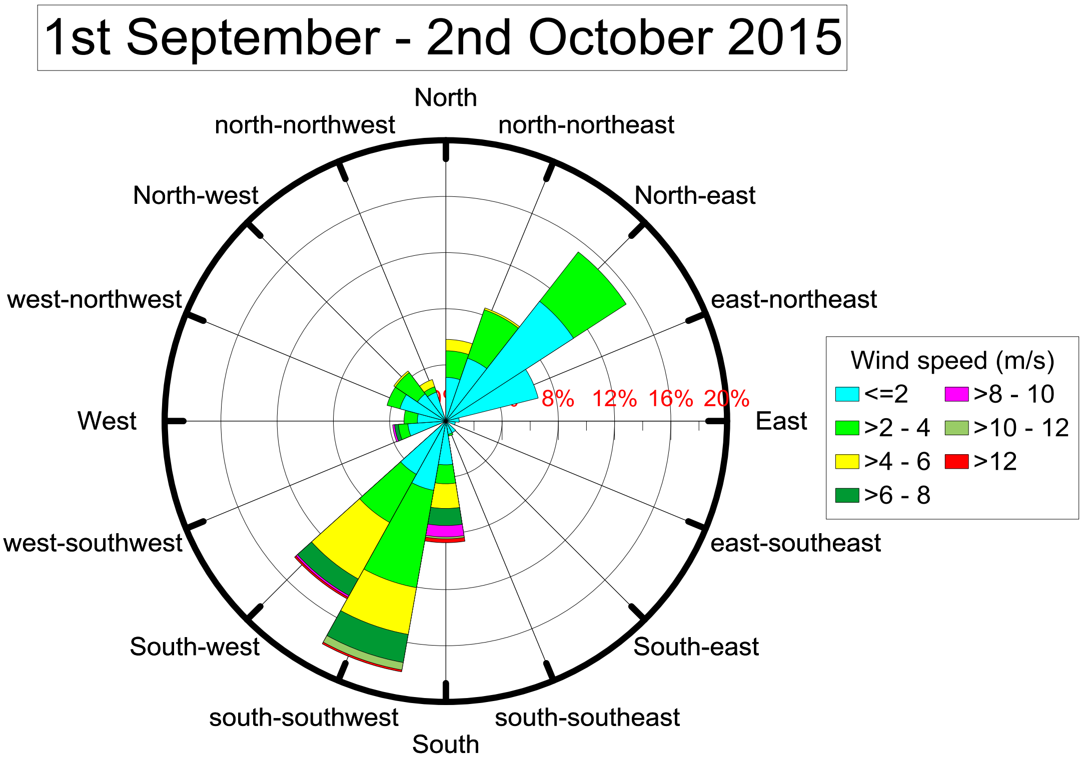

Fig. 3-89. Wind rose diagram for the period between the 1st of September and the 2nd of October 2015. The prevailing wind direction was south-southwest. Data from yr.no.

The dominating wind direction from 16th of August and 1st of September was south-southwest, with wind coming from that direction during 18% of the time (fig. 3-89). The north-east direction followed closely with winds coming in for 15% of the time. Winds from the south-west were frequent as well, with 14% of the time. Winds from other directions were less frequent during the period. Wind was calm during most of the period with the highest hourly average wind speed of 14,1 m/s, from the south, and a mean wind speed of 2,3 m/s. There was one storm during the period, in late September and early October, from the south, south-southwest and south-west (fig. 3-90).

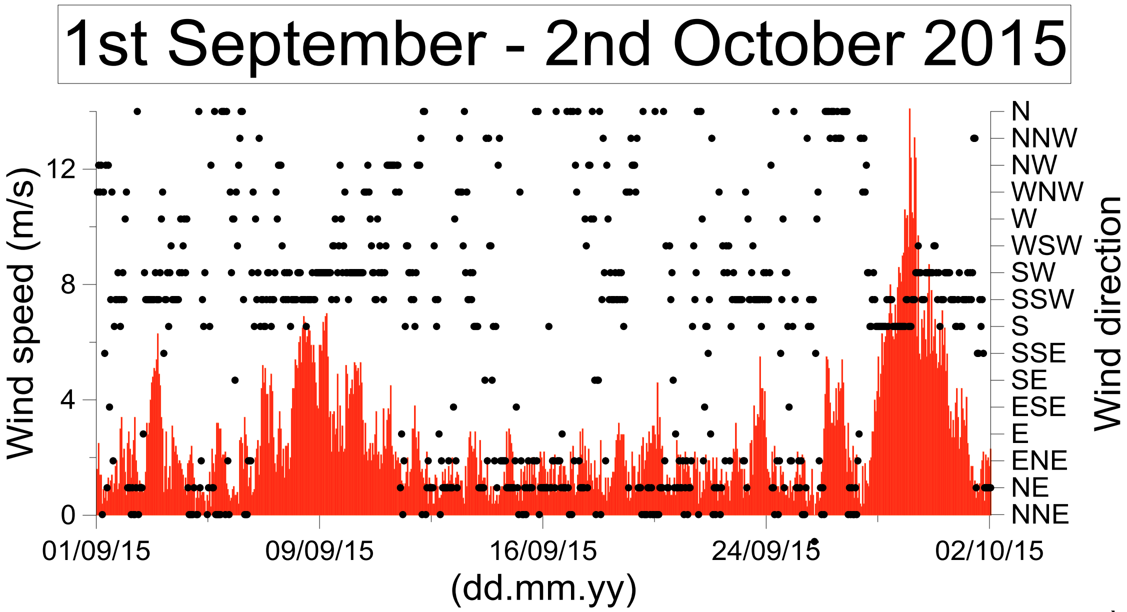

Fig. 3-90. A wind speed and direction diagram for the period between the 1st of September and the 2nd of October 2015. The red columns represent the wind speed during the period, while the black dots show the wind direction. Every dot represents an hour. Data from yr.no.

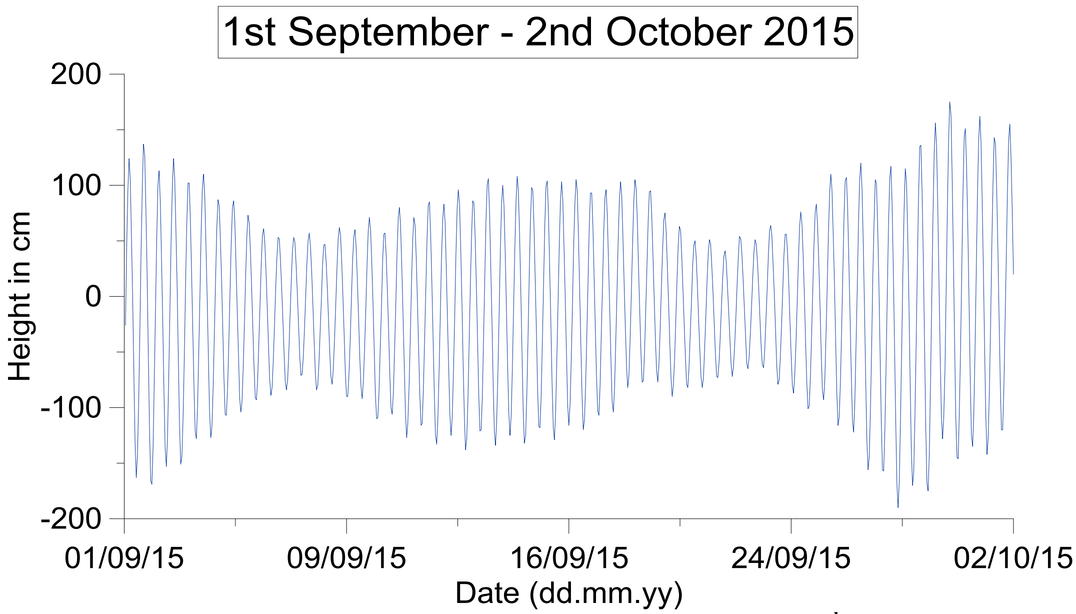

Fig. 3-91. Tidal diagram for the period between the 1st of September and the 2nd of October 2015. Data from http://kartverket.no/sehavniva/.

There were two spring tides and two neap tides during the period between the measurements in March and April (fig. 3-91). The mean tide height during the period was -9,2 cm, while the mean high tide height was 93 cm and the mean low tide height was -109 cm. The highest tide was 175 cm and the lowest tide was -177 cm. The tidal cycle was mostly regular during the period, but in late September and early October the tidal height increases significantly, most likely due to the storm in late September and early October.

3.1.3 Seasonal beach profile change

The one year cycle was split into two seasons, winter and summer, and fall and spring were incorporated into these two seasons. This was done as the sampling period of profile change for both the fall and the spring seasons would have been too short for any relevant changes to be compared. The winter season comprises the profile measurements from October 2014 to April 2015, while the summer season comprises of the profile measurements from May to October 2015. The seasons were split up according to profile evolution and stability during the cycle, the presence of snow and ice on the profiles, and changes in the prevailing wind direction and tide height. In order to examine the changes that occurred in the two seasons, the profiles from October 2014 and from April 2015 were compared to see the changes during the winter season, and the profiles from April 2015 and October 2015 were compared to see the changes during the summer season. The seasonal changes in the beach width, the profile area and the profile section volume can be seen in Table 1, where the profiles from October 2014 are compared to the profiles from April 2015, and April compared to October 2015. In Table 2 the mean beach width for the two seasons can be seen, where the beach width from each profile from every month is used.

Table 1. Seasonal increase (+) or decrease (-) in the beach width, the profile area, and the profile section of each profile. The winter profile is the change between October 2014 and April 2015 and the summer is the change between April and October 2015

	Beach width (m)			Profile area (m^2)		Profile section (m^3)	
Season:	October 2014	April 2015	October 2015	Winter	Summer	Winter	Summer
Profiles:							
A	38,44	38,14	39,96	+4,98	+10,53	+1842,6	+3896,1
B	35,45	35,54	36,02	+1,15	+2,05	+345,0	+615,0
C	45,95	46,22	47,49	-2,82	+6,36	-846,0	+1908,0
D	37,38	37,61	38,94	-0,91	+6,97	-273,0	+2091,0
E	40,56	38,91	39,48	-8,95	+7,22	-2237,5	+1805,0
F	41,53	41,47	46,65	-13,74	+16,34	-2473,2	+2941,2

Table 2. Mean beach width for the winter and summer season at each profile

Profiles	A	B	C	D	E	F
Winter	36,21	34,87	44,79	36,70	37,96	41,88
Summer	39,49	35,80	46,33	38,21	39,08	42,43

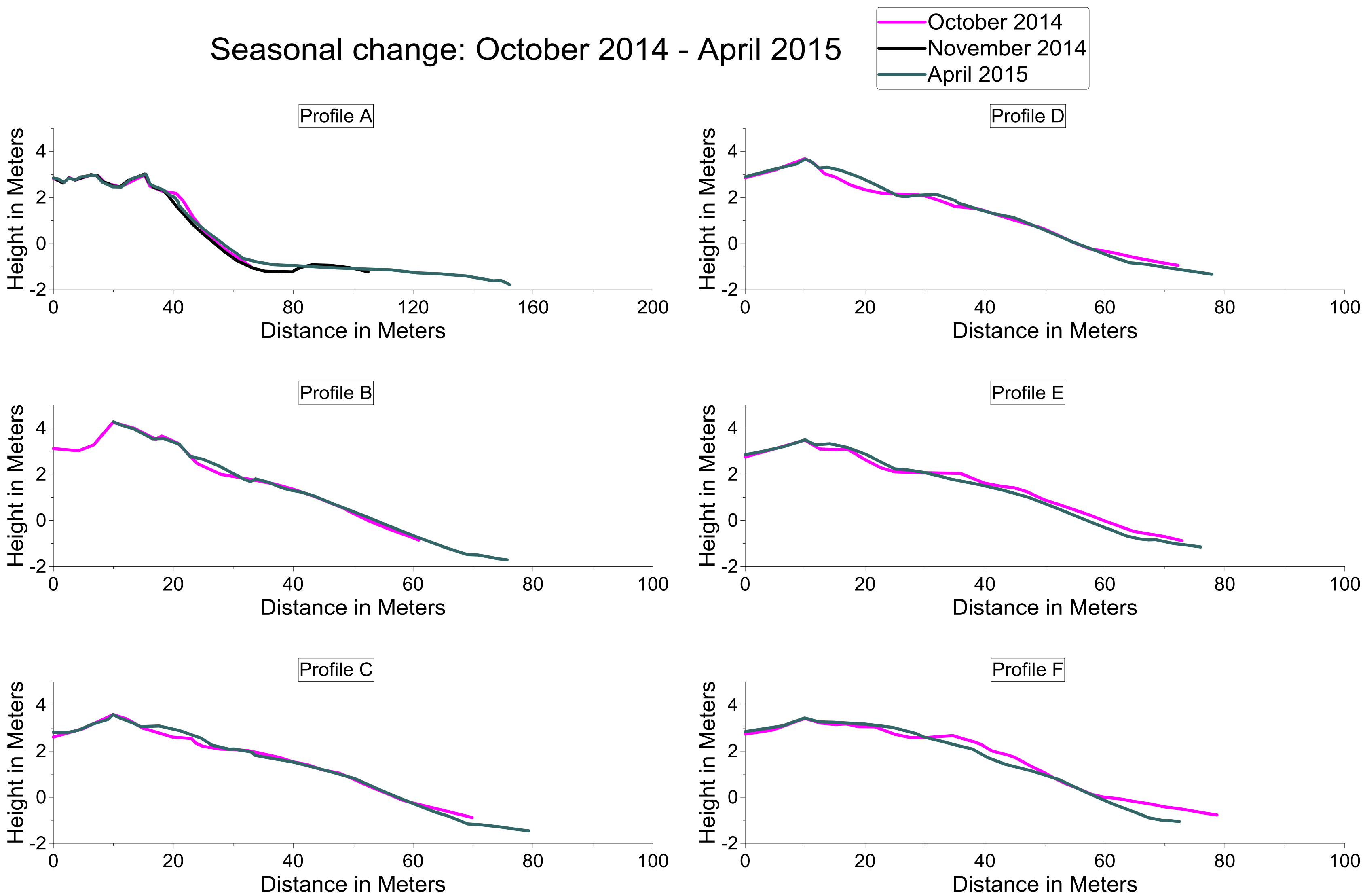

Fig. 3-92. Profile changes between October 2014 (magenta) and April 2015 (dark green)

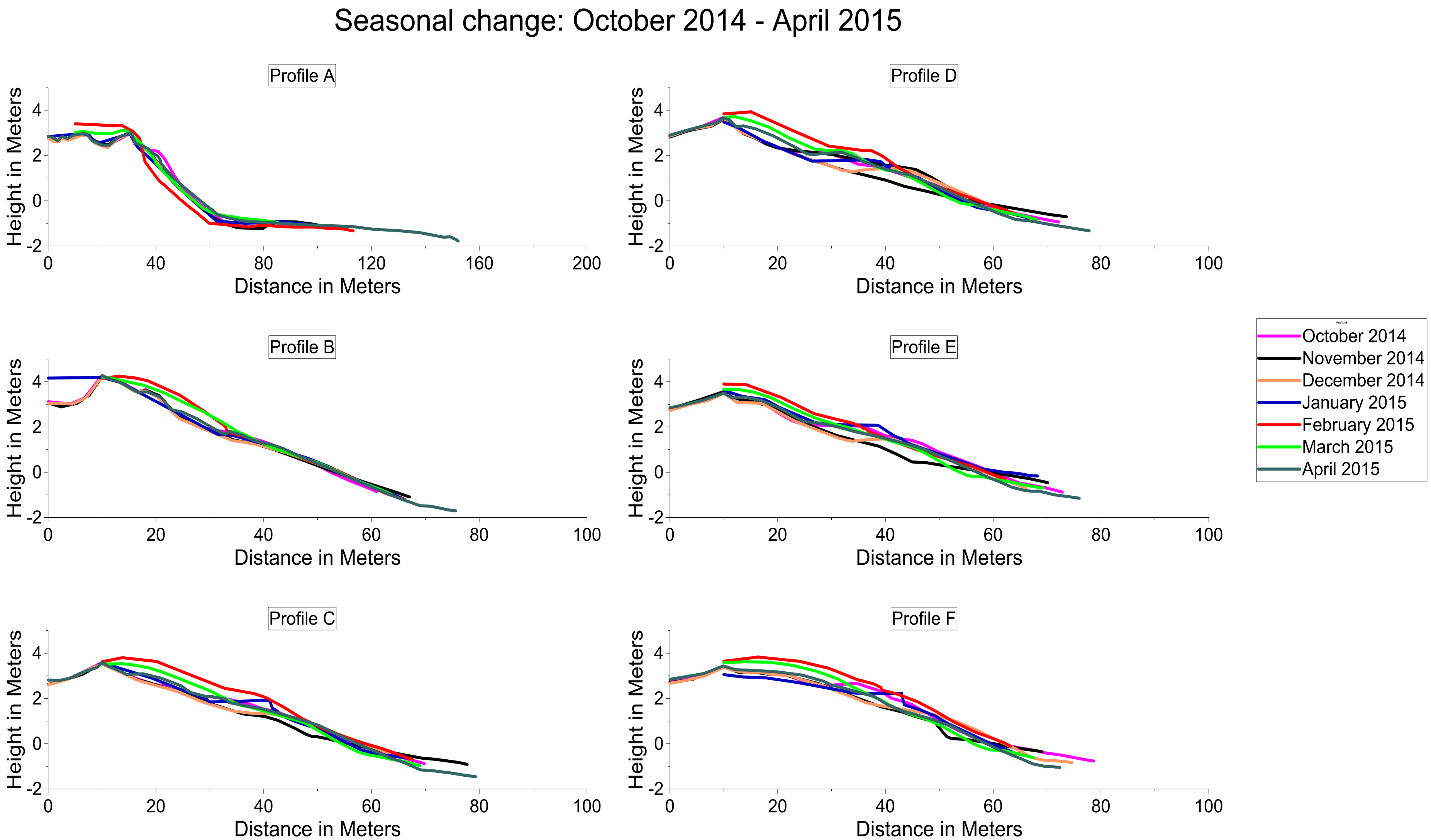

Fig. 3-93. Profiles from the winter season between October 2014 and April 2015. Seven profile lines were measured at each of the six profiles at Sandbukt beach during the season.

All the six profiles underwent large changes during the winter season (fig.3-93), but the profiles from October 2014 and April 2015 did not differ greatly from one another(fig.3-92).
At profile A there was both accretion and erosion on the berm. Most of the erosion was caused by the storm in early November, from which the berm never recovered. On the small part of the berm that remained after the storm, there was a minor accretion. The accretion was probably caused by sand that accumulated on the ice, that was present at the berm through most of the winter months, and was then deposited ontop of the berm once the ice melted. The erosion of the berm was 2,93 m3 and the accretion was 0,29 m3, giving net erosion of 2,64 m3 of the berm during the period. The beach face had accretion of 1,81 m3 during the period and had recovered fully from the storm. The storm had caused extensive erosion on the beach face that had decreased the beach width and increased the beach gradient. The beach face did not recover from this erosion until April, with little to no change in the beach face between November and March. The sudden recovery of the beach face at Profile A is likely linked to the increase of sediment available for the beach when spring melt started in early April, bringing in high amounts of sediments via Breivika River. The low tide terrace and the sandbar where not measured on October the 3rd, and therefore the measurement from November the 12th is used in comparison. It is possible that the total accretion on the terrace and the sandbar would have been less in the season if the profile line in October had extended to that area, as there could have been some erosion between October and November due to the storm. The erosion during the storm was much less on the lower beach face than it was at the berm, so it is possible that there was little to no erosion on the terrace and the sandbar, or even accretion as the material that was eroded was carried offshore. The total accretion on the low tide terrace during the period was 6,54 m3 while the total erosion was 1,27 m3, giving a net accretion of 5,27 m3. Most of the accretion comes from the increase height of the low tide terrace, or 5,75 m3, which had begun to increase in Janury and reached its peak in March. The other area that had accretion during the period was the seaward side of the sandbar, which had accretion of 0,79 m3, as the sandbar got wider. The erosion occurred on the upper part of the sandbar, reducing it in height. The total accretion at Profile A was 8,64 m3 during the period while there was total erosion of 3,66 m3, giving a net accretion on the profile of 4,98 m3. The beach width decreased by 30 cm, from 38,44 m in October 2014 to 38,14 m in April 2015, while the beach gradient increased by 0,02°, from 3,28° to 3,30°.
Profile B was the most stable profile during the winter months. The profile had the least amount of erosion during the storm in November, where only small parts of the beach ridge, the berm and the upper beach face were eroded. There was a minor erosion on the beach ridge

during the season, where the second peak of the ridge was smoothed out. This erosion of 0,17 m3 was most likely caused by aeolian processes during the storm in November, when vegetation had started to receed from the ridge and left it more exposed to wind erosion. Most of the backshore was covered in snow and ice from early December to April, which both prevented deposition of material directly on to the profile and protected the beach ridge and the berm from possible erosion. As a result, there were no changes on the beach ridge and the berm from December to April, when most of the snow and ice had melted away. In April there was still some snow on the upper part of the berm, but that area of the berm had not had any erosion during the storm and had remained stable under the ice cover. This is further demonstrated when the profile lina from May is compared to the one measured in October (fig.xx), where both the profile lines lie at the exact same place on the upper berm. The lower part of the berm did however not remain stable during the season. The storm in November caused some erosion there, which did not start to recover until between December and January. By February the lower berm had regained the same extent as it had before the storm, but there were layers of ice underneath the surface sand there, and remained there until March. Between March and April the ice started to melt underneath the sand, which caused the sand to collapse which lowered the profile at that location and created a small mound in front of it. Due to this collapse and the creation of the mound, there was accretion of 0,2 m2 and erosion 0,11 m3 on the berm between October and April. The berm crest also underwent erosion in the season, with 0,14 m3 of material being removed, giving the berm a net erosion of 0,05 m3 for the season. The beach face and the low tide terrace were fairly stable during the season, with only minor erosion on the beach face and minor accretion on the terrace during the storm in November. The beach face had recovered in December and did not undergo any major changes between December and April. The height of the low tide terrace was increased during the storm in November, and retained most of it increased height until April. The accretion in the season for the beach face and the low tide terrace was 1,37 m3 with no erosion on them when October and April are compared. The total accretion at Profile B was 1,57 m3, while total erosion was 0,42 m3, giving a net accretion of 1,15 m3 during the winter season. The beach width increased by 9 cm, from 35,45 In October 2014 ot 35,54 in April 2015, while the beach gradient decreased by 0,01°, from 4,83° to 4,82°.

When the profiles from October 2014 and April 2015 from Profile C are compared there is no large difference in them, but the profile varied greatly during the season. The Profile had extensive erosion between October and November, where large parts of the beach face and the berm were removed. The seaward face of the beach ridge had a slight erosion in the season, where 0,14 m3 were removed during the storm in November, and the ridge had not regained it former position by April. On the boundary between the ridge and the berm, there was a small mound there in October, but had been removed by November, causing erosion there of 0,29 m3. The berm started to recover by December, but did not fully recover until March and April. By April the berm had regained its former height and width in most areas, but small area on the berm crest had not recovered where an area of 0,82 m3 was still missing. The height of the middle of the berm in April was the same as it had been in October, but there seems to have been a layer of ice underneath the sand, as this area had collapsed slightly by the time measurements were taken in May. The beach face had recoverd by December from the erosion in the previous month, with only minor changes there in the months that followed. There was accretion of 0,13 m3 on the upper beach face, while there was some erosion on the lower part. The low tide terrace had been raised in early November, but had been lowered back again by April, and was lower than it had been in October, leading to erosion of 1,69 m3 there and on the lower part of the beach face. The total erosion of the profile in the winter season was therefore 2,95 m3, while accretion of 0,13 m3 occurred, giving a net erosion of 2,82 m3. Despite the profile having greater erosion than accretion during the season the beach width increased by 0,27 m in the season, from 45,95 m to 46,22 m, and the beach gradient decreased by 0,02°, from 3,44° to 3,42°.

Profile D underwent large changes during the season but the by April the profile had a similar form as it had had in October 2014. During the storm in November large portions of the beach face and the berm were removed. By December a new berm had been formed but, similar in width to the previous one, but was much lower on the profile. The new berm was then covered by snow between December and January and was covered until some point between the February and March measurements. By March the berm had been built up to the same height as it had been before the storm, becoming wider as well, and stayed like that until April. Beacuse of the increase in the berm width, there was accretion of 1,33 m3 on the berm in April compared to October 2014, while an area of 0,19 m3 had been eroded, giving a net accretion of 1,14 m3. A small part of the upper berm was still covered with snow in April, but no erosion or accretion took place there before the area was covered with snow, and the area was undisturbed once the area was free of ice in May. The beach face recovered more quickly, being similar in length in December as it was in October, and by January it was similar to that of October. The beach face underwent erosion every other month, with accretion inbetween, until in April when the beach face was at almost the same location as it had been in October. There was some accretion on the beach face between October and April, where a small area of 0,41 m3 had formed on the upper beach face. The low tide terrace had been raised in heigth in November, but had been eroded below its October height by April. The erosion on the terrace in the season was 2,46 m3, giving Profile D a total erosion of 2,65 m3 on the profile in the season, and total accretion of 1,74 m3. The net erosion at Profile D was therefore 0,91 m3. The beach width increased by 23 cm in the season, from 37,38 m to 37,61 m, and the beach gradient decreased by 0,03°, from 4,35° to 4,32°.

Profile E underwent similar erosion and deposition during the storm in November as Profile D did. The beach face had extensive erosion, most of the berm was removed and the low tide terrace was raised in height. A new berm had started to form by December but was at a lower height than it had been. By March it had mostly been restored to the height it was at in October, but was still lacking in width. Between March and April the width of the berm did not increase, and therefore erosion on the berm occurred between October and April. A small part of the upper berm was still covered with snow in April, but no erosion or accretion took place there before the area was covered with snow, and the area was undisturbed once the area was free of ice in May. The beach face had recovered by December but was eroded in the months following, until a small accretion occurred between March and April. The accretion was not extensive enough to restore the erosion from the previous months. The low tide terrace was raised in November and again in January, but was lowered in the other months including April, where the terrace was considerably lower than October. The erosion of the berm, the beach face, and the terrace was continous over the whole beach at Profile E, resulting in a net erosion of 8,95 m3. The beach widht decreased by 1,65 m, from 40,56 m to 38,91 m, and the beach gradient increased by 0,16°, from 3,73° to 3,89°.

At Profile F the berm was mostly removed in November, but begann to be built up again before December when it was covered with snow. By April the berm had only recovered slightly and was still well below its height in October. Parts of the berm were still covered by snow in April, but the snow was only covering the upper part of the berm where no erosion had occurred in November and no changes were recorded on the berm in May. The beach face was mostly restored in December, but had been pushed furhter out by the accretion that occurred between November and December. In the months that followed the beach face was slowly brought back to the line in October, and In April a large part at the middle of the beach face was at the same place as it had been in October. The Upper and lower beach face were however lower than they had been in October. The low tide terrace was not raised during November like most of the other profiles, but remained stable. The terrace was then pushed further out and lowered as the beach width increased between November and December. By

March the terrace had been pushed back where it was in October, but had become even lower and continued to be lowered between March and April. There was therefore extensive erosion on the terrace when October and April are compared. The erosion of the berm and the upper beach face was 5,99 m3 in the season and the erosion on the lower beach face and the low tide terrace was 7,71 m3, giving a net erosion of 13,74 m3. The beach width decreased by 0,06 m, from 41,53 m to 41,47 m, and the beach gradient increased by 0,01°, from 3,53° to 3,54°.

To further study the changes within the winter season, the mean, the minimum and the maximum profile height was calculated for each profile (fig. 3-94). The minimum height is mostly the profile line from November 2014, where extensive erosion had occurred, and the maximum height on the berm is due to snow and ice cover. The changes on the beach face and the low tide terrace are not extensive at profiles A and B, with small height increase on the terrace at Profile A. Profiles C, D, E, and F show some height changes during the season indicating periods of raising and lowering of the beach face and the low tide terrace.

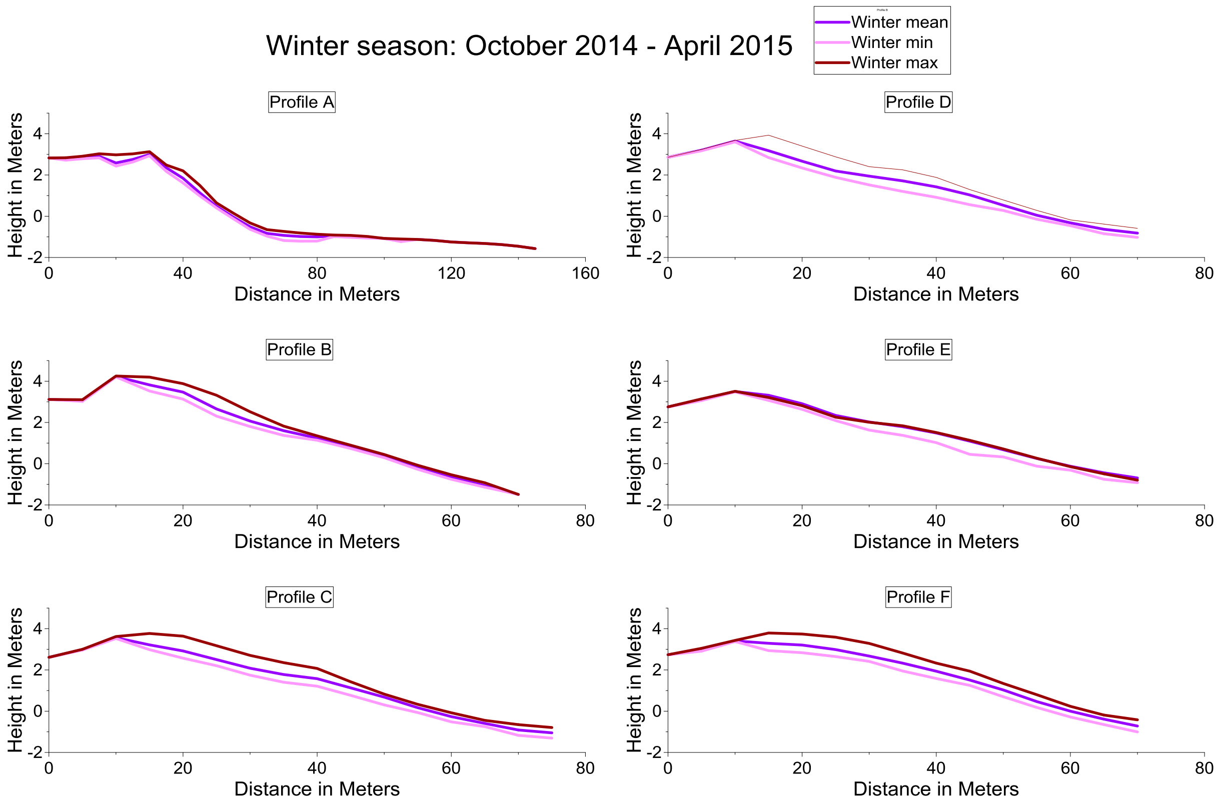

Fig. 3-94. The mean, the min, and the max profiles for each profile during the winter season.

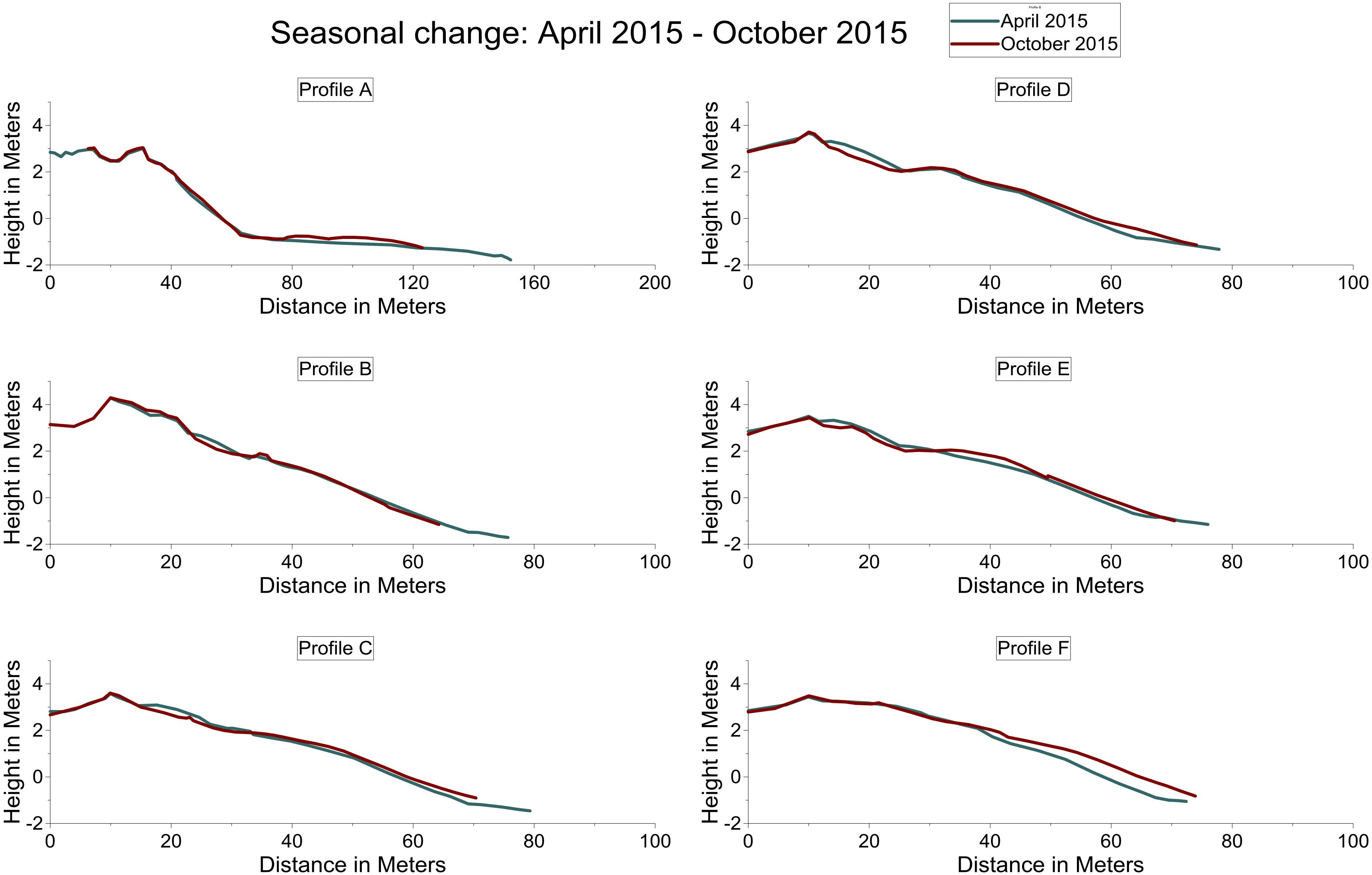

Fig. 3-95. Profile changes between April and October 2015. The profile lines measured in April are dark green, while the lines from October are dark red.

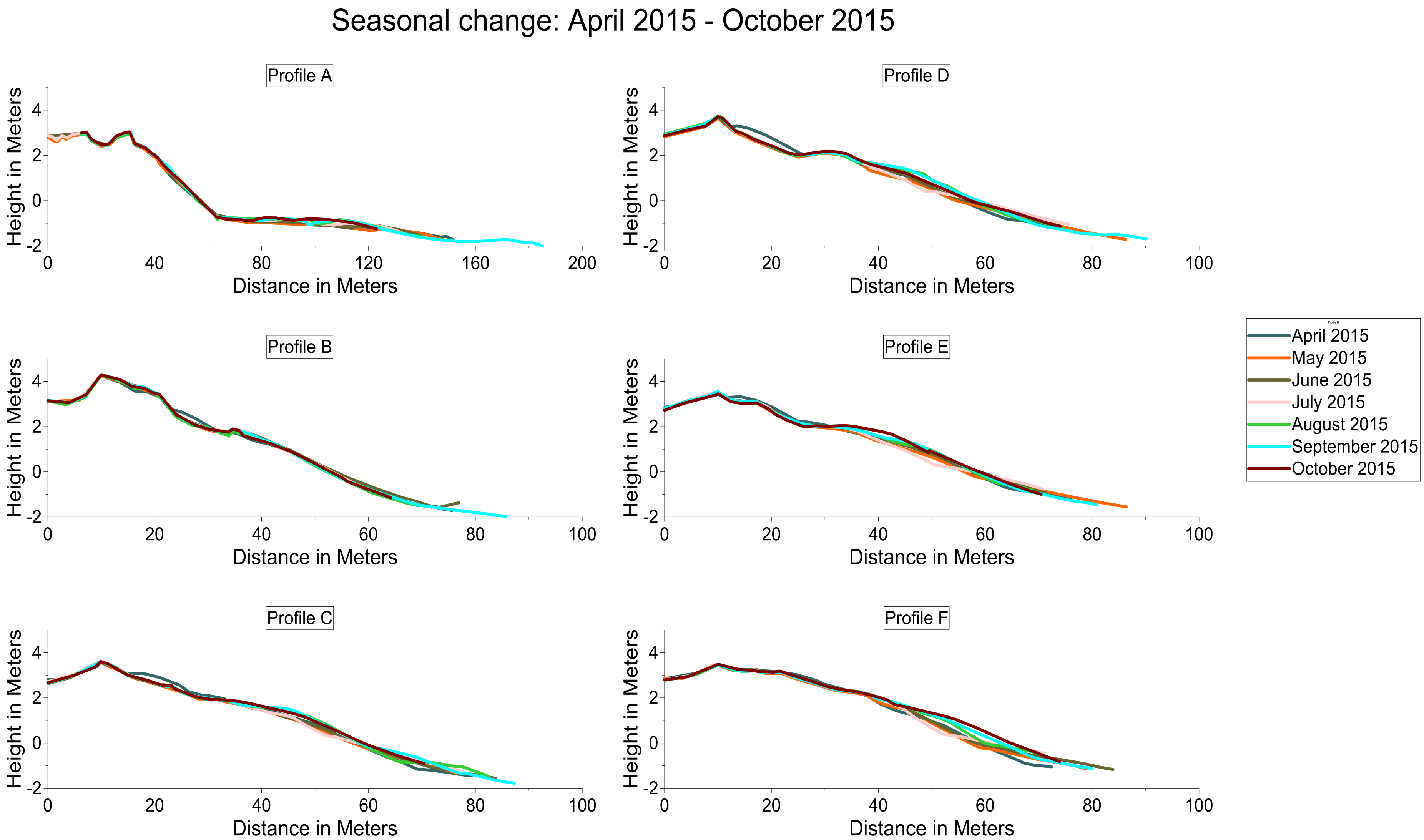

Fig. 3-96. Profiles from the summer season between April and October 2015. Seven profile lines were measured at each of the six profiles at Sandbukt beach during the season.

All the six profiles only had minor changes during the summer season (fig. 3-96), and the profiles from April and October 2015 did not differ greatly from one another(fig. 3-95).

Profile A remained stable during the summer months with no large events that caused extensive erosion or accretion. The beach ridge and the berm remained stable throughout the season with no changes to the profile line, except an increase of few cm on the back end of the ridge that was caused by increased vegetation. The beach face had small accretion in every month of the season, apart from between July and August, where small erosion occurred. The overall accretion on the beach face between April and October 2015 was 2,04 m3. The low tide terrace was raised from April to August, but was lowered in both September and October which caused erosion of 0,46 m3 in the season. The sandbar grew substantially during the season, increasing by 8,94 m3. The bar was at the same height as the low tide terrace in April but started to build up mass in June and had two tops during the late summer. The two tops were created by erosion on the middle of the bar due to drainage channels that drained the upper beach as the tide went down. The total accretion at Profile A during the summer season was 10,99 m3, and the total erosion was 0,46 m3, giving a net accretion of 10,53 m3 in the season. The beach width increased by 1,84 m, from 38,14 m to 39,96 m, and the beach gradient decreased by 0,15°, from 3,3° to 3,15°.

Profile B remained stable through the summer season as well, with only minor changes on the profiles between April and October. There was a small accretion on the beach ridge where a small depression, on the seaward side of the ridge , was filled up with sand by aeolian processes. The accretion on the ridge was 1,52 m3. The berm did not change much, but both a minor accretion and erosion occurred on the berm. The accretion was caused by the growth of the small mound that had formed on the berm in April when ice underneath the sand melted and the sand collapsed. This mound grew over the course of the season, both by aeolian proccesses and sand broaught in by waves up to it. The seaward part of the mound was eroded between September and October, and the accretion was 0,53 m3 between April and October. The berm erosion was on the landward side of the mound, and was probably caused by wind evening out the surface there once the sand had collapsed. The beach face was mostly stable, but experienced some erosion in July and August, but most of that erosion had been filled up by October. The total erosion of the beach face was 1,64 m3, giving the Profile an accretion of 2,05 m3 during the season and erosion of 1,73 m3, making the total accretion 0,32 m3 for the season. The beach widht increased by 0,48 m, from 35,54 m in April to 36,02 m in October, and the beach gradient decreased by 0,06°, from 4,82° to 4,76°.

During the summer season, Profile C mostly experience accretion, apart from between June and July when a runnel was formed on the beach face causing erosion there. The beach ridge had accretion of 0,23 m3, where the erosion that took place in November 2014 had occur, and restoring the ridge to same volume as it had been in October 2014. A small mound, 0,05 m3 in size, was formed between May and June on the boundary of the beach ridge and the berm, at the exact same location as the mound that got eroded away between October and November had been. This mound continued to grow during the season, and by October it had reached almost the same height and width as it had in the previous year. The area on the middle of the berm, where the ice had been under the snow, was lowered when the ice melted, and an area of 0,47 m3 was removed. The outer part of the berm remained stable in the first months of the season, but between July and August the berm grew in both height and width, before being lowered slightly by October. The beach face was mostly stable during the season, with small accretion occurring almost every month, apart from between June and July when erosion occurred and a runnel was formed high up on the beach face. The low tide terrace was raised and pushed further out by the accretion on the beach face during the season, and an accretion of 6,55 m3 occurred on the beach face and the terrace during the season. The total accretion on the profile during the season was 6,83 m3 and the total erosion was 0,47 m3, giving a net accretion of 6,36 m3 for Profile C in the summer season. The beach width increased by 1,27 m, from 46,22 m in April to 47,49 m in October, and the beach gradient decreased by 0,09°, from 3,42° to 3,33°.

Profile D had large changes within the summer season, but no large changes were between the profiles in April and October. The beach ridge and the upper berm remained stable troughout the period, were the only change was the dissapearance of the remaining snow on the upper berm. The lower part of the berm remained mostly stable as well, but between July and August in grew in width that was eroded back between September and October. The largest change on the beach face occurred between June and July, where a runnel was formed on the middle of the beach face due to erosion there. The beach face quickly recovered and by October the height of the beach face had increased compared to April. The low tide terrace was raised between April and July, and then lowered again between July and August, only to be raised slightly by October. The terrace was slightly higher than it had been in April, and with that accretion combined with the accretion on the beach face and the lower part of the berm, the total net accretion was 6,97 m3 while no erosion occurred in the season. The beach width increased by 1,33 m, from 37,61 m in April to 38,94 m in October, and the beach gradient decreased by 0,15°, from 4,32° to 4,17°.

At Profile E the beach ridge remained stable, but the berm had both accretion and erosion on it. The upper part of the berm had minor erosion, that occurred between April and May and was most likely caused by melting of ice underneath the sand there. No collaps structure were however seen on the surface and therefore it is possible that the erosion was caused by aeolian processes. The lower part of the berm remained mostly stable until July, when between July and August it started to be raised and reached its greatest height in October. The beach face remained rather stable throughout the season, apart from when a runnel was formed on it in July. After the formation of the runnel the beach face became stable again and by October it had been raised slightly above the height in April. The height of the low tide terrace remained the same during the season but its with increased when the runnel was formed on the beach face in July. The width of the terrace had decreased again by October and small accretion had occurred there. The total net accretion of the berm, the beach face and the low tide terrace was 7,22 m3. The beach widht increased by 0,57 m, from 38,91 m in April to 39,48 m in October, and the beach gradient decreased by 0,06°, from 3,89° to 3,83°.

At Profile F the beach ridge remained stable through the season, as well as the upper part of the berm. The lower part of the berm was raised in height between most months of the summer season, and by October the berm had been both raised up and increased in width. The beach face was stable until the period between June and July, where slight erosion occurred, but after that there was accretion on the beach face until October that increased the height of it over what it had been in April. The low tide terrace was raised from April to August, but was after that eroded but was still at heigher elevation in October than it had been in April. The total net accretion at Profile F was 16,34 m3, with no erosion occurring. The beach width increased by 5,18 m, from 41,47 m in April to 46,65 m in October, and the beach gradient decreased by 0,4°, from 3,54° to 3,14°.

To further study the changes within the summer season, the mean, the minimum and the maximum profile height was calculated for each profile (fig. 3-97). When the three lines are compared, it can be seen that no large changes occurred in the backshore, apart from the snow covere there being removed between April and May. The berm crest, the beach face, and the low tide terrace all show small changes, with the largest changes occuring at profiles C, D, E, and F. At profile A the beach face and the sandbar show small changes, mostly due to movement and accretion on the sandbar.

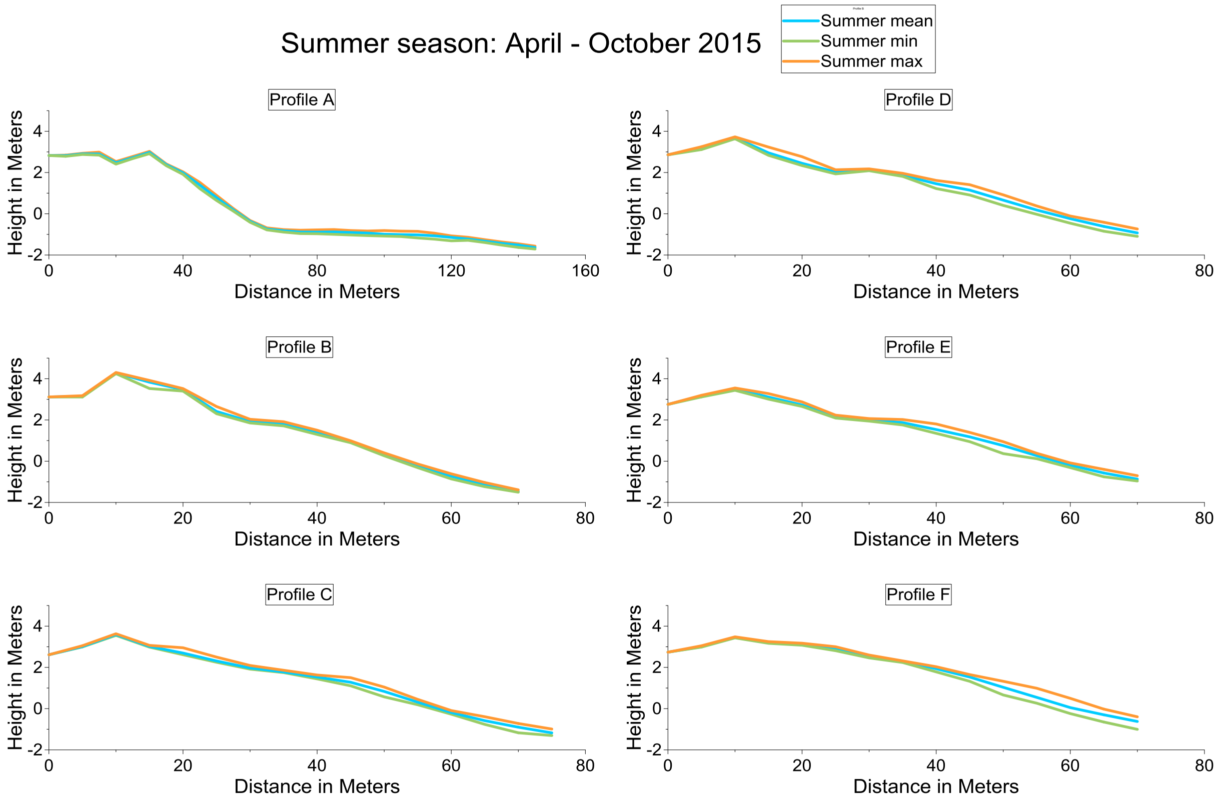

Fig. 3-97. The mean, the min, and the max profiles for each profile during the summer season.

When the mean profiles are compared the difference is not high (fig. 3-98). The summer season mean at the beach face, the low tide terrace, and the sandbar at Profile A are slightly raised compared to the winter mean and the sandbar is more flat. At Profile B the two mean lines are virtually identical, appart from the mean for the winter season lying higher on the berm and the summer season mean having higher berm crest elevation. The difference in the berm mean is due to the snow cover there during the most of the winter months while accretion occurred on the berm crest during the summer months. The mean for the summer is also slightly lower at the low tide terrace. At Profile C the berm has similar differences as Profile B, and the mean summer profile has raised beach face compared to the winter mean, with a slightly lowered low tide terrace. Profile D also has the same differences on the berm as profiles B and C, and has a raised berm in the summer mean profile. The beach face is also raised while the low tide terrace is lower than the winter mean. Profile E had the same difference on the berm, while the beach face is almost the same, with the summer mean slightly higher. The low tide terrace shows some lowering from the winter to the summer season. Profile F has also the same difference on the berm, but is much less, and the mean beach face is the same between the two seasons while the low tide terrace was raised from the winter to the summer season.

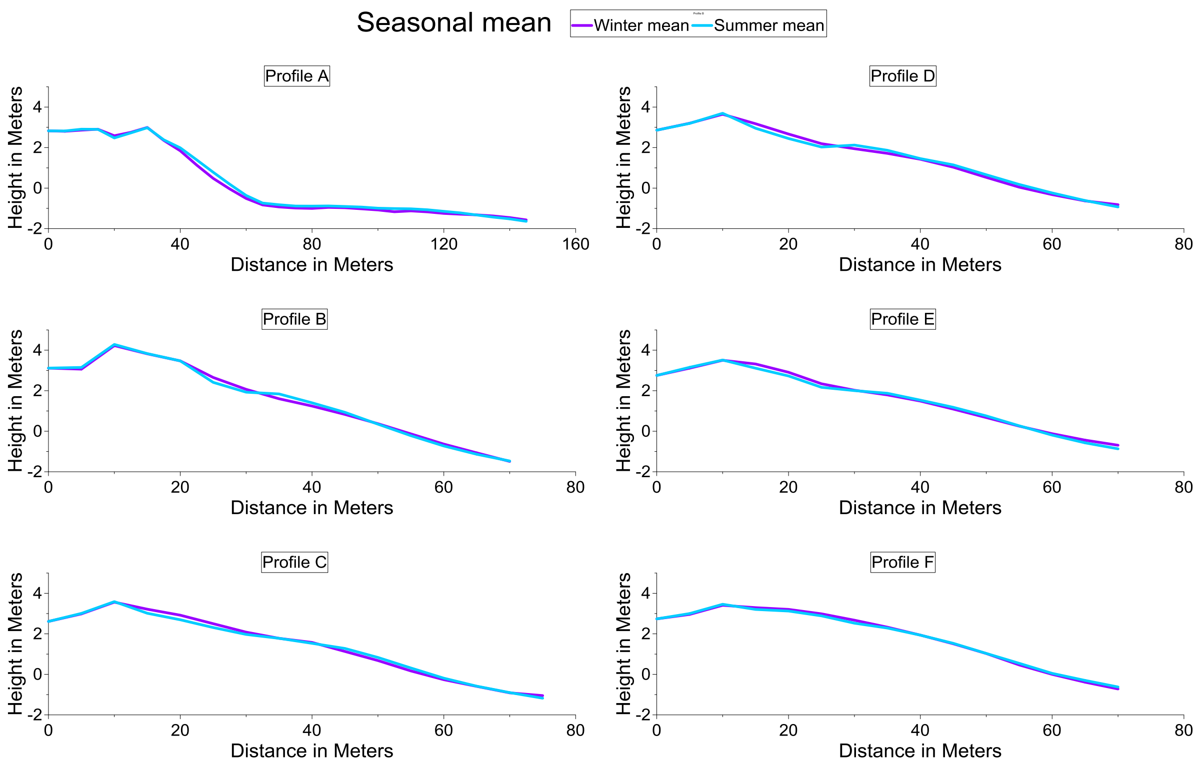

Fig. 3-98. The mean profile for the winter and summer season at each profile.

Larger differences is seen when the minimum and the maximum height of the winter and the summer profiles are compared (fig. 3-99). The minimum height for the berm and the beach face, and at profile A the sandbar, for the winter season is essentially the profile line measured in November 2014. The low tide terrace minimum height is the same for profiles C, E and, F, while the winter minimum is lower than the summer minimum at Profile A but higher at profiles B and D. The maximum height at the berm and the berm crest was reached during the winter season while snow covered it, apart from Profile A where the maximum was during October 2014. The maximum height of the beach face is either equal for the two seasons, or the summer season has higher elevation. The low tide terrace shows the opposite trend, where the maximum height is either equal for the two seasons, or the winter season has higher elevation.

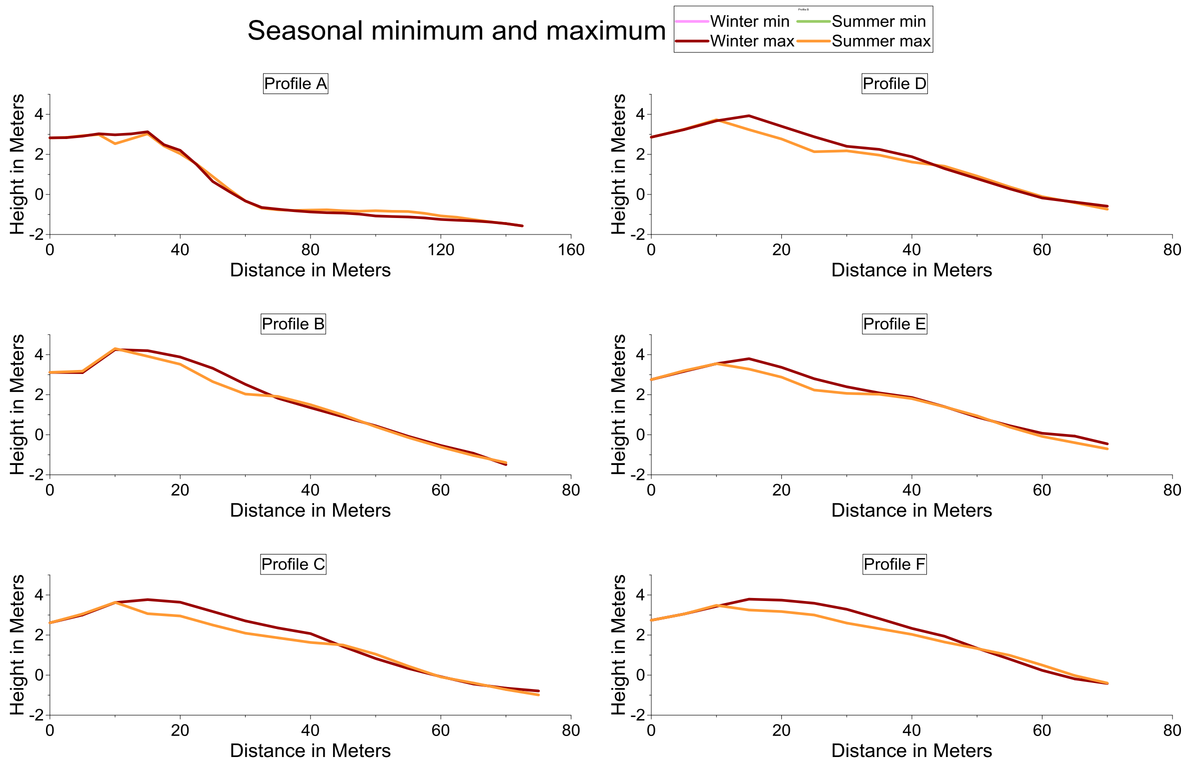

Fig. 3-99. The minimum (min) and maximum (max) height of the profiles for the winter and summer season at each profile.

When the changes in beach width at the profiles are compared to each other (fig. 3-100), it can be seen that profiles C, D, E, and F have a similar pattern. The beach width at these profiles decreases and increases every other month or so, with only a few instances that do not follow that trend. The decrease and increase in the width of these four profiles is similar throughout the cycle, with the largest reduction of width in November and July followed by a large increase in the beach width in the following month. The period between August and October is the only period where the changes in the beach width for these profiles differ, where there is a small decrease at Profiles C, D, and E, while there is an increase in the beach width at profile F. Profiles A and B were much more stable throughout the one year cycle and do not show similar patterns of reduction and increase in beach width as the other four profiles. At Profile A the beach width, after the erosion between October and November 2015, remains relatively stable between November 2014 and March 2015, and the reduction in the beach width in February is incorrect. Between March and April the width starts to increase, reaching its peak in July, and remains fairly stable until October. At Profile B the beach width starts to increase after November, regaining its former width between by April and remains relatively stable until October. The beach width maximum for each profile varies as well, with profile A reaching its peak width in July, B in June, C, D, and E in August and F in September.

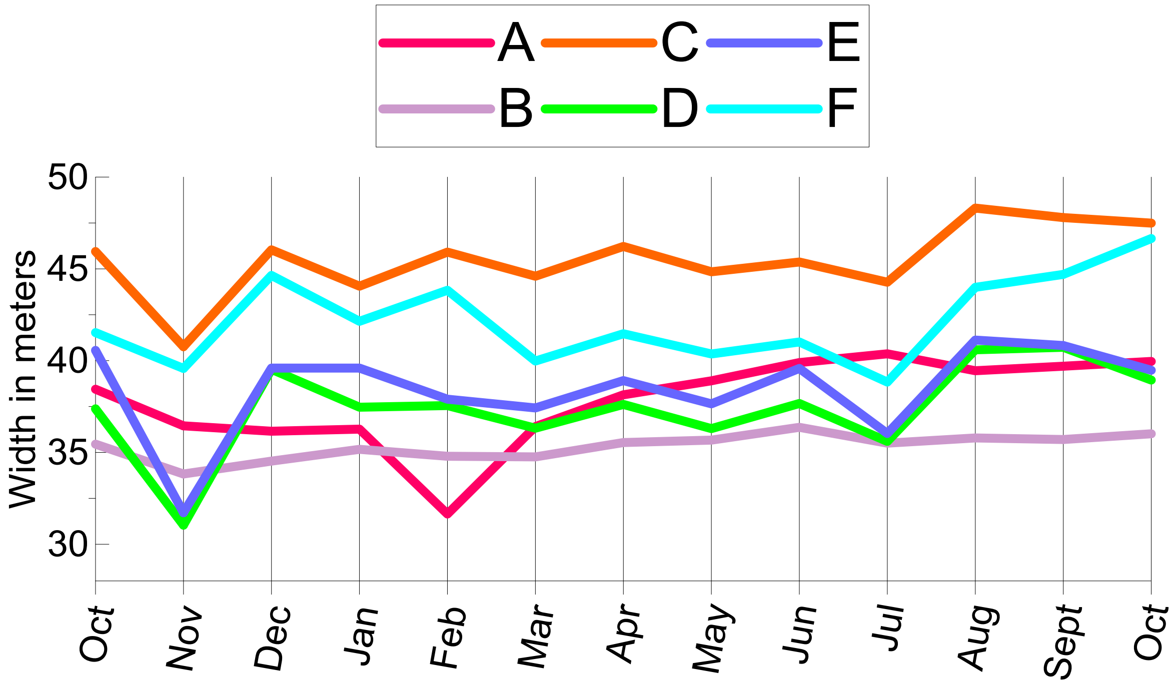

Fig. 3-100. The beach width of the six profiles for every month during the one year cycle from 2014 – 2015.

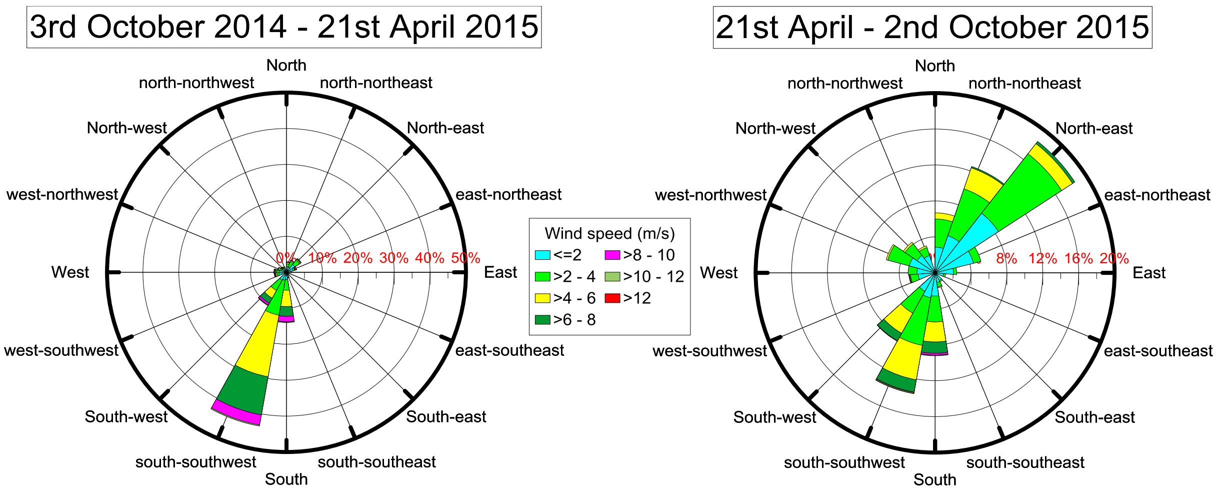

Fig. 3-101. Wind rose diagrams for the winter season (3rd of October to 21st of April) and the summer season (21st of April to 2nd of October). The change in prevailing wind direction between the seasons is clearly evident, with the winter season having south-southwest as the prevailing wind direction while the prevailing wind direction during the summer season was north-east. Changes in windstrength are also apparrent, as higher windspeed was more frequent during the winter season. Data from yr.no.

The prevailing wind direction during the winter season was from the south-southwest (fig. 3-101), with wind blowing in from that direction for about 43% of the time. South and south-west wind directions were the next two most frequent wind directions, but only had wind coming in from those directions for about 13% and 10% of the time. Other wind directions were less frequent. The prevailing wind direction during the summer season was from the north-west (fig. 3-101), with wind blowing in from that direction for about 18% of the time.

South-southwest and north-northeast wind directions were common as well, with about 14% and 13% respectably, and south and south-west followed them with 10% and 9%. Other wind direction were less frequent. Wind speed was mild during most of the season, with only one storm that came in from the south-southeast late in September. When the wind rose diagrams for the two seasons are compared a clear difference can be seen (fig. 3-101). The south-southwest wind direction completely dominated the winter season, while it was less frequent during the summer season where the north-east was the prevailing wind direction. The highest hourly average wind strength from the south-southwest was also greater during the winter season than the summer season, where the highest hourly during the winter time was 11,2 m/s while it was 10,4 m/s for the summer season. Although the highest hourly average during the summer season is close to that of the winter season, that average occurred during a storm late in September, and the highest hourly average when the storm is not taken into concideration was 8,1 m/s. The mean windspeed for the winter season was 4,16 m/s while the average for the summer season was 2,64 m/s. There was also a large difference in windstrength between the winter and summer season when the wind was blowing in from the north to the north-east. During the summer season, northerly winds were common but the windspeed was low, rarely exceeding 4-6 m/s and majority of the time the windspeed was below 4 m/s. In contrast northerly winds were more rare during the winter season, but when they occurred the wind speed was higher and the only time during the one year cycle where there was extensive erosion on all six profiles was during a storm that came in from the north to north-east.

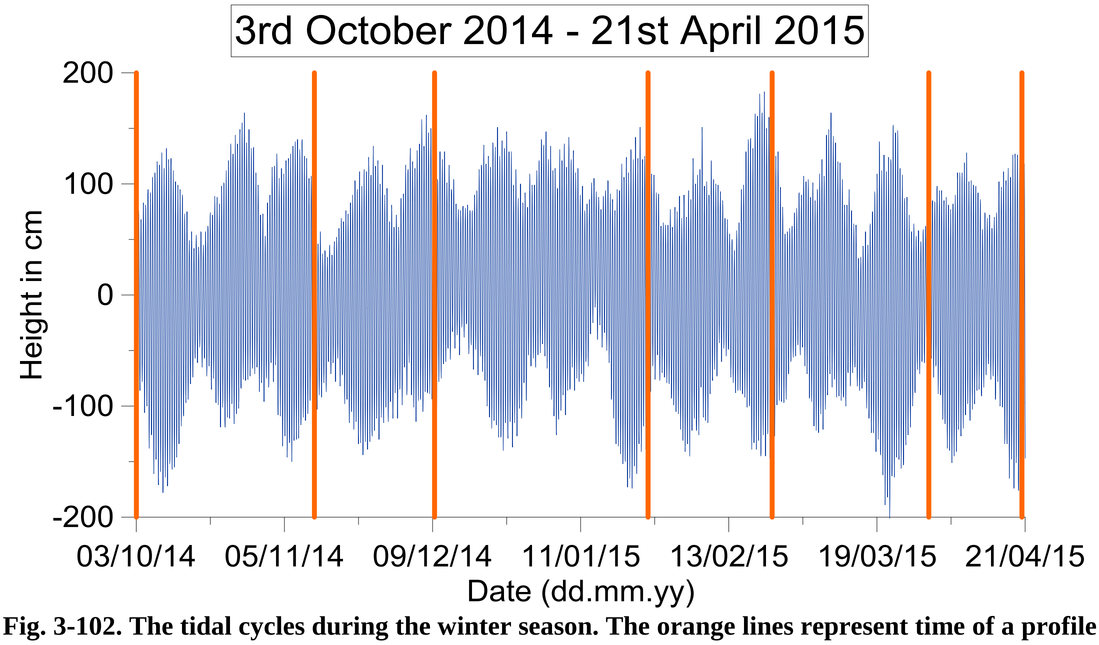

Fig. 3-102. The tidal cycles during the winter season. The orange lines represent time of a profile measurement during the season. Data from http://kartverket.no/sehavniva/.

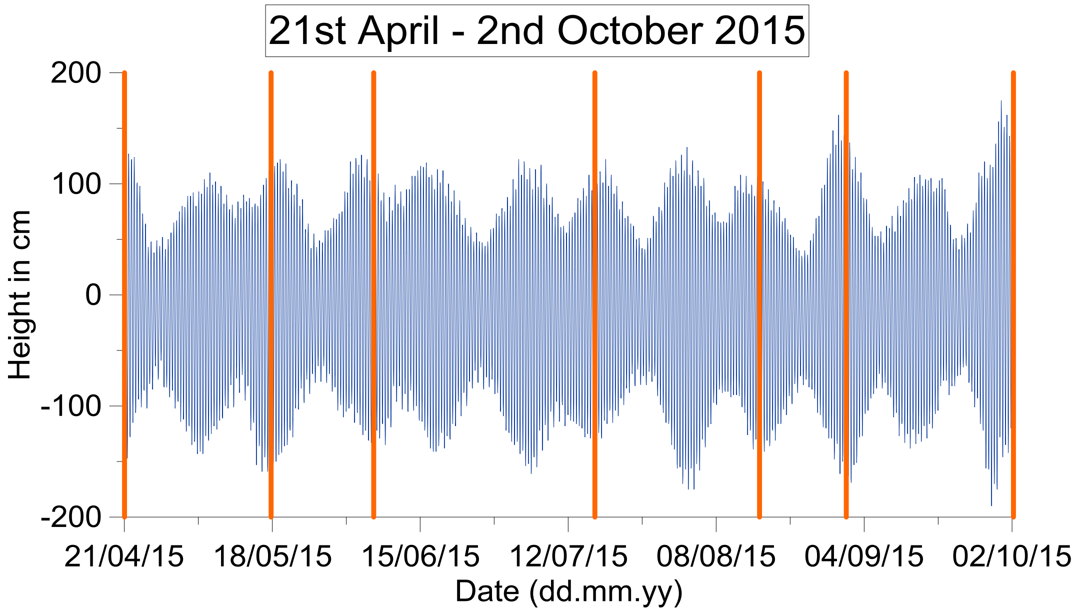

Fig. 3-103. The tidal cycles during the summer season. The orange lines represent time of a profile measurement during the season. Data from http://kartverket.no/sehavniva/.

When the tidal cycles of the two seasons are compared, they show a similar trend as the wind charts, but instead of increased wind speed during the winter season they show increase in tidal height. Each tidal cycle during the winter season (fig. 3-102) is more distorted, indicating outside forces acting on the tide and either increasing it or decreasing it, while the summer season tidal cycles (fig.3-103) are more regular, indicating less of outside forces acting upon it. The mean tide height was 1,3 cm above the NN during the winter season while it was at -11,5 cm below the NN during the summer season (Table 3). The mean high tide height was 100,67 cm during the winter season and the mean low tide height was -99,22 cm. The mean high tide height for the summer season was 87,66 cm and the mean low tide height was -111,65 cm. The difference in the tidal height during the seasons means that during the winter season, there is interaction between the beach and the sea at greater height and/or for longer duration than during the summer season. This allowes greater erosion and/or accretion to occurr and potentially influences the shape of the beach profile. However, when the mean profiles for each season are compared, there is no large scale differences between the height or width of the berm at Sandbukt Beach during the winter and the summer season. This lack of differences could either be due to decreased wave energy during the wintertime, due to prevailing south-southwest wind direction, or that the snow and ice cover that was present on the beach during most of the winter months prevents or decreases erosion and/or accretion on the berm crest and the berm itself. The role of snow and ice cover on the shape of the beach profile will be discussed further in chapter 5.1.

Table 3. Seasonal mean tide height (MTH), mean high tide height (MHTH) and mean low tide height (MLTH)

	MTH (cm)		MHTH (cm)		MLTH (cm)	
Season:	winter	summer	winter	summer	winter	summer
	1,30	-11,50	100,67	87,66	-99,22	-111,65

The small difference in the mean profiles between the two seasons suggest that, even though large changes have occurred at each profile during the two seasons, the beach is relatively stable with only minor erosion and accretion occuring and is quick to recover from any event. This can be seen best on fig. 3-100, where the alternating increase and decrease of the beach width is evident and no long periods of increased beach width are present at most of the profiles. The stability of the beach can be seen as well in the minimum and maximum height of the profile, where the difference is not great at any of the profiles during either of the seasons, apart from the effect the snow and ice cover had on the berm height and the erosion between October and November 2014. It seems that profiles A and B are not affected in the same manner as profiles C, D, E, and F, and that the profiles are more stable. That is likely due to both of the profiles being further to the north, and therefore partly barred by incoming waves from the north by Fjellenden mountain, and the presence of the sandbar outside of Profile A could cause the waves to break further outside in the shoreface, therefore decreasing the wave energy that the beach is exposed to in that area.

3.1.4 Annual beach profile change

During the one year cycle, from 3rd of October 2014 to 2nd of October 2015 (fig. 3-104 and 3-105) Sandbukt Beach grew in both volume and widht. The overall volume of material added to the beach was 9830 m3, with majority of the accreted material being deposited at Profile section A. Of the six profiles, only Profile E did not grow in width or volume where a small reduction of both the beach width and the profile section volume occurred. The year was marked by lack of storms from the north, where only one major erosional event occurred during a storm from the north in early November 2014. The

At profile A, the berm was eroded by 1,36 m3 but the beach face and the sand bar had accretion of 2,94 m3 and 13,78 m3 respectively, giving a net gain of 15,36 m3 for profile A. The volume of accretion was 5683 m3 for profile section A, or 58% of the total increase in volume during the year cycle. The accretion of the sand bar for the year cycle was calculated using the profile measured on the 12th of November 2015, as the sandbar was submerged during the measurement taken on the 3rd of October 2014 and could not be measured. During the one year cycle the beach width increased by 1,52 m, from 38,44 m in October 2014 to 39,96 m in October 2015, and the beach gradient decreased by 0,13°, from 3,28° to 3,15°.

At Profile B, the beach ridge, the berm, and the beach face had accretion of 0,6 m3, 0,38 m3, and 0,56 m3 respectively, while the low tide terrace had erosion of 0,13 m3, giving a net gain of 1,41 m3 for Profile B and a volume of 423 m3 for profile section B, or 4% of the total increase in the volume during the year cycle. During the one year cycle the beach width increased by 0,57 m, from 35,45 m in October 2014 to 36,02 m in October 2015, and the beach gradient decreased by 0,07°, from 4,83 to 4,76.

At profile C, the beach ridge, parts of the berm, and the beach face had accretion of 0,25 m3, 0,18 m3, and 4,03 m3 respectavly, while the berm and the mound on the berm had erosion of 0,71 m3 and 0,07 m3 repsectavly, giving a net accretion for Profile C of 3,68 m3 during the one year cycle. The volume of accretion was 1104 for profile section C, or 11% of the total increase in volume during the year cycle. During the one year cycle the beach width increased by 1,54 m, from 45,95 m in October 2014 to 47,95 m in October 2015, and the beach gradient decreased by 0,11°, from 3,44° to 3,33°.

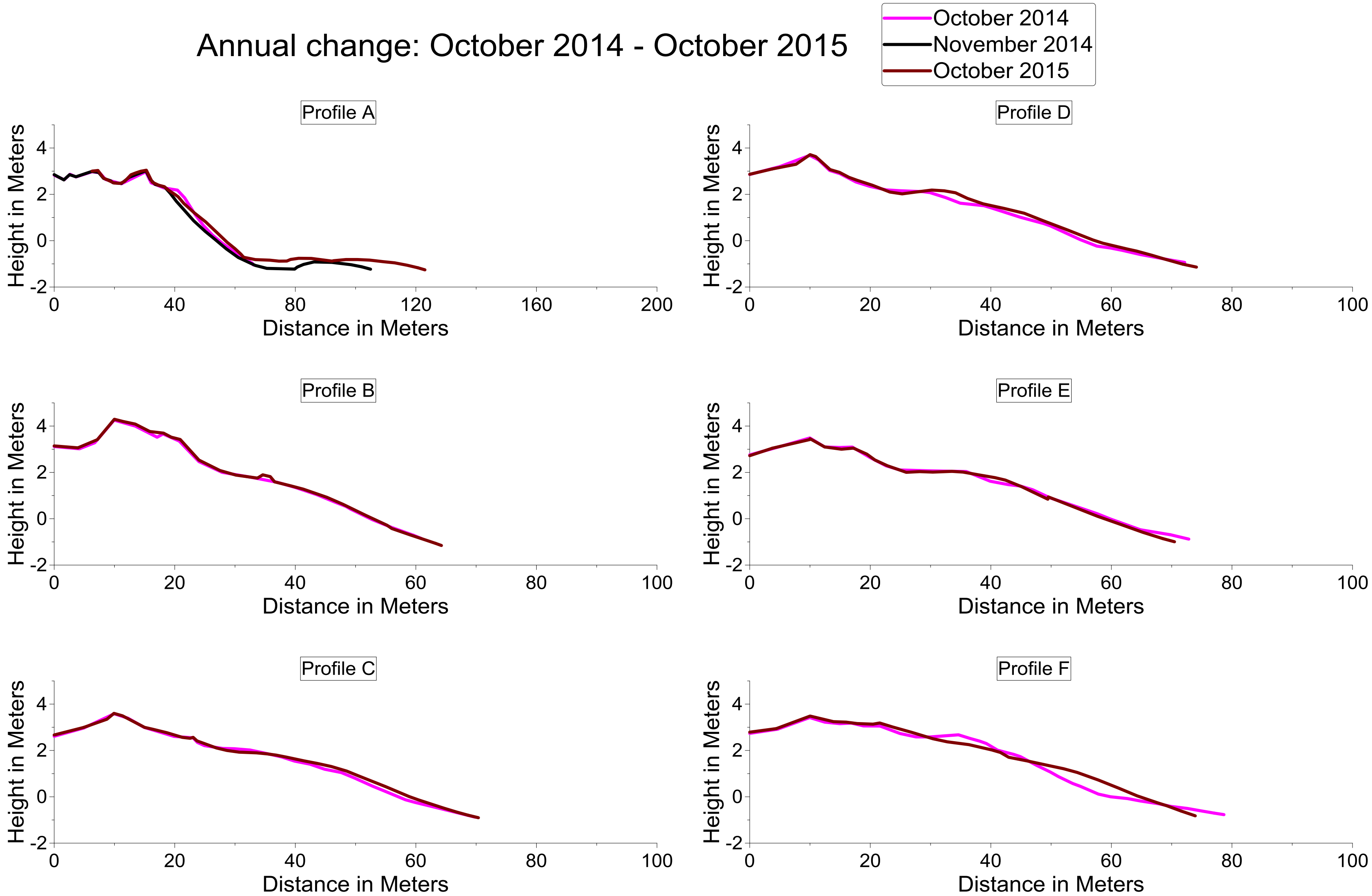

Fig. 3-104. Profile changes between October 2014 and October 2015. The profile line from November 2014 is used as well for Profile A in order to account for the changes on the low tide terrace and the sandbar.

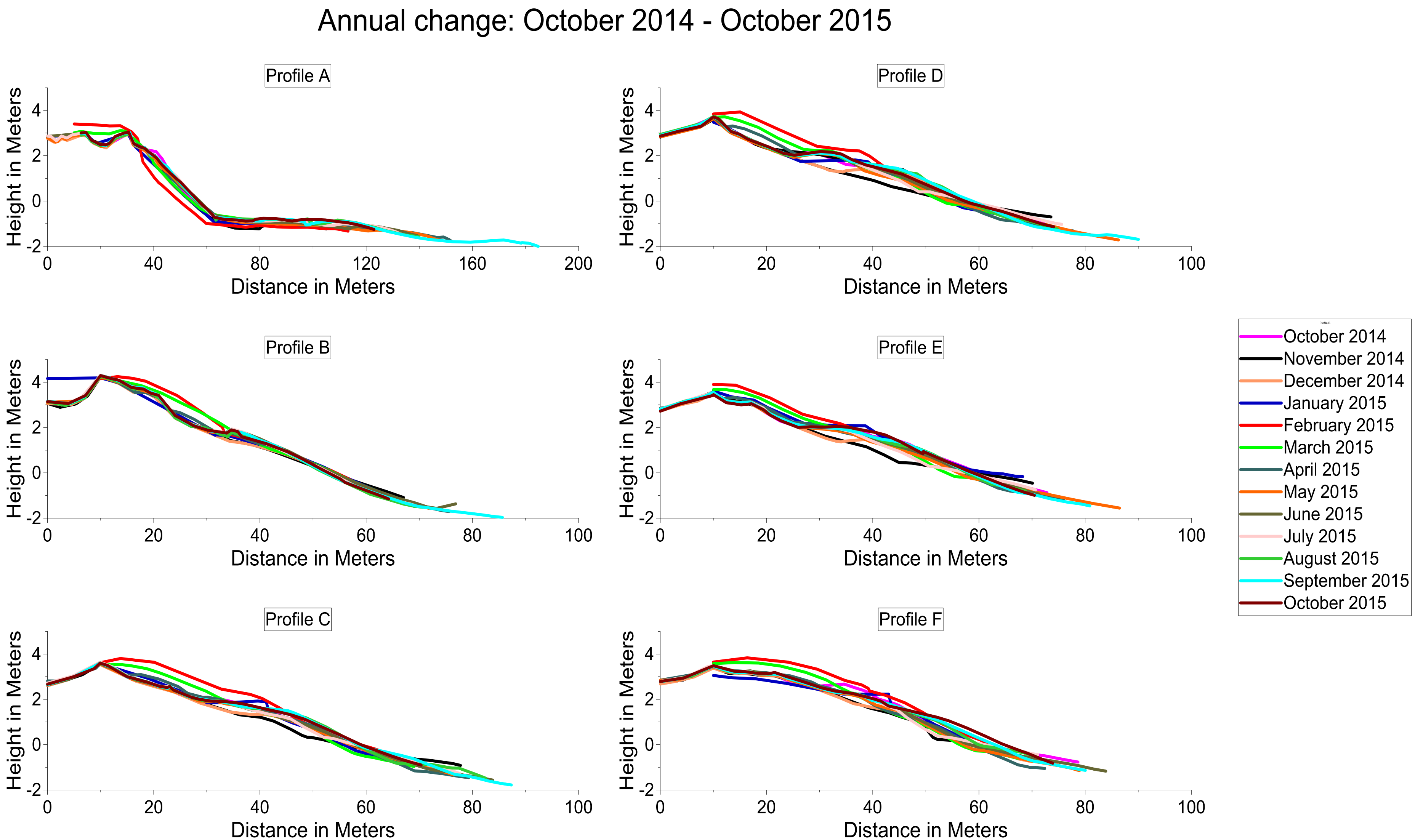

Fig. 3-105. Profiles from the one year cycle from October 2014 to October 2015. Thirteen profile lines were measured at each of the six profiles at Sandbukt beach during the cycle.

At Profile D, the beach ridge and the beach face experienced accretion of 0,37 m3 and 6,31 m3 respectively, and the berm and parts of the beach face had erosion of 0,47 m3 and 0,14 m3 respectively, giving a net gain of 6,07 m3 for profile D. The volume of accretion was 1821 m3 for profile section D, or 19% of the total increase in volume during the year cycle. During the one year cycle the beach width increased by 1,56 m, from 37,38 m in October 2014 to 38,94 m in October 2015, and the beach gradient decreased by 0,18°, from 4,35° to 4,17°.

At Profile E, the beach ridge, the berm, the beach face, and the low tide terrace had erosion of 0,05 m3, 0,23 m3, 0,93 m3, 1,46 m3 respectevly, while there was accretion of 1,18 m3 on the berm crest. The total net loss of material on the profile was therefore 0,03 m3. The volume of erosion was 7,5 m3 for profile section E, or 0% of the total increase in volume during the year cycle. During the one year cycle the beach width decreased by 1,08 m, from 40,56 m in October 2014 to 39,48 m in October 2015, and the beach gradient increased by 0,09°, from 3,74° to 3,83°.

At Profile F, the base of the beach ridge and the upper berm had accretion of 1,15 m3. There was an erosion of 2,8 m3 on the berm crest and the upper beach face, while the middle of the beach face had accretion of 7,21 m3 and the lower beach face had erosion of 1,08 m3. The total net gain of material on Profile F was therefore 4,48 m3, and the volume of material added on profile section F was 806,4 m3, or 8% of the total increase in volume during the year cycle. During the one year cycle the beach width increased by 5,12 m, from 41,53 m in October 2014 to 46,65 m in October 2015, and the beach gradient decreased by 0,39°, from 3,53° to 3,14°.

When the mean annual and the annual profiles from October 2014 and 2015 are compared (fig. 3-106) it can be seen that they are quite similar in terms of morphology. The variance between the three profiles increases on the southern part of the beach, especially on profiles E and F. The berm height on the mean annual profile lies higher in comparison to the two October profiles, and is due to the snow and ice cover that was present there during most of the winter season.

Profile A shows growth over the one year cycle, as the mean profile is higher than the October 2014, one part of the mean profile is however lower, and that is the berm. The berm never recovered from the erosion between October and November 2014, but had grown slightly by October 2015, and is higher ther than at the mean profile. The October 2015 profile is higher than the mean profile on the whole length of the profile, especially on the beach face and the sandbar. This corresponds with the increased beach width for the year and increase in volume of the beach face and the sandbar during the one year cycle. Profile B shows decrease of the height of the beach face during the one year cycle, as the mean profile is lower than the October 2014, but at some point the height increased again and has similar height in October 2015 as it had in 2014. The changes in the low tide terrace is exactly the oppsite, with elevation on the mean profile than the October profiles, indicating growth of the low tide terrace during the year but had been reduced once again by October 2015. Profile C shows no changes on the low tide terrace for the year, but both the October profiles have higher elevation on the berm crest and the beach face. This indicates similar trend as at Profile B, where the beach face is lower during lengthy periods of the year, but has similar height once again by October 2015. Profile D shows an annual growth over the whole profile, as the mean profile is equal or higher than the October 2014 profile but lower than the October 2015 profile. Profile E shows similar changes as Profile B, where the mean profile is lower than the two October profiles. The decrease in the profile height during the one year cycle had not fully receeded by October 2015, as the profile is lower than the one from 2014. Profile F shows decrease of the berm width and height, both on the mean profile and the October 2015, when compared to the October 2014 profile. That is due to the erosion of the berm between October and November 2014, and the berm hand not recovered by October 2015. The beach face had slow growth in height during better part of the year, as seen by the mean profile being only slightly higher than the October 2014 profile, but late in the year cycle the growth of the beach face increased and the beach face on the October 2015 profile is much higher than the mean profile. The low tide terrace was lowered during the year cycle, evident by the mean profile being lower than the October 2014 profile, but had regained its height by October 2015.

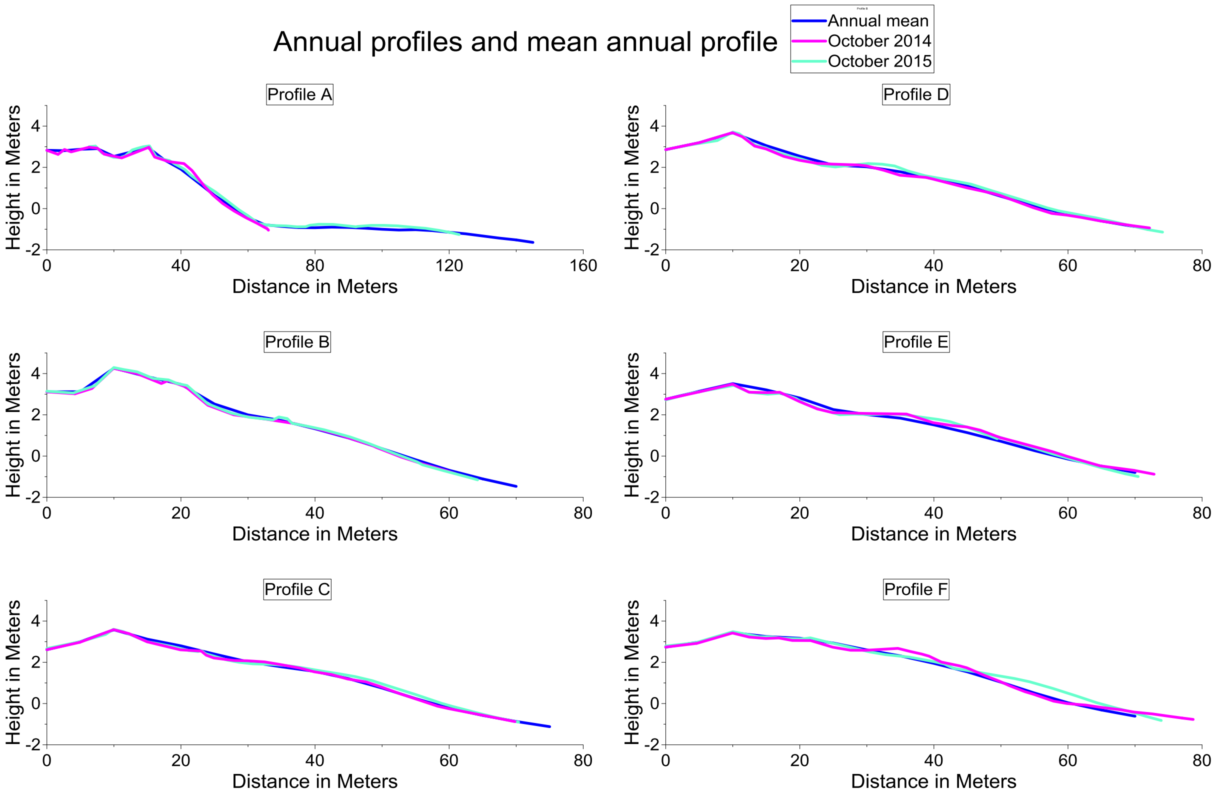

Fig. 3-106. The Mean annual profile compared to the annual profiles of October 2014 and 2015.

The prevailing wind direction during the one year cycle was south-southwest, with wind coming in from that direction for 30% of the time (fig. 3-107). There were seasonal differences in the prevailing wind direction, with the winter season having prevailing southern winds, while the summer season had prevailing northern winds. Despite the north-east direction being the prevailing wind direction during the summer months, wind from the south was more frequent during the year. The mean wind speed for the year cycle was 3,49 m/s. Storm frequency from the north was low during the year, with only one major storm and a few minor ones. If the storm frequency would have been higher, or if one of the minor storm had been a major storm, the changes in both the seasonal and annual beach profiles could have been greater. With prevailing wind direction from the south-southwest, the wave energy on the beach should have been at its minimum and no large changes should have occurred on the beach. This seems to be the case, as only once were there large erosional event on the beach, between October and November 2014, and that occurred during a northern storm. No other large northern storm occurred during the season, and even though the prevailing wind direction during the summer season was from the north-east, the wind speed was low. Furthermore, the beach width is mostly stable during the year cycle with only minor changes. Aeolian erosion of the seaward side of the beach ridge and the berm would also have been less beacause of the south-southwest prevailing wind direction, as the beach ridge decreases the wind speed on the berm when the wind comes in from that direction. The beach ridge is protected by thick vegetation cover on the landward side during the summer season and snow cover during the winter season. That could explain the complete lack of erosion on the landward side despite the prevailing wind direction of south-southwest and the multiple storms that occurred during the cycle from that direction.

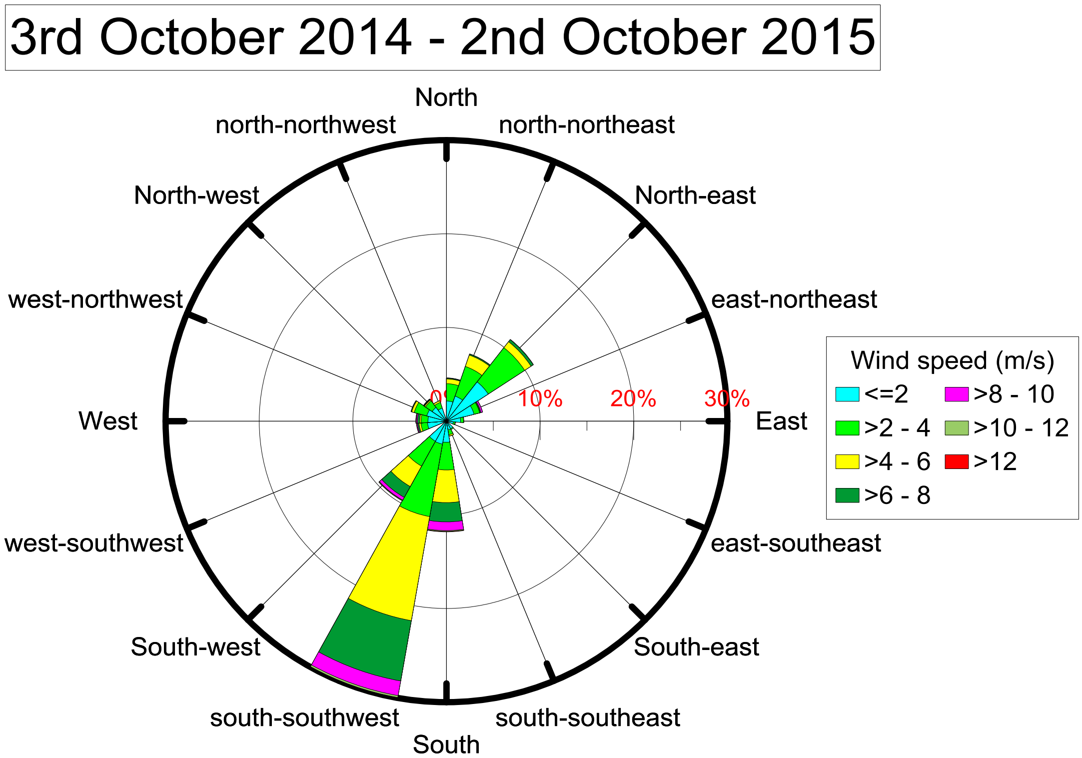

Fig. 3-107. Wind diagram for the one year cycle. South-southwest was the prevailing wind direction during the one year cycle. South, south-west, and north-east wind directions were common as well. Data from yr.no.

3.1.5 Shoreface profiles

Six profiles were measured with the Fishfinder echo device, in an extension from the six beach profiles at Sandbukt (fig. 3-108). The profiles were measured during a low tide, and have been corrected for the changes in the tidal height. The deviation of the echo-profiles compared to the beach profiles was significant, where the echo-profiles were on the western side of each beach profile and the line did not always stay true to the direction of the beach profile. The reasons for the deviations are that the profile markers on the beach were not visible, so the location of each profile was established with a GPS, and there were waves coming in from the north that pushed the boat to the south, and therefore the boat had to be steered into the waves. Although the deviation is great, the echo profiles show the topography of the foreshore close to each beach profile and the changes along the beach.

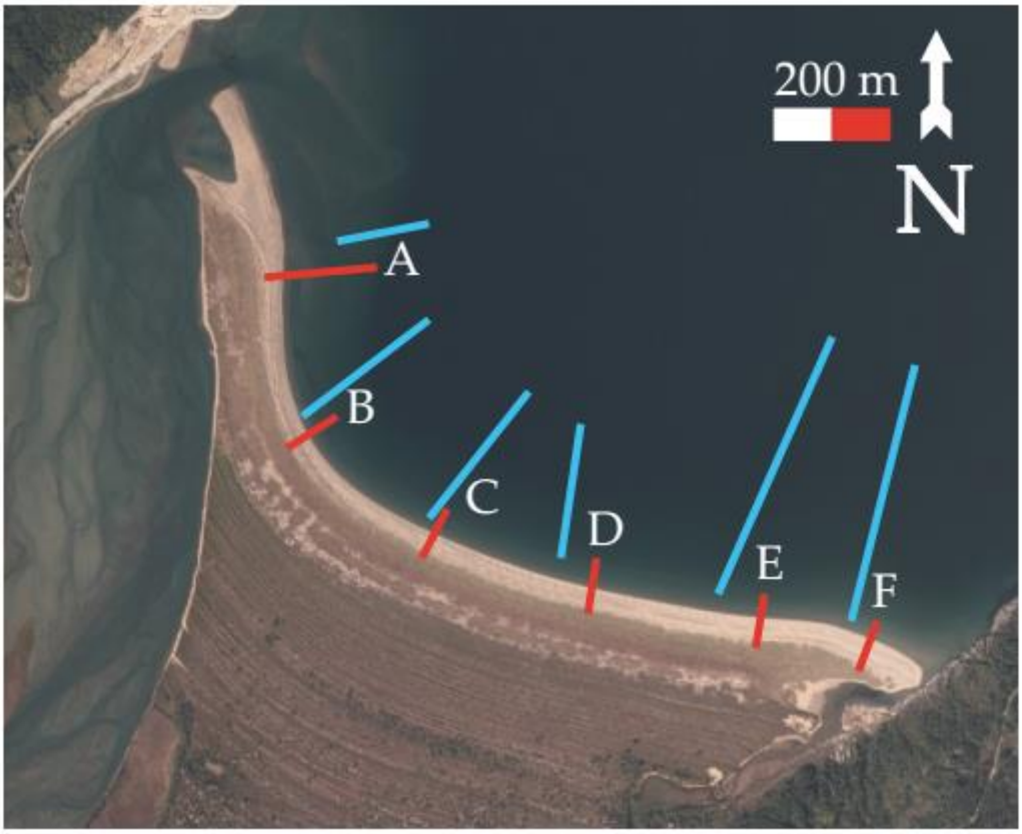

Fig. 3-108. The echo-profile lines in relation to the beach profile lines.

Profiles A, B, C, and D all show similar topography (fig. 3-109), with a gently sloping upper shoreface and a steep break in the slope that eventually becomes less steep on the lower shoreface. The break in the slope occurs at about 5 m depth at profiles B, C, and D, while it is at about 2,5 m depth at Profile A. The profile line at Profile A was just outside one of the low tide discharge channels of Breivika River. The profile is fairly flat, and does not show any signs of either erosion on the seafloor or of sandbars. At Profile E the upper shoreface has a similar gradient as the other four, but there is no distinct break in the slope on the lower shoreface, although the steepness increases at about 10 m depth, but rather a continuous increase in depth (fig. 3-109(. At Profile F the gradient remains similar throughout the profile with no distinct break, but it is possible that there is a break in the slope further out from the beach (fig. 3-109). None of the profiles had any indications that there were any longshore bars or troughs on the shoreface, but at the end of the profile line at profiles C and E there is a slight increase in the elevation of the seafloor that could represent a trough with a bar in front of it.

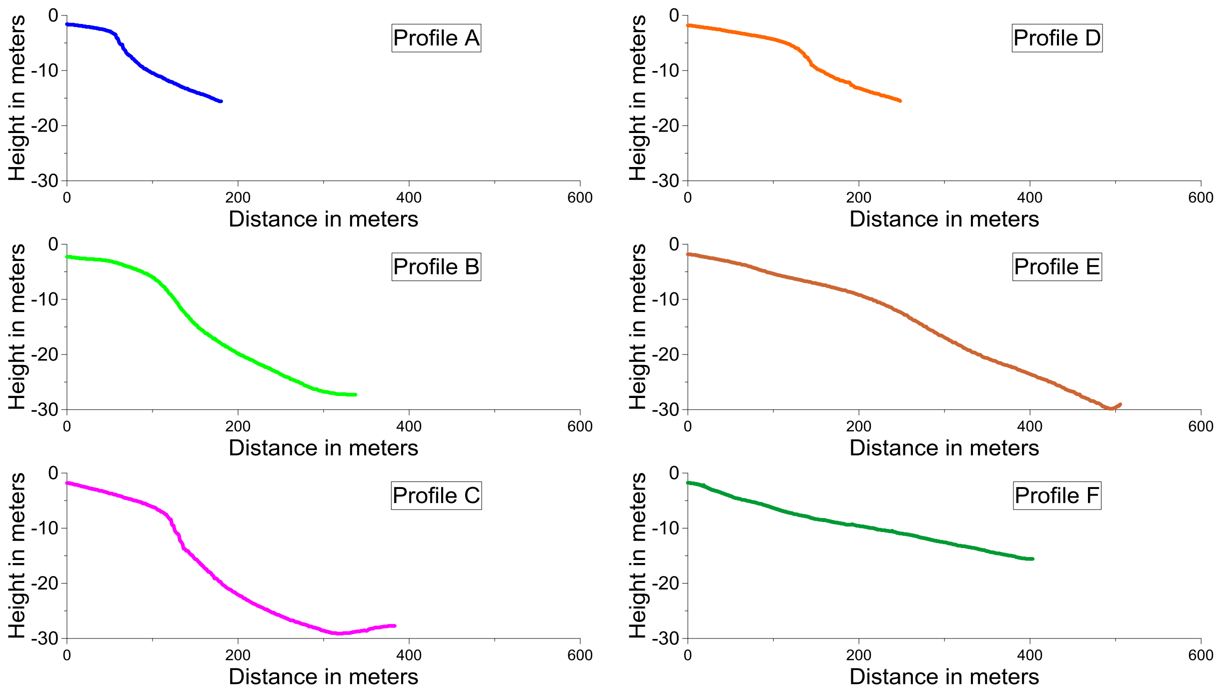

Fig. 3-109. The six echo-profiles at Sandbukt. Each profile is named after the beach profile they are extension of.

When the location of the 5, 10, 15, 20 and 25 m lines from each profile are compared (fig. xx), a shape similar to that of the beach emerges. On the northern part of the beach, the upper shoreface is fairly narrow and the depth increases greatly not far from the beach. In the middle, between profiles B and D, the upper shoreface remains narrow, but starts to get wider around Profile D. Around profiles E and F, the upper shoreface is much wider, with small to no break in the slope and is shallower further out in the lower shoreface. The steepness of the profiles on the northern side of the beach could indicate rapid accretion, due to proximity to the delta at the outlet of Breivika River, whereas the more gently sloping profiles on the southern side of the beach could indicate that the sediments there have been reworked to a higher degree than they have been on the northern side. This correlates with the beach profiles, as the northern profiles (A and B in particular) seem to be much less effected by waves than the other profiles, especially profiles E and F.

The amount of material brought on to the shoreface around Profile A, by Breivika River, should be considerable, and although the upper shoreface there is shallower than at the other profiles, there does not seem to be a buildup of material there that causes extension of the upper shoreface terrace and the break in the slope is at similar depth as at the other profiles.

The depth lines at profiles B and C are similar to that of Profile A, but between profiles C and D, the depth increase starts to become more gradual (fig. 3-110). This gradual depth increase continuous at profiles E and F, where there is little to no brake in the slope and the depth lines extend much further out than at the other profiles. This could be a seasonal form of the shoreface where material is accreted on the southern side of the beach due to dominating northern winds, and presumably waves, during the summer.

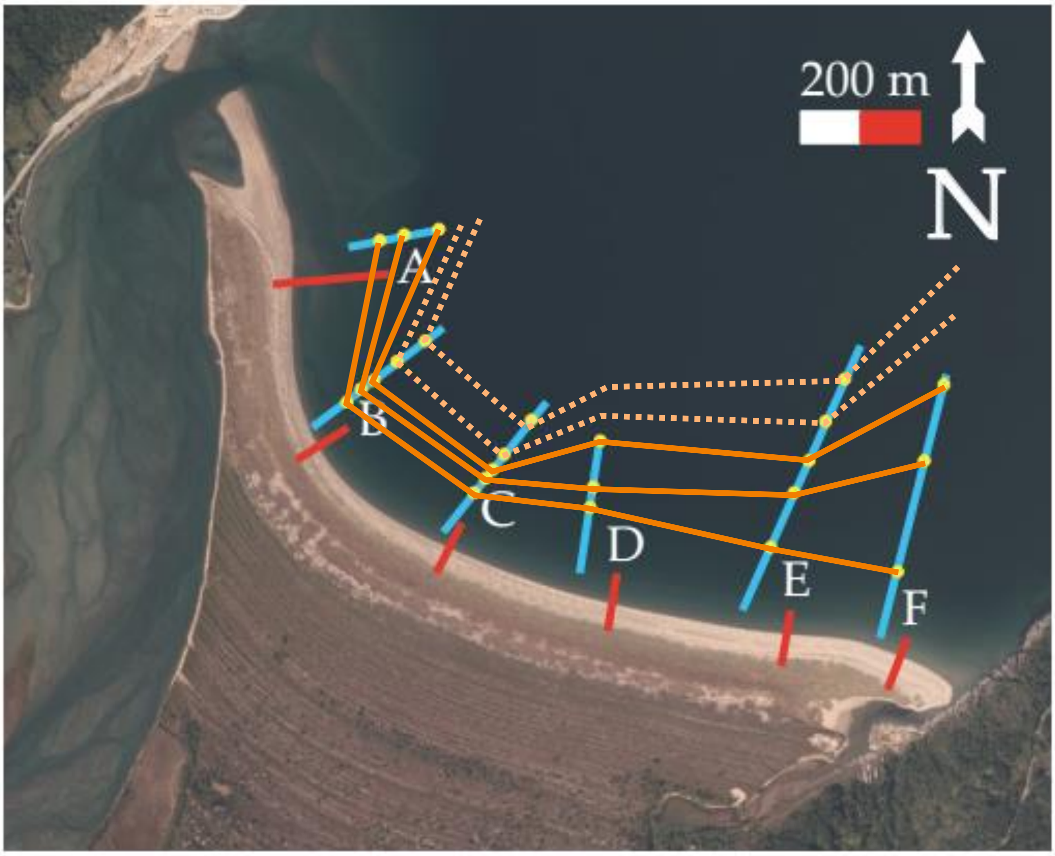

Fig. 3-110. The echo-profile lines in relation to the beach profile lines, with the 5, 10, 15, 20, and 25 meter depth marked with yellow circles. The borders of the depth lines (unbroken line) and possible depth line (broken line) are drawn, showing the topography of the shoreface. Modified from Norgeibilder.no

3.1.6 Profile response to storms

3.1.6.1 Storms with wind direction from the north to north-east

During the one year cycle, only three events occurred that could be called storms coming in from the north to the north-east, and two events that could be considered minor storms. The first storm hit Sandbukt beach on the 3rd of November and lasted until the night of November the 5th (fig. 3-111). This is the only one of the five events that had significant wind speed over extended period of time, and the only one that caused severe erosion of the beach. The other two storms where in January 2015 and the minor storms were in March and July. The November storm was chosen to examine the beach profile response to northerly storms due to it being the longest lasting storm, coinciding with high tides, and hitting Sandbukt Beach shortly before a monthly profile measurement.

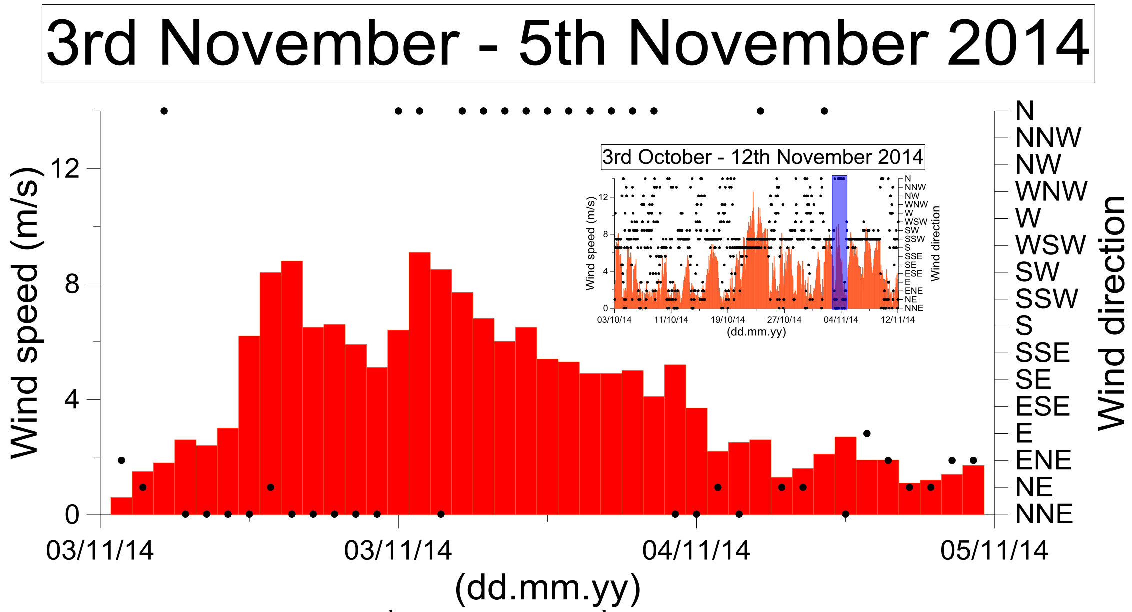

Fig. 3-111. Wind speed plot for 3rd of November to 5th of November 2014. The red columns are hourly averages of wind speed, measured at Tromsø observation station during the period, and the black dots represent the wind direction. The storm had two peaks in hourly average of wind speed, both on the 3rd of November and wind speed slowly decreased after the second peak. The storm started with a north-northeast wind direction but changed into north wind direction for the latter part of the storm. The hourly wind average for 3rd of October to 12th of November can be seen on the smaller image on the plot. The blue shaded are marks the northern storm during that period. Data from yr.no.

The storm lasted for about 41 hours, from 09.00 in the morning on the 3rd of November to about 01.00 on the night of November the 5th. The storm had two peaks, both of them during the evening of the 3rd and winds speed slowly decreased after that until the end of the storm. The wind started to blow from the east and the north-northeast and changed to northern wind direction later on the 3rd. On the night of the 4th the wind started to shift frequently between the northerly directions (fig. 3-111). The highest hourly average of wind speed was 9,1 m/s from the north at 22.00 on the 3rd, with the highest gusts reaching 17,1 m/s (yr.no). The most common wind direction during the storm was from the north, with wind coming from that direction for about 15 hours, or 37% of the storm duration (fig. 3-112). North-northeast direction followed closely with 14 hours, or 34%, but north-east, east-northeast, and east wind direction were less frequent.

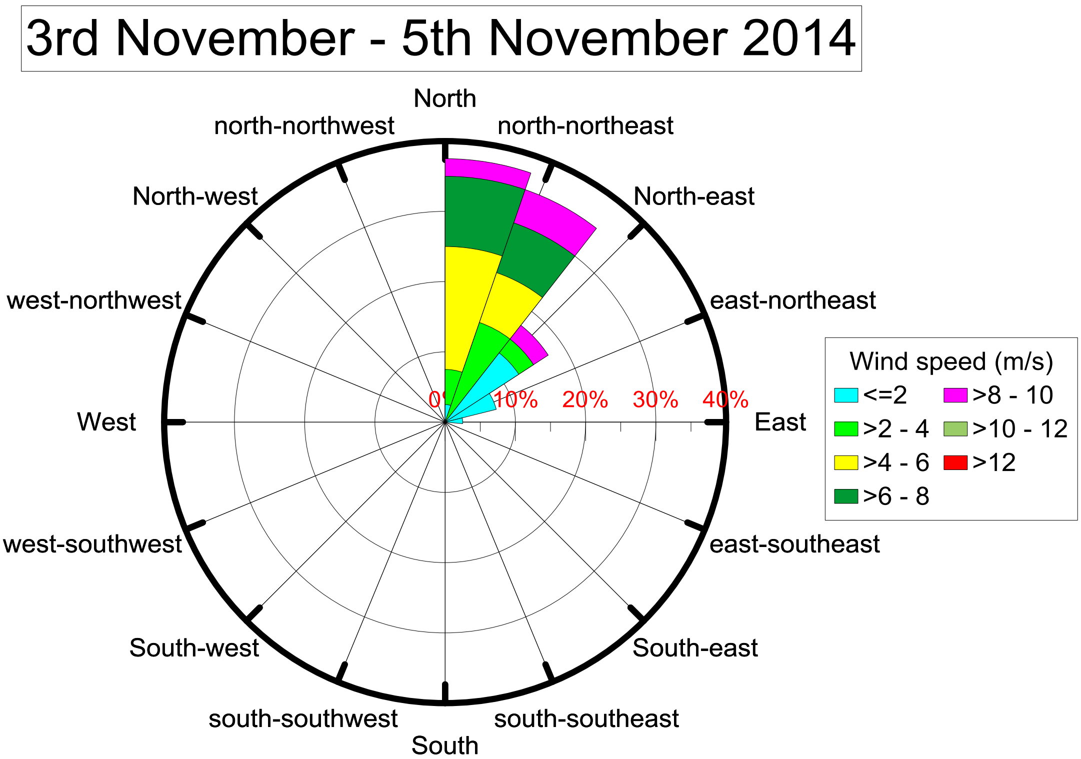

Fig. 3-112. Wind rose diagram for the storm period from 3rd to 5th of November. The prevailing wind direction was from the north, followed closely by north-northeast. The storm reached wind speed of 8-10 m/s, but calmer wind was more frequent. Data from yr.no.

At the time of the storm the tidal cycle was about half way between neap- and spring tide. During the storm there were three low tides and four high tides, with the four high tides being at 116 (1), 127 (2), 105 (3), and 114 (4) cm (fig. Xx) above the Norwegian vertical datum of 1954 (NN) and the three low tides at -63,-108, and -109 cm below the NN. In fig. 3-113 the height of the tides during the storm, marked by orange, can be seen in relation to tidal height before and after the storm. The storm had some effect on the predicted tidal hight for the period, increasing the height of the first two high tides and the first low tide. The high and low tides that came after the storm had reached its second peak were not affected (fig. 3-114). The first storm peak coincided with the first low tide, but the second storm peak occurred during the second high tide. The fact that the storm peak coincided with both a low and a high tide could have increased the erosion caused by the storm. As the tide moved from low tide to high tide, the storm waves would have been able to erode almost the whole beach face and during the high tide the waves would have reached further up the beach than if the peak had only occurred during a low tide.

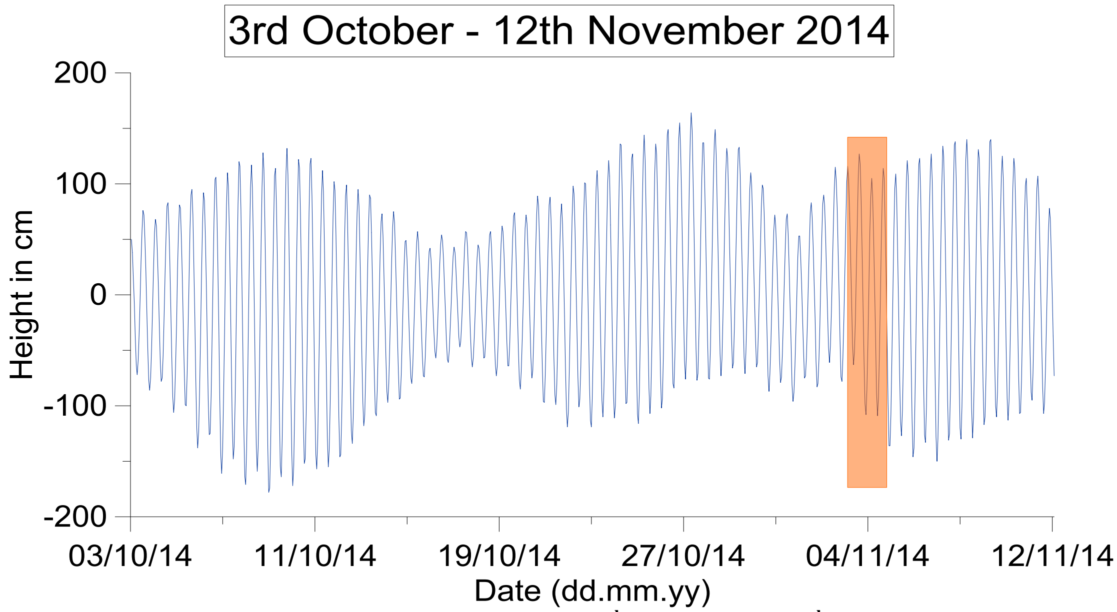

Fig. 3-113. Tidal diagram showing the tidal cycles from 3rd of October to 12th of November 2014. The area marked by orange is the storm duration, with three low tides and four high tides. Data from http://kartverket.no/sehavniva/.

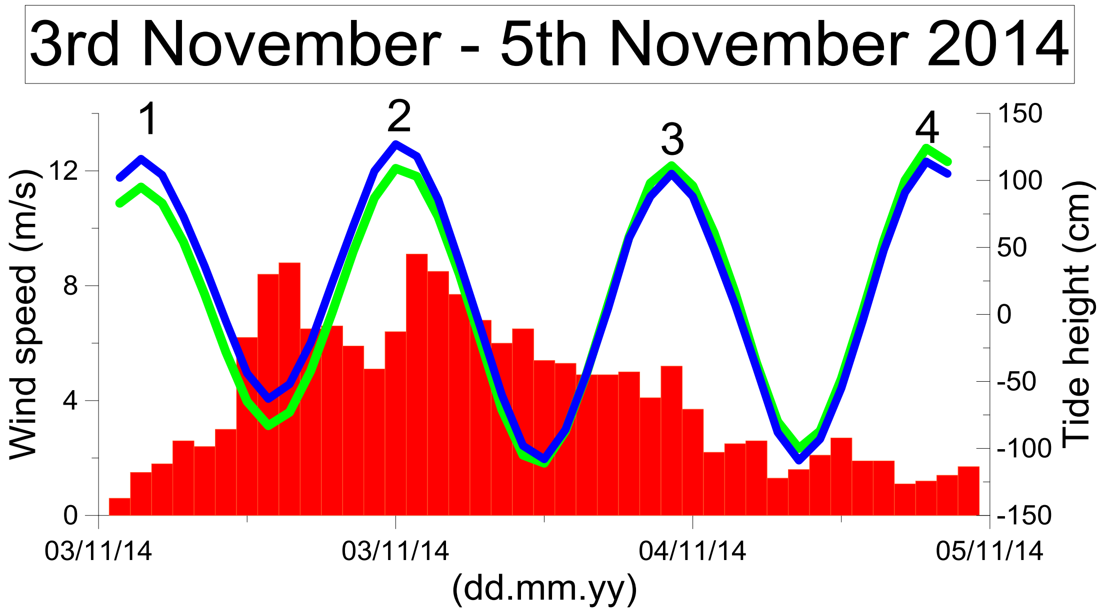

Fig. 3-114. Plot of hourly average wind speed marked by the red columns and the predicted (green line) and observed (blue line) tidal height during the storm. The storm had two peaks, with slightly stronger winds on the second peak than the first. The highest tide was the second high tide (marked „2“on the plot) and was 127 cm above NN. The second peak of the storm and the second high tide occurred at the same time. Data from yr.no and kartverket.no/sehavniva/.

Profile D was measured on the 3rd of November, at the beginning of the storm, but due to equipment problems, the rest of the profiles could not be measured. The profile on November the 3rd had a well-developed berm and a fairly steep beach face, and accretion had occurred on the beach face since October the 3rd (fig. 3-115). The beach width was 39,97 m and the slope was 4,07°. The profile on November the 12th had a gentle sloping beach face, with no major morphological features present on the profile, except for two rows of runnels and small bars below them. The beach width was 31,04 m and the slope was 5,23°. During the storm the berm was completely removed, as well as a large portion of the beach face. Total m^3 eroded of the profile during the storm was 16,97 m^3. The erosion caused the beach width to decrease by 8,93 m and the angle of the beach to increase by 1,16°.

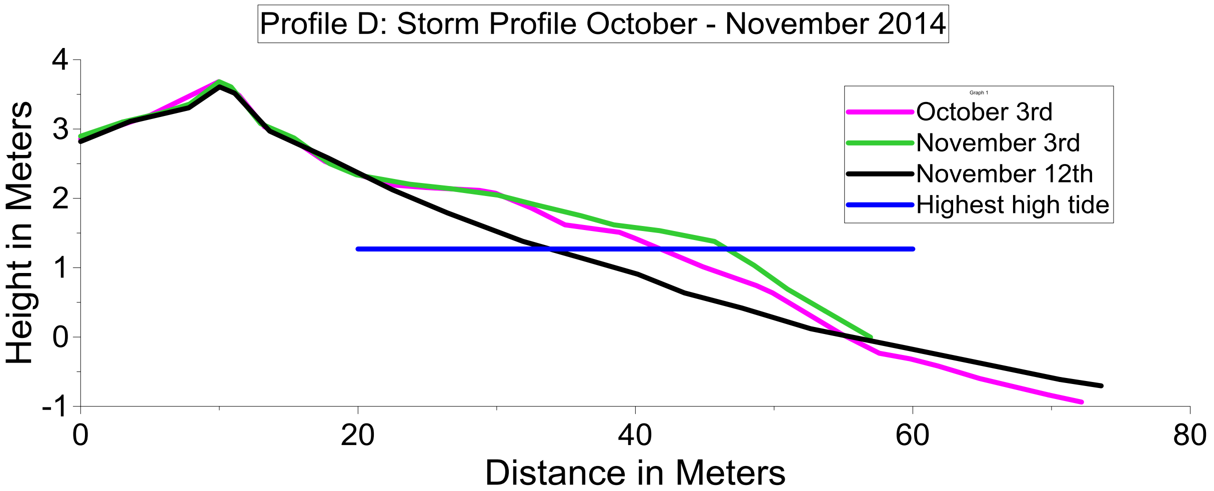

Fig. 3-115. Profile lines from 3rd and 12th of November 2014 at Profile D. The profile from November the 3rd was measured on the morning of the 3rd, at the start of the storm. The storm caused extensive erosion on the berm and the beach face and removed large amount of material from the beach at Profile D. The highest high tide during the storm was at 127 cm above NN on November the 3rd, and is marked by the blue line.

In order to examine the effect of the storm on the other five profiles, the profiles from October the 3rd have to be compared to the profiles from November the 12th, and since the profile measured at Profile D on the 3rd of November does not reach the low tide terrace, the comparison is useful for Profile D as well.

All five profiles experienced extensive erosion between 3rd of October to 12th of November (fig. 3-116) and show similar changes in their profiles as Profile D. The berm on all profiles was either heavily eroded or completely removed, the upper beach face eroded, and accretion occurred on the lower beach face and the low tide terrace. The beach width decreased at all profiles and the slope of the beach increased on all profiles as well. At Profile A the berm and the beach face were eroded, but a small berm remained in place. There was no measured accretion or erosion on the lower part of the profile since measurements in October did not reach to the sand bar. The erosion caused the beach width to decrease by 2,1 m, from 38,4 m to 36,4 m, the slope to increase by 0,17, from 3,28° to 3,45°, and 6,47 m^2 of material was removed from the profile. The total volume eroded from Section A was therefore 2393,9 m^3.

At Profile B a 3,57 m^3 area of the berm and the beach face was eroded, but a 1,85 m^3 accretion occurred on the lower beach face. The beach width decreased by 1,7 m, from 35,5 m to 33,8 m, the slope increased by 0,23, from 4,83° to 5,06°, and total of 1,72 m^3 of material was removed from the profile. The total volume removed from Section B was therefore 516 m3 At Profile C a 11,22 m^3 area of the berm and the beach face was eroded, eroding the berm away completely, but a 1,53 m^3 accretion occurred on the lower beach face. The beach width decreased by 4,9 m, from 45,9 m to 40,8 m, the slope increased by 0,44°, from 3,44° to 3,88°, and total of 9,69 m^3 of material was removed from the profile. The total volume removed from section C was therefore 2907 m3. At Profile D a 12,8 m^3 area of the berm crest and the beach face was eroded, but a 3,47 m^3 accretion occurred on the lower beach face. The beach width decreased by 6,4 m, from 37,4 m to 31 m, the slope increased by 0,88°, from 4,35° to 5,23°, and total of 11,27 m^3 of material was removed from the profile. The total volume removed from section D was therefore 3381 m^3. At Profile E a 16,89 m^3 area of the berm and the beach face was eroded, removing the berm completely, but accretion of 4,48 m3 occurred on the lower beach face. The beach width decreased by 8,9, from 40,6 m to 31,7 m, the slope increased by 1,04°, from 3,73° to 4,77°, and total of 12,41 m^3 of material was removed from the profile. The total volume removed from section E was therefore3102,5 m^3. At Profile F a 0,23 m^3 accretion occurred at the toe of the beach ridge and at the lower beach face, but a 12,12 m^3 erosion occurred at the berm and the beach face, removing the berm completely. The beach width decreased by 1,9 m, from 41,5 m to 39,6 m, the slope increased by 0,17°, from 3,53° to 3,7°, and total of 11,57 m^3 was removed from the profile. The total volume removed from section F was therefore 2082,6 m^3. The total volume removed from the beach during the period was about 14383 m^3, with total erosion of about 17075 m^3 and total accretion of about 3216 m^3. The total accretion was most likely more extensive in the foreshore, and if it had been possible to extend the measured profile lines further seaward on both 3rd of October and 12th of November, the total accretion would have been higher. The total volume eroded should also be higher, since it is likely that profiles A, B, C, E and F would also have had some accretion between October the 3rd and November the 3rd, as Profile D had (fig. 3-115)

The tidal height gives indication of the wave height and wave power that was present during the storm. The tide height was at 127 cm above NN, and was at about the half way mark of the eroded areas at each profile. Since erosion occurred on the beach at 1 – 2 m higher elevation than the tide (fig. 3-116), it means that the breaking waves would have had to be at least that high in order to be able to erode that part of the beach. Wave uprush could also have plaid a role in the erosion, and might have reached the base of the beach ridge at some locations.

It is clear that the most extensive erosion occurred at Profiles C, D, E, and F, while less erosion occurred at Profiles A and B. The volume for each section is misleading, as the width of the sections are not the same. The reason for the difference in the amount of erosion on the beach is likely linked to the angle of the beach in regards to the incoming wave angle. Profiles C, D, E, and F are on the part of the beach that are most exposed to waves coming in from the north to north-east, while the area around Profiles A and B is somewhat shielded from waves from that direction by the Fjellenden mountain and the shallow area with sandbars just outside Profile A. The Fjellenden mountain protrudes into Ullsfjord and prevents waves from the north to reach profiles A and B directly, and the sand bars at the outlet of Breivika River disperses the wave energy over wider area and the waves brake further away from the beach than at other locations on Sandbukt Beach.

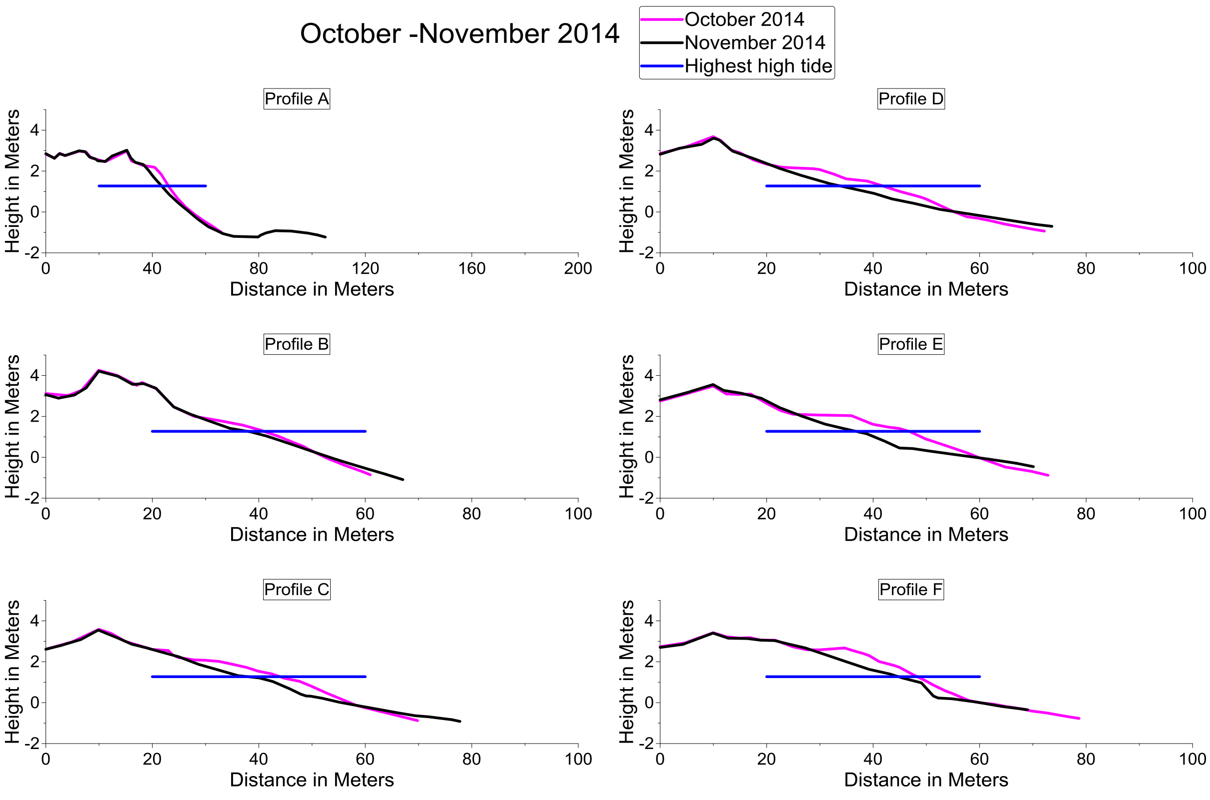

Fig. 3-116. The six profiles at Sandbukt, measured in October and November 2014. Erosion of the berm and the beach face occured during the period on all six profiles, and accretion on the lower beach face and the low tide terrace on all except profile A. The tide height of the highest tide is shown with a blue line, and was 127 cm above NN, on the 3rd of November.

Fig. 3-117. Photo from Profile F on the November 12th. Two rows of runnels and bars beneath them, the higher runnel is on the beach face and the lower one on the low tide terrace. A mixture of wave and current ripples can be seen in both of the runnels, and a rip channels cutting through the runnels.

Large parts of the beach were removed during the storm, and the morphology changed significantly. The beach and the beach face gradient had increased on all profiles, as the berm was removed or decreased in width. Other changes the storm had on the morphology of the beach was the creation of two rows of runnels that extended over large parts of the beach, and this was the only time during the one year cycle that the beach had two rows of runnels (fig. 3-117). Both the upper and lower runnel extended from the outlet of Filma River, south of Profile F, to about midway between Profiles C and B. There was no runnel present on Profiles B and A. The bottom of the runnels was covered with a mixture of wave and current ripples, and had sandbars on their seaward boundary that had been cut periodically by rip currents. This morphology was probably created during the onshore-offshore transport of sediments during the storm, which left a large volume of material on the lower part of the beach. A large beach step was also created during the storm, and had similar extent as the runnel, that is from the outlet of Filma River and to about half way in between Profiles C and B. The beach step was highest and steepest at Profile F, and decreased in height and steepness the further away it got from Profile F. Newly fallen snow covered large part of the beach, extending down to the lower part of the beach face, during the measurement on November the 12th. The snow cover obscured smaller morphological features on the beach.

The other two northern storms occurred in January 2015. The first one was from the 16th to the 17th, where winds from the north-east and east-northeast reached 8 m/s for extended periods of time. The tidal cycle was at neap tide and the height of the tide during the storm did not reach great height on the beach. Profile measurements taken on the 26th of January revealed only small erosion of the beach face (see chapter 3.1.2) but due to the amount of time between the measurements of December 9th and 26th of January, it is not clear whether the erosion was caused by the storm. It is likely however that that is the case, since the prevailing wind direction during the period was from the south-southwest, and strong winds from the north only occurred during the storm.

The second storm was from the 28th to 29th of January, where wind speed reached 10 $^{m/s}$ from the east and east-northeast, with east-northeast being the dominant direction. The tidal cycle was midway between a spring and a neap tide and the height of the tide during the storm reached high up on the beach face. Profile measurements taken on the 23rd of February showed small accretion on the profiles since January (see chapter 3.1.2) and there are no indications that the storm had large effects on the profiles. The storm could however have caused some erosion but the profiles had recovered by the 23rd, since over three weeks went by in between the storm and the profile measurements.

The two minor storms were on the March 20th and 7th of July. In March the highest wind speed during the storm was 12,2 $^{m/s}$ from the north-west, but the storm only lasted for about 4 hours. The tidal cycle was at spring tide and the height of the tide reached the middle of the beach face. Profile measurements taken on the 31st of May (see chapter 3.1.2) showed erosion on the on the lower part of the beach face, and a runnel had formed in the depression caused by the erosion. Profile A and B were however not affected.

In July the highest wind speed during the storm was 7,3 $^{m/s}$ from the north-east, but lasted much longer than the one in March, or about 23 hours. The tidal cycle was half way between spring tide and neap tide, and the peak of the storm occurred during rising tide. Profile measurements taken on the 17th of July (see chapter 3.1.2) showed erosion on the upper part of the beach face, and a runnel had formed in the depression caused by the erosion. Similar to the minor storm in March, profiles A and B were not affected.

Extensive erosion on the beach face and the formation of a runnel there only occurred three times during the one year cycle. In all three cases, a storm or a minor storm had hit the beach in the days leading up to the measurements. The reason for why the other two storms did not have the same effect on the beach profile is unknown, but a combination of tide height and wind direction during the storm and storm duration might be the cause. There is possibly another factor that influenced the erosion of the two storms in January, and that is the snow and ice cover of the berm and the berm crest, a factor which will be discussed in chapter 5.1.

3.1.6.2 Storms with wind direction from the south to south-west

Storms from the south-southwest and the south were much more frequent during the one year cycle than storms from the north. Most of the storms occurred during the winter months from 2014 – 2015 and one occurred in late September in 2015. The storm in September 2015 was chosen to examine the beach profile response to southerly storms due to it being a severe storm, occurring at neap spring tide, and hitting Sandbukt Beach only a few days before a monthly profile measurement was made.

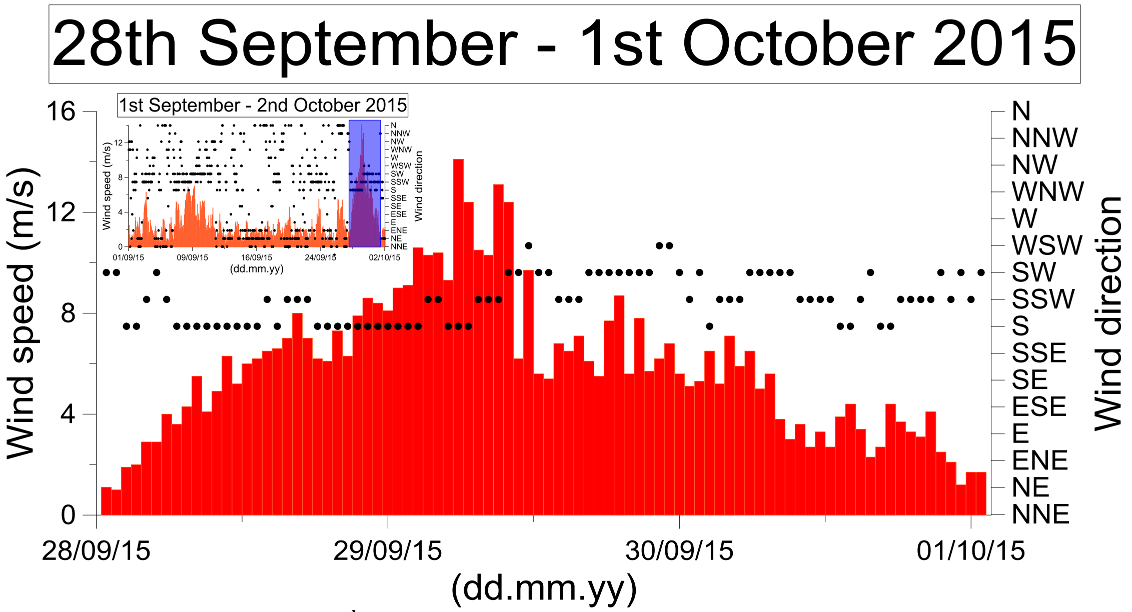

Fig. 3-118. Wind speed plot for 28th of September to 1st of October 2015. The red columns are hourly averages of wind speed, measured at Tromsø observation station during the period, and the black dots represent the wind direction. The storm had two peaks in hourly average of wind speed, both on the 3rd of November and wind speed slowly decreased after the second peak. The storm started with a north-northeast wind direction but changed into north wind direction for the latter part of the storm. The hourly wind average for 3rd of October to 12th of November can be seen on the smaller image on the plot. The blue shaded are marks the northern storm during that period. Data from yr.no and http://kartverket.no/sehavniva/.

The storm lasted for about 88 hours, from 03.00 in the night on the 28th of October to about 18.00 in the evening on the 1st of October in 2015. The storm gradually increased and reached its peak in the afternoon on the 29th of September. The storm started with a south wind direction, but during the peak the wind direction was south-southwest. The average wind speed during the peak was 14,1 m/s, and the highest gusts were 21,9 m/s (fig. 3-118). The storm gradually decreased once the peak had been reached and changed wind direction to south-west and south-southwest, with wind slowing down to less than 8 m/s shortly thereafter. The most common wind direction during the storm was from the south, with wind coming from that direction for about 31 hours, or 35% of the storm duration (fig. 3-119). South-southwest and south-west followed closely with 29 and 25 hours each, or 33% and 28%., and west-southwest for 3 hours, or 3%.

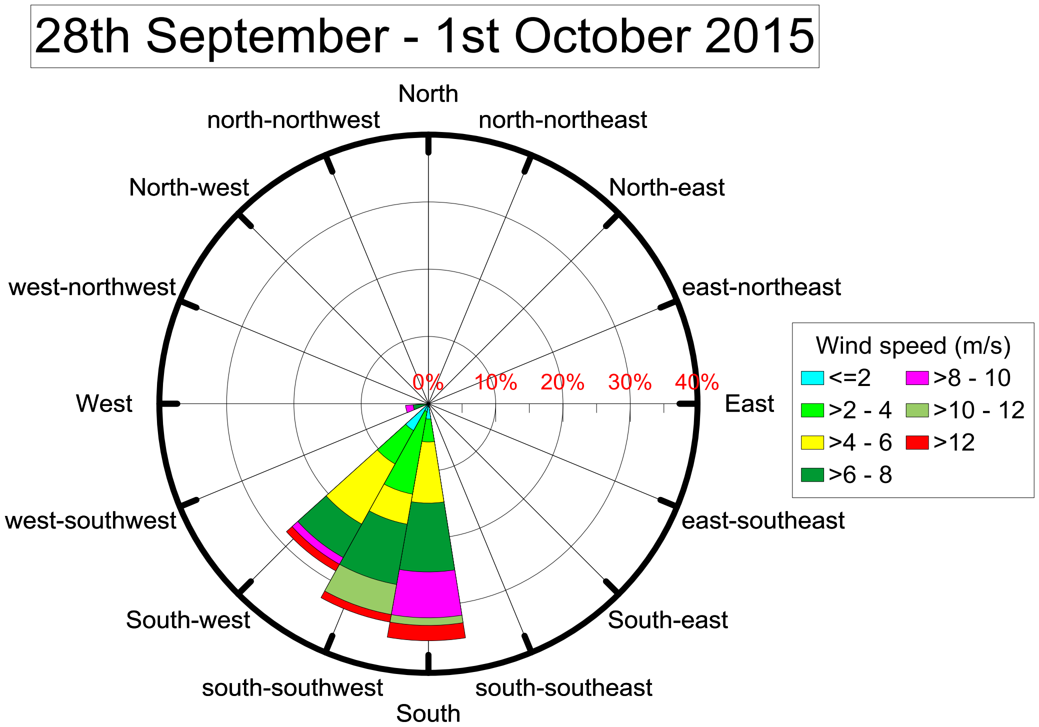

Fig. 3-119. Wind rose diagram for the storm period from 28th of September to 1st of October. The prevailing wind direction was from the south, followed closely by south-southwest. The storm reached wind speed of more than 12 m/s, but the most common wind speed was 4-8 m/s. Data from yr.no.

At the time of the storm the tidal cycle was reaching spring tide. During the storm there were seven low tides and eight high tides. The high tides were 84 (1), 115 (2), 136 (3), 156 (4), 163 (5), 151 (6), 162 (7), and 143 (8) cm above the NN (fig. 3-120). The seven low tides heights were -190, -170, -175, -128, -146, -135, -142 below the NN. In fig. 3-121 the height of the tides during the storm, marked by orange, can be seen in relation to tidal height before and after the storm. The storm does not seem to have had large effects on the tidal height, increasing it slightly before the peak of the storm, and decreasing the height of the low tides after the peak. The peak of the storm occurred between two low tides, with a high tide at 156 cm above NN in between. The whole of the beach face was therefore exposed for some time during the storm, as well as the berm crest.

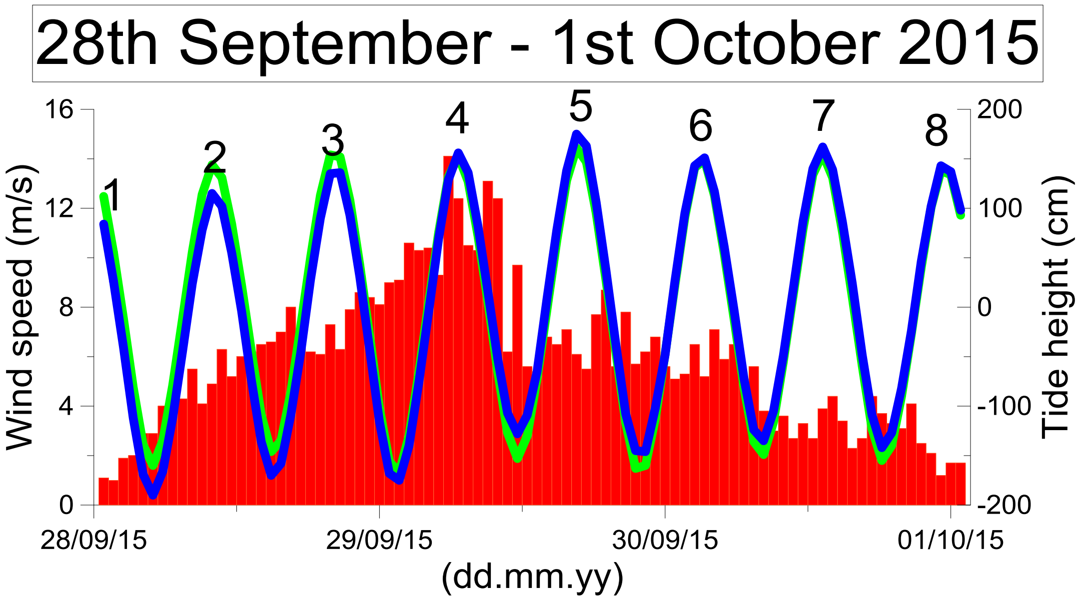

Fig. 3-120. Plot of hourly average wind speed marked by the red columns, and the predicted (green line) and observed (blue line) tidal height, during the storm. The storm reached its peak on the 29th of September. The highest tide was the fifth high tide (marked „5“on the plot) and was 163 cm above NN. The peak of the storm and the fourth high tide, with height of 156 cm above NN, occurred at the same time. Data from yr.no and http://kartverket.no/sehavniva/.

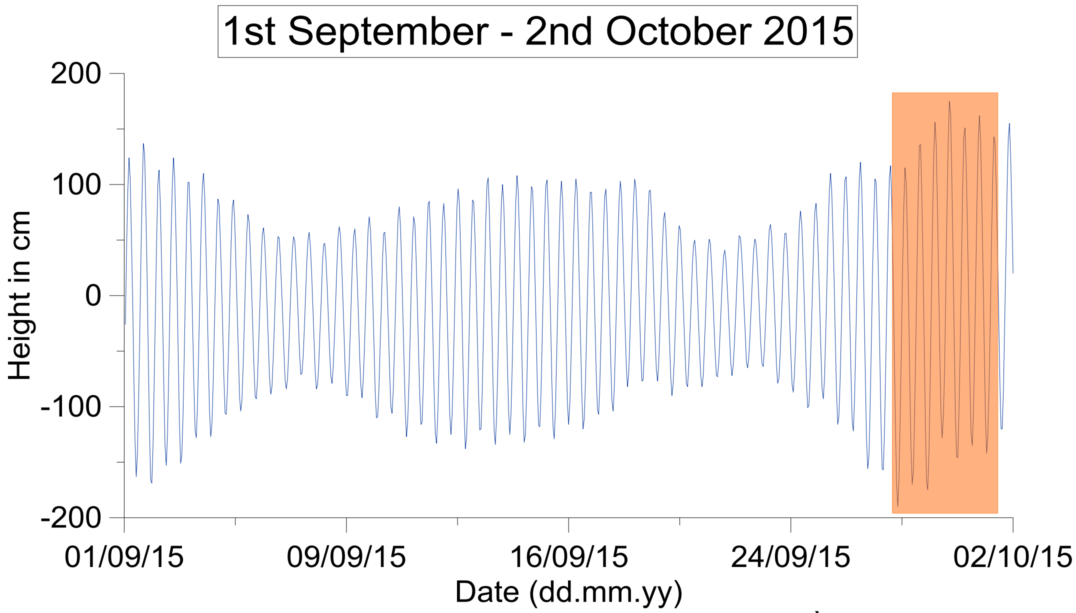

Fig. 3-121. Tidal diagram showing the tidal cycles from 1st of September to 2nd of October 2015. The area marked by orange is the storm duration, with seven low tides and eight high tides. Data from http://kartverket.no/sehavniva/.

In order to examine the effect of the storm, the profiles measured on the 2nd of October and on September the 1st are compared (fig. 3-122). Only minor morphological changes occurred on the beach between those two measurements and the profile response differs between each profile. At Profile A a minor erosion occurred on the upper part of the beach face, of 0,32 m^3, and a minor accretion, of 0,31 m^3, at the middle of the beach face. The sand bar had accretion and erosion as well, with accretion of 1,58 m^3 on the beach facing side of the sandbar and erosion of 0,82 m^3 on the seaward side of the bar. Most of both the accretion and the erosion are likely due to movement of the sandbar closer to the beach face. The beach width increased by 26 cm, from 39,7 m to 39,96 m and the beach gradient decreased by 0,02°, from 3,17° to 3,15°. The total accretion on the profile from September to October on the profile was 0,75 m^3 with 277,5 m^3 of material added on profile section A. At Profile B there was a erosion of 0,59 m^3 on the berm crest and accretion of 0,45 m^3 in the middle of the beach face. Due to the accretion on the beach face, the width of the beach increased by 32 cm, from 35,7 m to 36,02 m, and the gradient decreased by 0,04°, from 4,80° to 4,76°. The total erosion on the profile during the period was 0,13 m^3 with 39 m^3 of material eroded from profile section B. At Profile C there was accretion of 0,07 m^3 on the berm, while erosion of 0,58 m^3 and 1,1 m^3 occurred on the berm crest and the lower beach face. The beach width decreased by 30 cm, from 47,79 m to 47,49 m, and the gradient increased by 0,02°, from 3,31° to 3,33°. The total erosion on the profile during the period was 1,61 m^3 with 483 m^3 of material eroded from profile section C. At Profile D there was erosion of 3,35 m^3 on the upper part of the beach face, while there was accretion of 1,54 m^3 on the lower beach face. The beach width decreased by 1,79, from 40,37 m to 38,94, and the gradient increased by 0,18°, from 3,99° to 4,17°. The total erosion from the profile during the period was 1,81 m^3 with 543 m^3 eroded from profile section D. At Profile E there was erosion of 0,33 m^3 on the beach ridge, 0,37 m^3 on the base of the beach ridge, and 0,19 m^3 on the middle of the beach face. The erosion on the beach ridge and the base of the beach ridge was likely caused by aeolian processes, rather than waves, as there were no indications at Profile E on 2nd of October that waves had reached so far up the beach. There was accretion of 1,92 m^3 on the berm crest and 0,92 m^3 on the lower beach face. The beach width decreased by 1,34 m, from 40,82 m to 39,48 m, and the beach gradient increased by 0,12°, from 3,71° to 3,83°. The total accretion on the profile during the period was 1,95 m^3 with 487,5 m^3 of material added to profile section E. At Profile F there was accretion of 0,15 m^3 on the berm crest and 4,41 m^3 on the beach face. There was erosion of 0,15 m^3 on the berm crest, just below where the accretion had occurred. The beach width increased by 2 m, from 44,7 m to 46,7 m, and the beach gradient decreased by 0,14°, from 3,28° to 3,14°. The total amount of accretion during the period was 4,41 m^3 with 793,8 m3 of material added to profile section F.

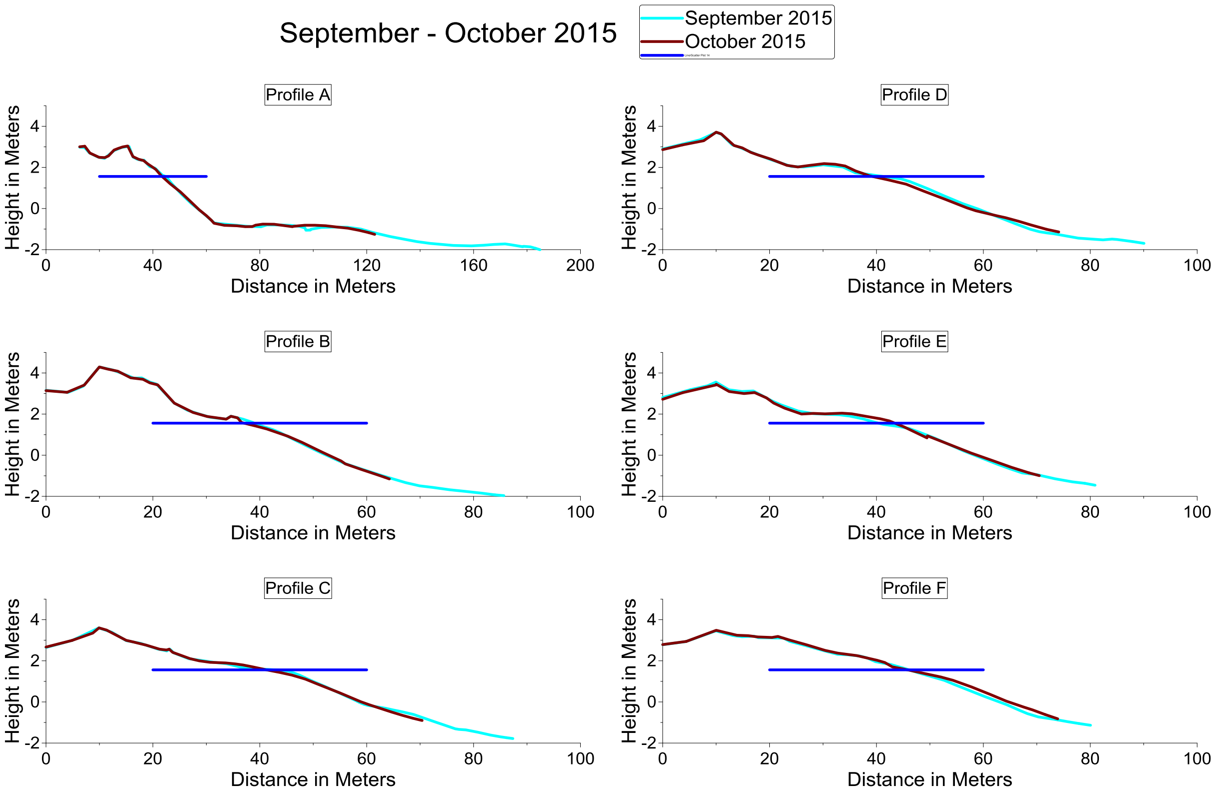

Fig. 3-122. The six profiles at Sandbukt, measured in September and October 2015. The tide height of the high tide during the peak of the storm is shown with a blue line. The tide was 156 cm above NN, on the 29th of September.

The storm did not have any large scale effect on the beach morphology, since neither large scale erosion nor accretion occurred at any of the profiles. There was a row of well-formed beach cusps during the measurements on 1st of September, and a second row had formed in the day following. The two rows extended from Profile F to about half way between profiles B and A. Both of the rows had erosional scarps on the horn, which had not been on the beach cusp row on the 1st of September. These two rows were still present on the beach on 25th of September, but on 2nd of October only one row was present. This row is likely to be the same row as was present at early September, as the tide height were similar at the beginning and the end of September, with a lower spring tide in between. The row had some erosional scarps as well, but only on cusps at profiles F to D. One unique development occurred at the beach, as two small beach cusps were on the beach just north of Profile A. This was the only time during the year cycle that beach cusps were present in that area.

As mentioned before, the storm did not have the same effect on all the profiles. This is best seen by that there was net erosion on profiles B, C, and D, while there was a net accretion on the other three. There was a total of 2453 m^3 of material removed from the beach between September the 1st and October the 2nd and total of 2848 m^3 of material added onto the beach, giving a net total accretion of 395 m^3 during the period. Due to the amount of time that passed between the two profile measurements in September and October, it is hard to tell if the storm is responsible for the erosion that occurred between the months. Weather was fair during the period, with no high wind speeds coming in from the north (see chapter 4.1.2). The profile changes in the period are similar to the changes that occurred on the beach in the months before, with small scale accretion and erosion over different parts of the beach. There is however one indication that the storm caused movement of sediments and that is the location of the erosion and accretion on the profiles in regard to the tide height during the peak of the storm (fig. 3-122). All areas that had accretion or erosion above the tide height were 0,5 m or less above the tide height and in, or just above, the swash zone during the high tide. This indicates that the wave height during the storm was not high, and since profiles C, D, E, and F all had accretion above the tide height and erosion below it, it seems that the wave energy was low and waves rather pushed material up the beach instead of eroding the berm crest and transporting it offshore. The only clear erosional impact of the storm is at Profile E, where small parts of the beach ridge were eroded away.

When comparing the effects of the two storms from the north and south, it is clear that the storm from the north had a much larger influence on the beach morphology. This is demonstrated further by the lack of large erosional events during the one year cycle, despite the frequent storms from the south. It seems therefore clear that storms coming in from the south have only a minor impact on the overall morphology at Sandbukt Beach. The low number of storms from the north during the one year cycle make it more difficult to fully study the storm impact on the beach due to lack of comparison, but there are indications that extensive erosion of the beach face will occur, followed by the formation of a runnel in the erosional scar. If the effect of the storm in November 2014 is compared to the effects of the two storms that occurred on the 7th and the 15th of October 1993 (Møller, 1995), a similar pattern can be observed. The two storms came in from the north and hit Sandbukt Beach in the days around spring tide. Prior to the storm in 1993, the beach profile was similar to that of Profile D was before the storm on November the 4rd 2014 (Fig. 3-123). The beach was well developed, wide with low gradient and a large berm. The storms caused erosion on large portion of the upper beach, removing most major morphological features. The berm was completely removed and deposition of material occurred on the lower beach face and the low tide terrace. The total amount of material removed from the observed profile was 12 m^3 during the first storm, and 5 m^3 in the second (Møller, 1995), combining for 17 m^3 compared to 16,97 m^3 in 2014. The storms in 1995 and 2014 had therefore almost identical effects on the beach, as the profiles display similar erosional patterns and almost the same amount of material was removed. One clear distinction can be made though, and that is that during the storm in 1993, the beach ridge at the profile was overtopped by waves, something that did not occur during the storm in 2014.

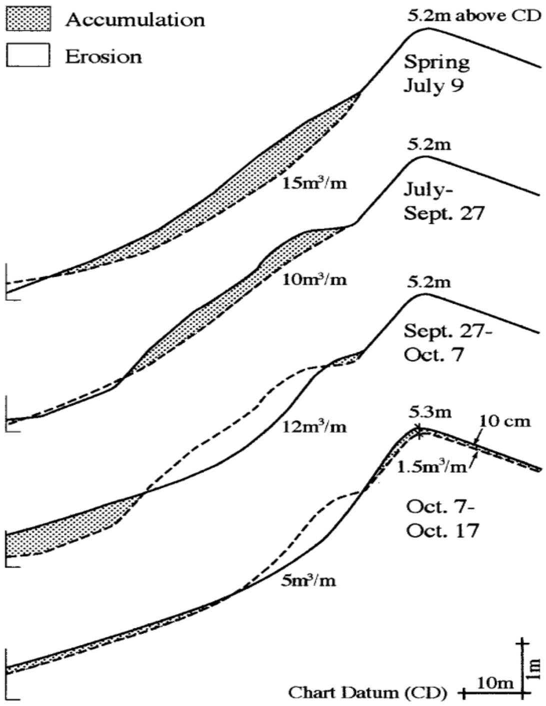

Fig. 3-123. The changes during the summer on the beach profile at Sandbukt in 1993, and the erosion caused by the two storms. From Møller, 2002.

There were no storms from the east or the west during the one year cycle. There was however, on the 28th of August 2015, a short period of time where the wind was blowing in from the south-east and south-southeast with wind speeds on hourly average between 4 and 5 $^{m/s}$ and gusts up to 11 $^{m/s}$. There were no high waves during this period, and it occurred mostly during low tide, but due to the strong winds there was substantial wind erosion on the beach and transport of material from the southern side of the beach to the northern side. The area around profile B received most of the material being transported, as during this wind direction the wind blows over most of the beach but crosses it at profile B and A. This is a likely the cause, or at least part of the cause, for the height discrepancy in the beach ridge, depending on location, where the beach ridge around Profile B is by far both the widest and highest.

3.2 Beach sub-surface architecture

3.2.1 Profile B

The section at Profile B was dug on the 28th of August and was located on the berm and the berm Crest (fig. 3-124).

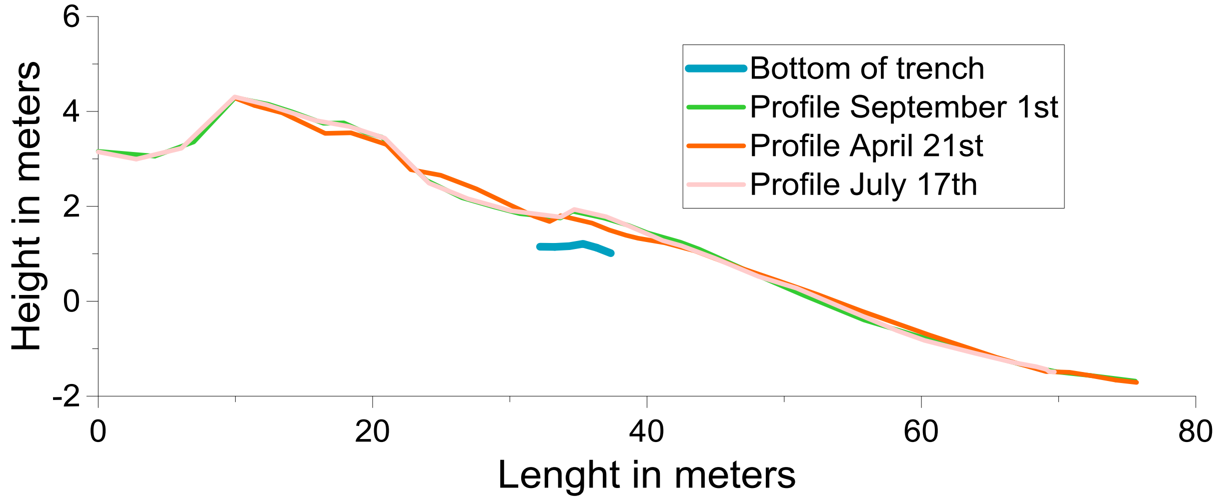

Fig. 3-124. The location of the bottom of the trench in relations to the beach profile. The mound can be seen directly above the trench bottom.

The objective was to get a cross-section of the mound (fig. 3-125), which had been formed on the berm in April, in order to determine how it had been formed and how the structures were preserved. In order to minimize the affect the trench would have on the evolution of the beach profile at Profile B, the section was dug about 10 meters to the north of the profile line. The trench was 5 meters in length, and was cut through a small mound there. This mound was similar to the mound that had formed in April at Profile B, and had formed at the same time. The width of the mound itself was about 3 meters, and it was about 30 cm high. After the mound formation in April, the mound had been raised slightly (fig. 3-126) and the seaward facing side had grown. It is not clear whether the additional layers were deposited by wind or waves, but the mound is at the wave run-up limit on the beach during non-storm conditions, and it is therefore most likely that it was by waves, although Aeolian processes could have plaid some part as well. The wave run-up must have been able to go above the mounds peak, as the layers continue behind the mound. There was no vegetation or sand ripples present on the top of or in the vicinity of the mound.

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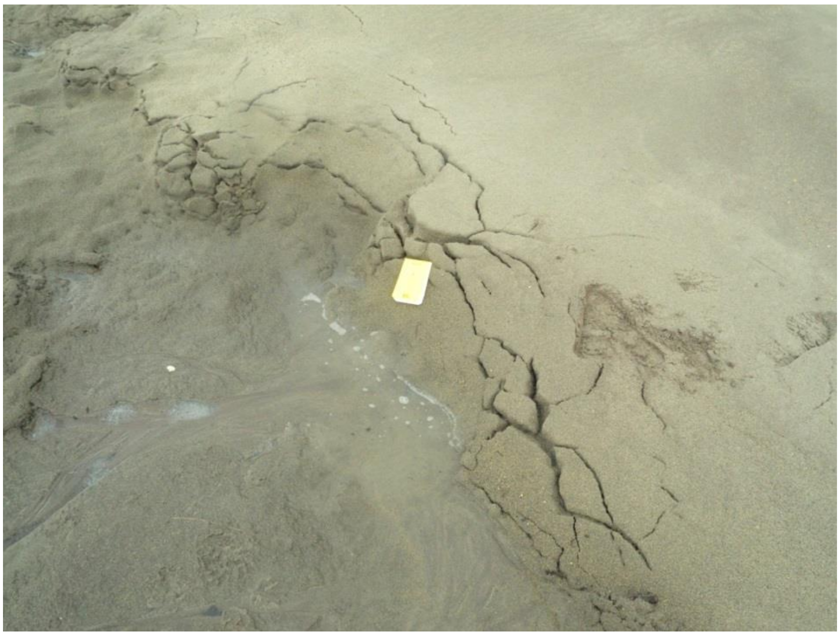

Fig. 3-125. Photo of the mound from April 2015. The beach ridge is on the left side of the photo, and the mound has a steeper landward side than seaward side.

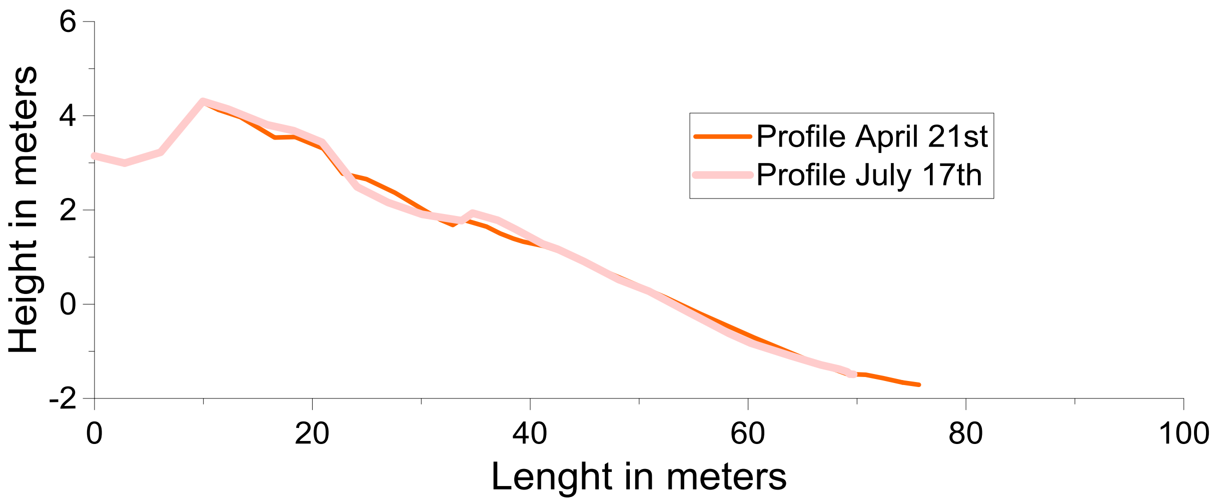

Fig. 3-126. Shows the beach profile change at Profile B between April 21st, when the mound started to form, and July 17th. The mound had been raised slightly during the period.

The section had sixteen different layers (fig.3-127). All of the layers where thinly laminated with thin lenses of either finer or coarser material. The grain size ranged from fine sand to coarse sand, with a general upward fining in the trench. Layers of red garnet sand were present in more abundance and thicker layers on the lower part of the trench, but thin layers were present in the upper part as well. A number of erosional surfaces were present as well, confined to the lower part of the trench (fig. 3-128). There was a small area where the sand was collapsed that caused the layers above it to be distorted (fig. 3-127 (light blue layer, below the top red layer) and fig. 3-128). This collapse corresponds with the location of where the sand collapsed in April when the ice melted, and is likely caused by the collapse of the overlying sand layers once the ice was removed. This distortion has since then be overlaid by a thin layer of thinly laminated sand, much like the rest of the trench. It seems that once the ice had cleared, and the sand on the ice had collapsed, the tides brought in new layers of sand during the summer time, as the berm crest grew in height from April to July (fig. 3-124). The added layers during the summertime are made out of thinly laminated fine dark sand and slightly coarser white sand. There is no bend in the layers beneath this distorted layer and no distortion as well. There was a small distortion in the layers, cutting through them, caused by vegetation (fig 3-127 (black layer) and fig. 3-129). This small patch of vegetation extended through three layers, and looks similar to the vegetation patches that are present on the berm during summer times (fig. 3-129). The vegetation caused no distortion in the surrounding layers, and was buried in what seems to be thinly laminated sand, with alternating layers of fine and medium sand. It is therefore likely that this vegetation was on the surface of a berm once during summer time, but was then buried by deposits. This suggests that the berm height at Profile B has been raised and no erosion has taken place for extensive amount of time. This is in accordance with the beach profile evolution at Profile B from October 2014 to October 2015, where the berm was not eroded during the year cycle.

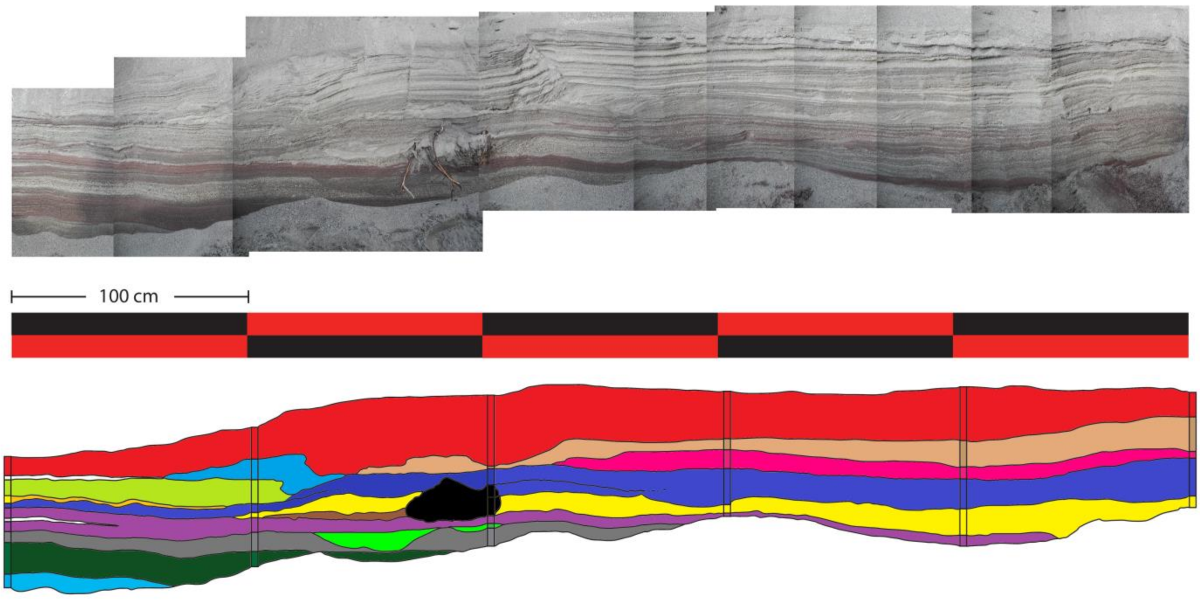

Fig. 3-127. The internal structure of the mound, and its surroundings, at Profile B.

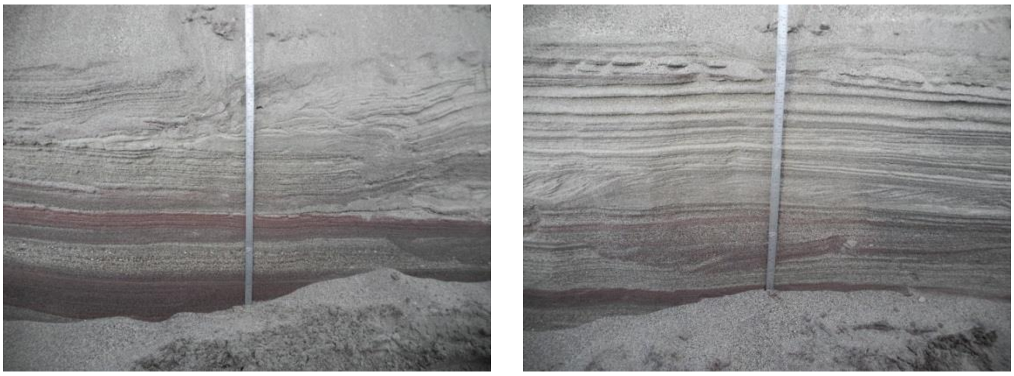

Fig. 3-128. The disturbed layer (on the left) caused by ice melt-out and erosional surface on the bottom part of the trench (on the right)

Fig. 3-129. The disturbance of the layers caused by roots in the trench (on the left) and surface vegetation on the berm (on the right).

3.3 Grain size analysis

The sediment samples were collected each month, during the profile measurements, from May to September 2015. Samples were collected from five different locations on the beach, the beach ridge, the berm, the beach face, the beach step or on the boundary of the beach face and the low tide terrace, and from the low tide terrace, but not all sample locations were sampled each month. By July, the vegetation density on the beach ridge had increased, making sampling there impossible from July to September, and at some instances sampling was impossible due to other factors, such as extensive drainage channels or tidal height. The total number of samples taken during the five month sampling period was 90. The samples were sieved in a sieve stack, ranging from -3Φ to 4Φ, at a ¼ Φ interval. A grain size and cumulative frequency curve was then calculated for each sample, and are displayed as bar- and line-graphs. On the graphs, the results are plotted centred on the nominal sieve mesh size and indicate the weight of the grain size ranging from that sieve mesh size, to the size above.

3.3.1 May

In May (fig. 3-130) samples were collected from four locations at each profile from the beach ridge, the berm, the beach face, and the low tide terrace, resulting in 24 samples.

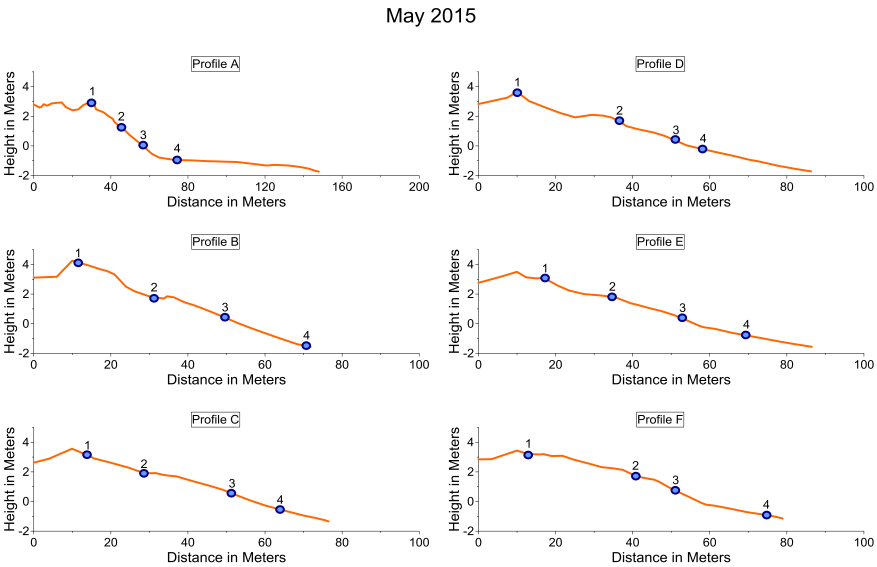

Fig. 3-130. The location of where each sample was taken on the beach profiles in May. Four samples were taken at each profile, from the beach ridge (1), the berm (2), the beach face (3), and the low tide terrace (4).

At Profile A the coarsest sediment was found at the beach face, or coarse sand, while medium sand was at the other three sampling locations. The grain size sorting varied from moderately well sorted (m. well sorted) to well sorted, where the ridge and the berm were well sorted while the beach face and the low tide terrace (terrace) were m. well sorted. The skewness of the samples was from very coarse skewed to fine skewed, with the ridge and the berm finely skewed, the berm symmetrical and the terrace very coarse skewed. The beach face sample was mesokurtic, while the others were leptokurtic, and the mode of the sediments was unimodal at all four locations. At Profile B the coarsest sediment was at the berm, or medium sand, while fine sand was at the other sampling locations. The grain size sorting varied from m. well sorted to well sorted, where the ridge and the beach face were well sorted and the berm and the terrace m. well sorted. The skewness of the samples ranged from very coarse skewed to fine skewed, with the berm and the beach face fine skewed, the ridge symmetrical and the terrace very coarse skewed. The ridge and the berm were mesokurtic, the beach face platykurtic, and the terrace leptokurtic .The mode of the sediments was bimodal, except at the terrace, where it was unimodal. At Profile C the coarsest sediment was medium sand, found at the ridge, the berm, and the terrace, while fine sand was on the beach face. The sorting of the samples ranged from m. well sorted to very well sorted, while the skewness ranged from symmetrical to mesokurtic. The samples were mesokurtic at all four locations and all, but the berm which was trimodal, were unimodal. At Profile D the grain size ranged from medium to fine sand, where fine sand was on the terrace, while medium sand on the other three sampling locations. The sorting ranged from m. well sorted to very well sorted, while the skewness ranged from symmetrical to fine skewed. All four samples were mesokurtic and the ridge and the terrace were bimodal, while the berm was trimodal and the beach face unimodal. At Profile E the grain size was medium sand at all four locations. The sorting varied from m. well sorted to very well sorted, where the beach face was very well sorted while the ridge and the berm where m. well sorted and the terrace well sorted. The ridge and the beach face samples were fine skewed, while the berm and the terrace samples were symmetrical. All four samples were mesokurtic and the terrace was bimodal while the other three were unimodal. At Profile F the four samples were all medium sand, where the berm was m. well sorted, the ridge and the terrace well sorted and the beach face very well sorted. All four samples were symmetrical, mesokurtic and unimodal. The Grain size distribution (%) and cumulative frequency curve (%) for the 24 sediment samples taken in May 2015 can be seen in fig 3-131 and fig 3-132, while the grain sorting statistics can be seen in Table 4 and in statistical terms in Table 5.

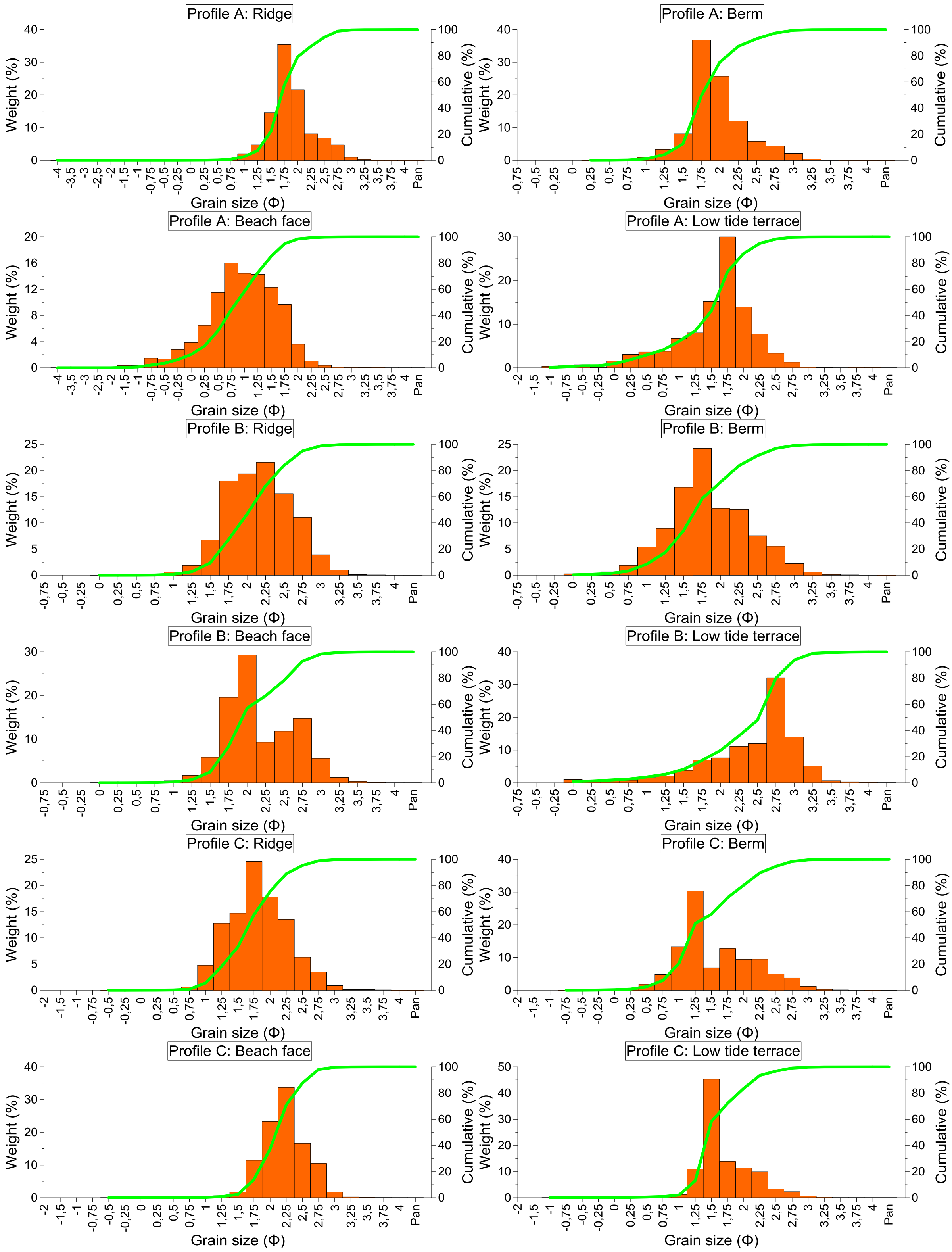

Fig. 3-131. Graphs showing the grain size distribution (%) and cumulative frequency curve (%) for the sediment samples taken at profiles A, B, and C in May 2015.

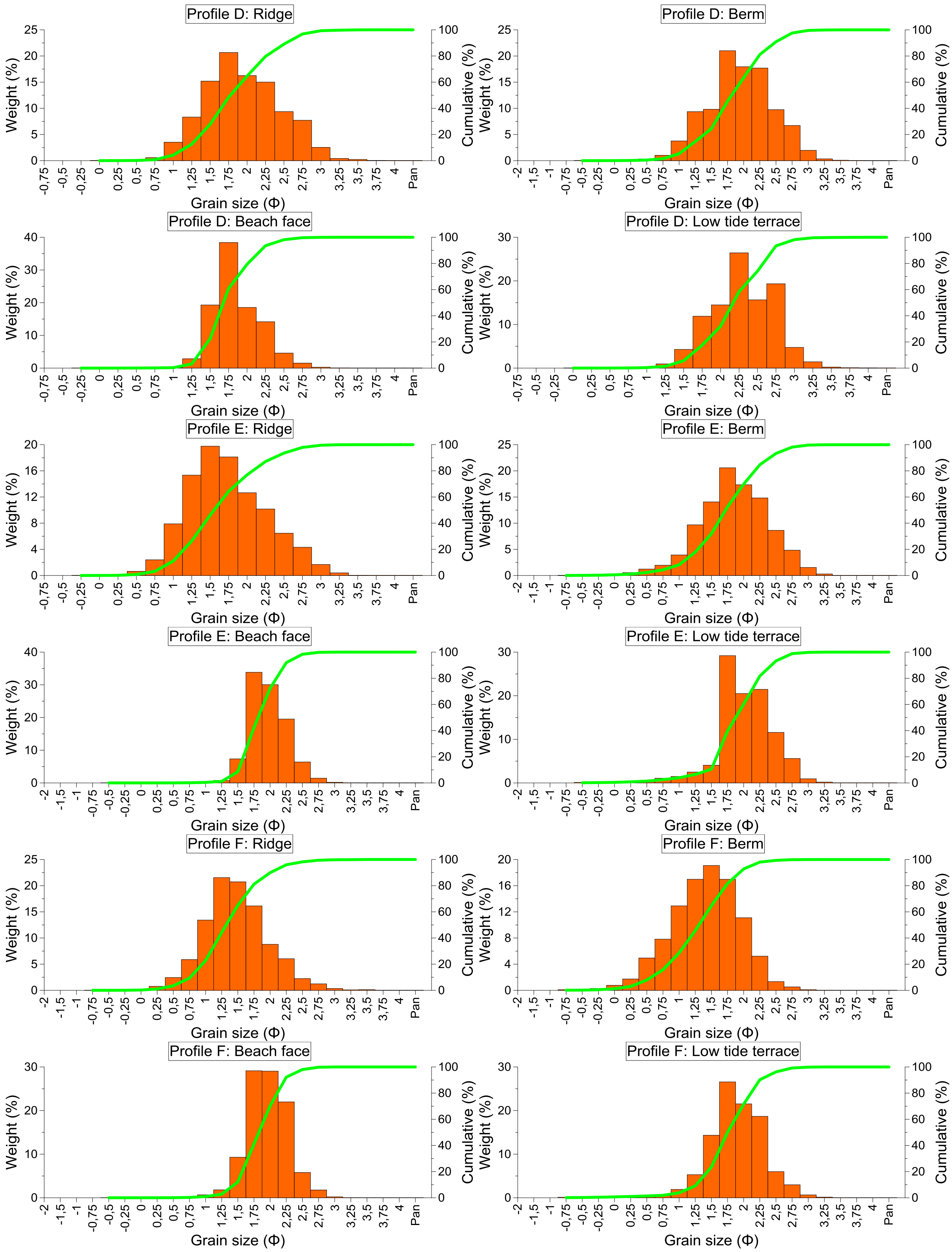

Fig. 3-132. Graphs showing the grain size distribution (%) and cumulative frequency curve (%) for the sediment samples taken at profiles D, E, and F in May 2015.

Table 4. Description of the textural characteristics of the sediments samples from the beach profiles for May 2015

	Profile A				Profile B			
	Ridge	Berm	B. Face	Terrace	Ridge	Berm	B. Face	Terrace
Mean (M_Z)	Medium Sand	Medium Sand	Coarse Sand	Medium Sand	Fine Sand	Medium Sand	Fine Sand	Fine Sand
Sorting (σ)	Well Sorted	Well Sorted	M. Well Sorted	M. Well Sorted	Well Sorted	M, Well Sorted	Well Sorted	M. Well Sorted
Skewness (S_K)	Fine Skewed	Fine Skewed	Symmetrical	Very Coarse Skewed	Symmetrical	Fine Skewed	Fine Skewed	Very Coarse Skewed
Kurtosis (K_G)	Leptokurtic	Leptokurtic	Mesokurtic	Leptokurtic	Mesokurtic	Mesokurtic	Platykurtic	Leptokurtic
Mode	Unimodal	Unimodal	Unimodal	Unimodal	Bimodal	Bimodal	Bimodal	Unimodal
	Profile C				**Profile D**			
	Ridge	**Berm**	**B. Face**	**Terrace**	**Ridge**	**Berm**	**B. Face**	**Terrace**
Mean (M_Z)	Medium Sand	Medium Sand	Fine Sand	Medium Sand	Medium Sand	Medium Sand	Medium Sand	Fine Sand
Sorting (σ)	Well Sorted	M. Well Sorted	Very Well Sorted	Well Sorted	M. Well Sorted	M. Well Sorted	Very Well Sorted	Well Sorted
Skewness (S_K)	Symmetrical	Very Fine Skewed	Symmetrical	Very Fine Skewed	Fine Skewed	Symmetrical	Fine Skewed	Symmetrical
Kurtosis (K_G)	Mesokurtic	Mesokurtic	Mesokurtic	Mesokurtic	Mesokurtic	Mesokurtic	Mesokurtic	Mesokurtic
Mode	Unimodal	Trimodal	Unimodal	Unimodal	Bimodal	Trimodal	Unimodal	Bimodal
	Profile E				**Profile F**			
	Ridge	**Berm**	**B. Face**	**Terrace**	**Ridge**	**Berm**	**B. Face**	**Terrace**
Mean (M_Z)	Medium Sand	Medium Sand	Medium Sand	Medium Sand	Medium Sand	Medium Sand	Medium Sand	Medium Sand
Sorting (σ)	M. Well Sorted	M. Well Sorted	Very Well Sorted	Well Sorted	Well Sorted	M. Well Sorted	Very Well Sorted	Well Sorted
Skewness (S_K)	Fine Skewed	Symmetrical	Fine Skewed	Symmetrical	Symmetrical	Symmetrical	Symmetrical	Symmetrical
Kurtosis (K_G)	Mesokurtic	Mesokurtic	Mesokurtic	Mesokurtic	Mesokurtic	Mesokurtic	Mesokurtic	Mesokurtic
Mode	Unimodal	Unimodal	Unimodal	Bimodal	Unimodal	Unimodal	Unimodal	Unimodal

Table 5. Textural characteristics of sediments from the beach profiles for May 2015

	Profile A				Profile B				Profile C			
	Ridge	Berm	B. Face	Terrace	Ridge	Berm	B. Face	Terrace	Ridge	Berm	B. Face	Terrace
Mean (M_Z)	1,737	1,812	0,595	1,439	2,032	1,697	2,035	2,334	1,668	1,408	2,091	1,570
Sorting (σ)	0,404	0,368	0,629	0,593	0,438	0,537	0,472	0,580	0,465	0,583	0,335	0,385
Skewness (S_K)	0,195	0,290	-0,066	-0,318	-0,008	0,112	0,257	-0,429	0,047	0,404	0,015	0,445
Kurtosis (K_G)	1,331	1,301	0,998	1,365	0,916	1,035	0,860	1,178	0,953	0,939	1,053	1,053
	Profile D				Profile E				Profile F			
	Ridge	Berm	B. Face	Terrace	Ridge	Berm	B. Face	Terrace	Ridge	Berm	B. Face	Terrace
Mean (M_Z)	1,801	1,794	1,718	2,159	1,596	1,708	1,831	1,898	1,332	1,276	1,831	1,752
Sorting (σ)	0,514	0,510	0,327	0,433	0,540	0,529	0,297	0,407	0,487	0,529	0,315	0,408
Skewness (S_K)	0,107	-0,011	0,222	-0,021	0,145	-0,017	0,126	0,029	0,085	-0,067	0,041	0,030
Kurtosis (K_G)	0,946	1,035	1,009	0,914	0,968	1,018	0,959	1,089	1,085	1,007	0,961	1,050

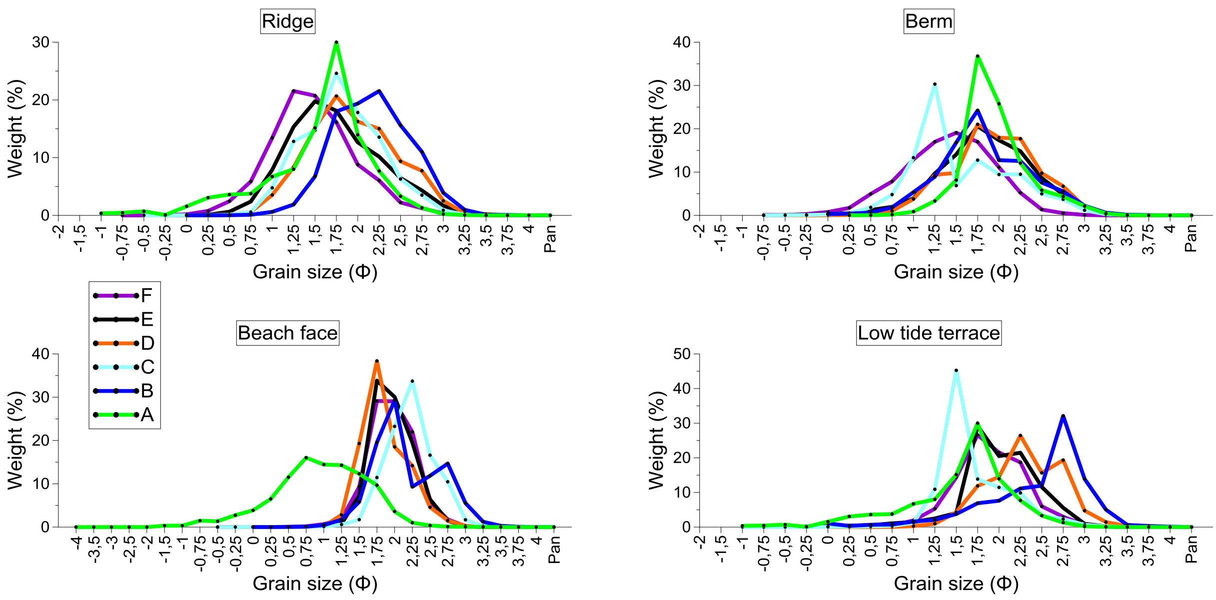

Fig. 3-133. Graphs compering the grain size distribution at every sample location in May, at each beach profile, to each other

When the grain size distribution for the four sampling locations are compared to the same sampling locations at other profiles (fig. 3-133), they do not show a distinct pattern in grain size trend over the beach. The ridge had medium sand at profiles A and C – F, while there was fine sand at Profile B. When the grain size distribution is compared, it can be seen that the ridge sample from Profile F is the coarsest, followed by E, then A, C, and D and finally B. This could indicate aeolian transport of material away from the beach ridge at the profiles, and at Profile B the transport is either less than at the other profiles or that the ridge around that profile receives higher amounts of finer sediments from the beach face. The Berm had medium sand at every profile, where Profiles C and F had slightly coarser sand than the rest of the profiles. The samples from the beach face were the most well sorted material found on the beach, where Profile A had the coarsest sand, followed by profiles D, E, and F, while the finest sand was at Profiles B and C. The terrace had medium sand at profiles C, A, E, and F, with the sample from Profile C being slightly coarser than the other three. At profiles D and B the samples were fine sand, with the sample from Profile D being slightly coarser than at Profile B.

3.3.2 June

In June (fig. 3-134) samples were collected from three locations at each profile from the berm, the beach face, and the low tide terrace, but due to faulty sampling bags only 3 samples from the berm could be sieved.

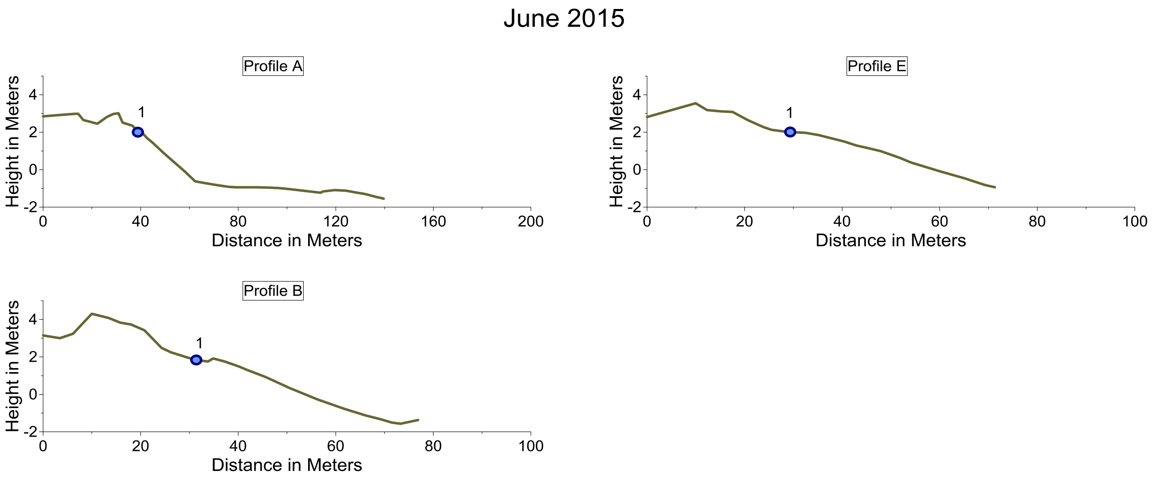

Fig. 3-134. The location of where each sample was taken on the beach profiles in June. Three samples were taken at from the berm at profiles A, B, and E.

The Grain size distribution (%) and cumulative frequency curve (%) for the 3 sediment samples taken in June 2015 can be seen in fig 3-135, while the grain sorting statistics can be seen in Table 6 and in statistical terms in Table 7. In June the coarsest sediment from the berm was at Profile A where it was coarse sand. The sample was well sorted, fine skewed, leptokurtic and unimodal. The berm samples from profiles B and E were medium sand, mesokurtic and unimodal. The sample from Profile B was m. well sorted and fine skewed, while the sample from Profile E was well sorted and symmetrical. When the three samples are compared to each other (fig. 3-135) the mild decrease in grain size from Profile A to Profile B and from Profile B to Profile E can be seen.

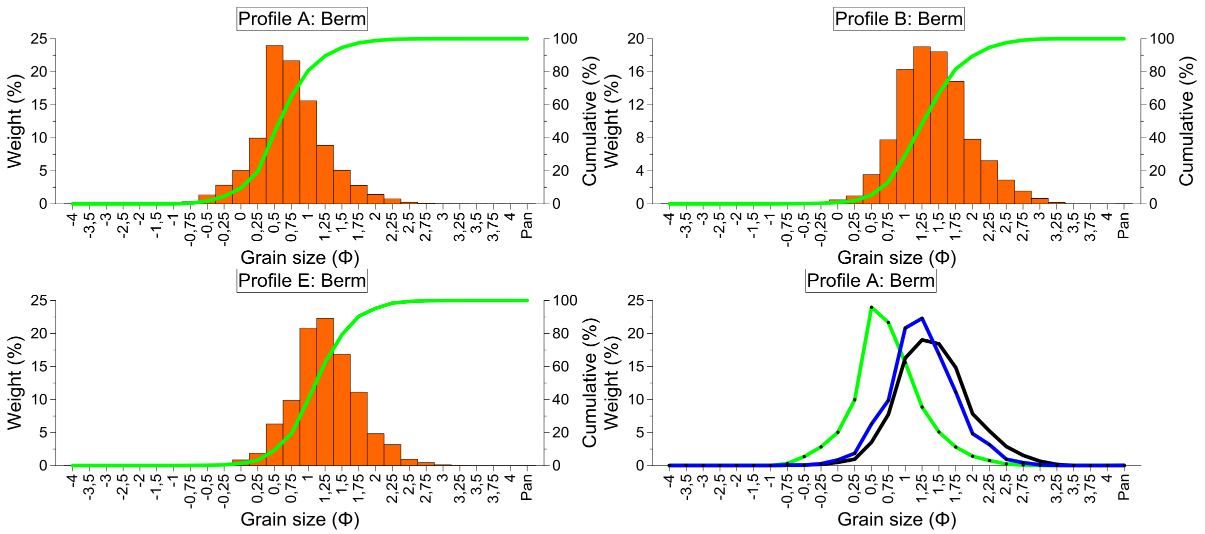

Fig. 3-135. Graphs showing the grain size distribution (%) and cumulative frequency curve (%) for the 3 sediment samples taken in June 2015, and the comparison of the grain size distribution of the three samples.

Table 6. Textural characteristics of sediments from the beach profiles for June 2015

	Profile A	Profile B	Profile E
	Berm	Berm	Berm
Mean (M_Z)	0,602	1,286	1,118
Sorting (σ)	0,497	0,529	0,489
Skewness (S_K)	0,105	0,102	0,050
Kurtosis (K_G)	1,169	1,051	1,109

Table 7. Description of the textural characteristics of the sediments samples from the beach profiles for May 2015

	Profile A	Profile B	Profile E
	Berm	Berm	Berm
Mean (M_Z)	Coarse Sand	Medium Sand	Medium Sand
Sorting (σ)	Well Sorted	M, Well Sorted	Well Sorted
Skewness (S_K)	Fine Skewed	Fine Skewed	Symmetrical
Kurtosis (K_G)	Leptokurtic	Mesokurtic	Mesokurtic
Mode	Unimodal	Unimodal	Unimodal

3.3.3 July

In July (fig. 3-136) 23 samples were collected from four locations at each profile, from the berm, the beach face, the boundary of the beach face and the low tide terrace, and the low tide terrace.

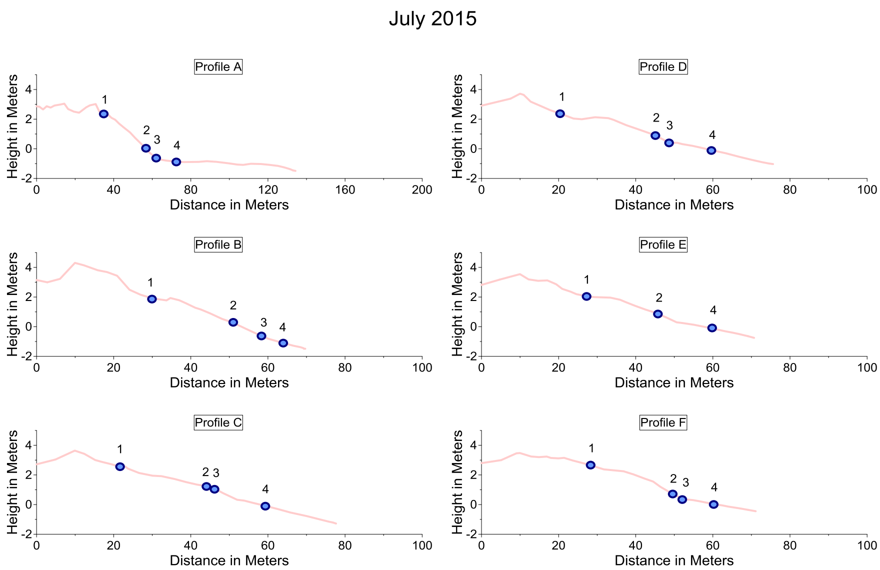

Fig. 3-136. The location of where each sample was taken on the beach profiles in July. Four samples were taken at each profile, from the berm (1), the beach face (2), the boundary of the beach face and the low tide terrace (3), and the low tide terrace (4).

At Profile A the coarsest sediment was from the boundary of the beach face and the low tide terrace (boundary), or very fine gravel, while the beach face sample was coarse sand and the berm and the terrace were medium sand. The grain size sorting varied from moderately sorted to well sorted, where the berm and the beach face samples were well sorted, the boundary moderately sorted and the terrace was m. well sorted. The skewness of the samples ranged from symmetrical to coarse skewed, where the berm sample was symmetrical, the boundary was fine skewed, and the beach face and the terrace were coarse skewed. The berm and the boundary samples were mesokurtic, the terrace leptokurtic and the beach face very leptokurtic. The beach face and the terrace samples were unimodal, while the berm sample was bimodal and the boundary sample trimodal. At Profile B the coarsest sediment was at the boundary, or fine gravel, while there was medium sand on the berm, coarse sand on the beach face and very coarse sand on the terrace. The grain size sorting varied from moderately sorted to very well sorted, where the berm samples was very well sorted, the boundary and the terrace well sorted and the beach face was moderately sorted. The skewness of the samples ranged from symmetrical to very coarse skewed, with the boundary and the terrace samples being symmetrical, the berm fine skewed and the beach face very coarse skewed. The berm and the terrace samples were mesokurtic, the boundary leptokurtic and the beach face very leptokurtic. The terrace sample was bimodal while the other three were unimodal. At Profile C the coarsest sample was from the boundary, or very coarse sand, while there was medium sand at the other three locations. The sorting of the samples was m. well sorted at the berm and the boundary, while the beach face and the terrace samples were very well sorted. The samples from the berm and the boundary were symmetrical and the samples from the beach face and the terrace were fine skewed. All four samples were mesokurtic, and the berm sample was bimodal while the other three were unimodal. At Profile D the boundary sample was the coarsest sample, with coarse sand, and the other three locations had medium sand. The samples from the berm and the boundary were m. well sorted and the beach face and the terrace samples were very well sorted. The boundary sample was coarse skewed, while the other three samples were fine skewed. All four samples were mesokurtic and the berm sample was bimodal while the other three were unimodal. At Profile E all three samples were medium sand, with the berm being m. well sorted, the beach face very well sorted and the terrace well sorted. The berm and the terrace samples were symmetrical while the beach face was fine skewed. The three samples were all mesokurtic and unimodal. At Profile F the boundary and the terrace were the coarsest samples, with coarse sand, while there was medium sand on the berm and the beach face. The samples from the berm and the boundary were m. well sorted, while the beach face was well sorted and the terrace very well sorted. The terrace sample was fine skewed and the other three were symmetrical. The berm and the boundary samples were mesokurtic and bimodal, while the beach face and the terrace were leptokurtic and unimodal. The Grain size distribution (%) and cumulative frequency curve (%) for the 3 sediment samples taken in June 2015 can be seen in fig. 3-137 and fig 3-138, while the grain sorting statistics can be seen in Table 8 and in statistical terms in Table 9.

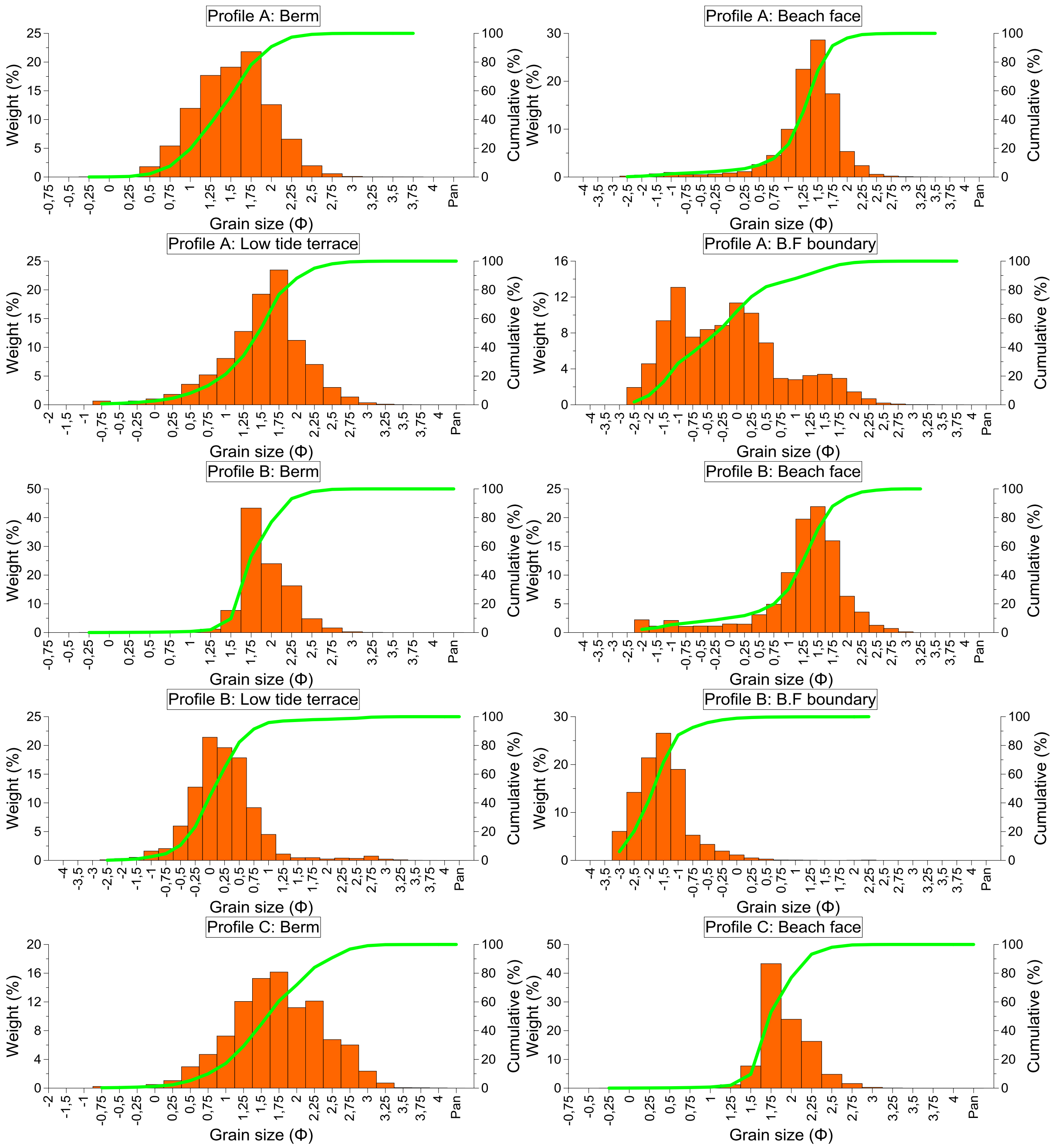

Fig. 3-137. Graphs showing the grain size distribution (%) and cumulative frequency curve (%) for the sediment samples taken at profile A, B, and C in May 2015.

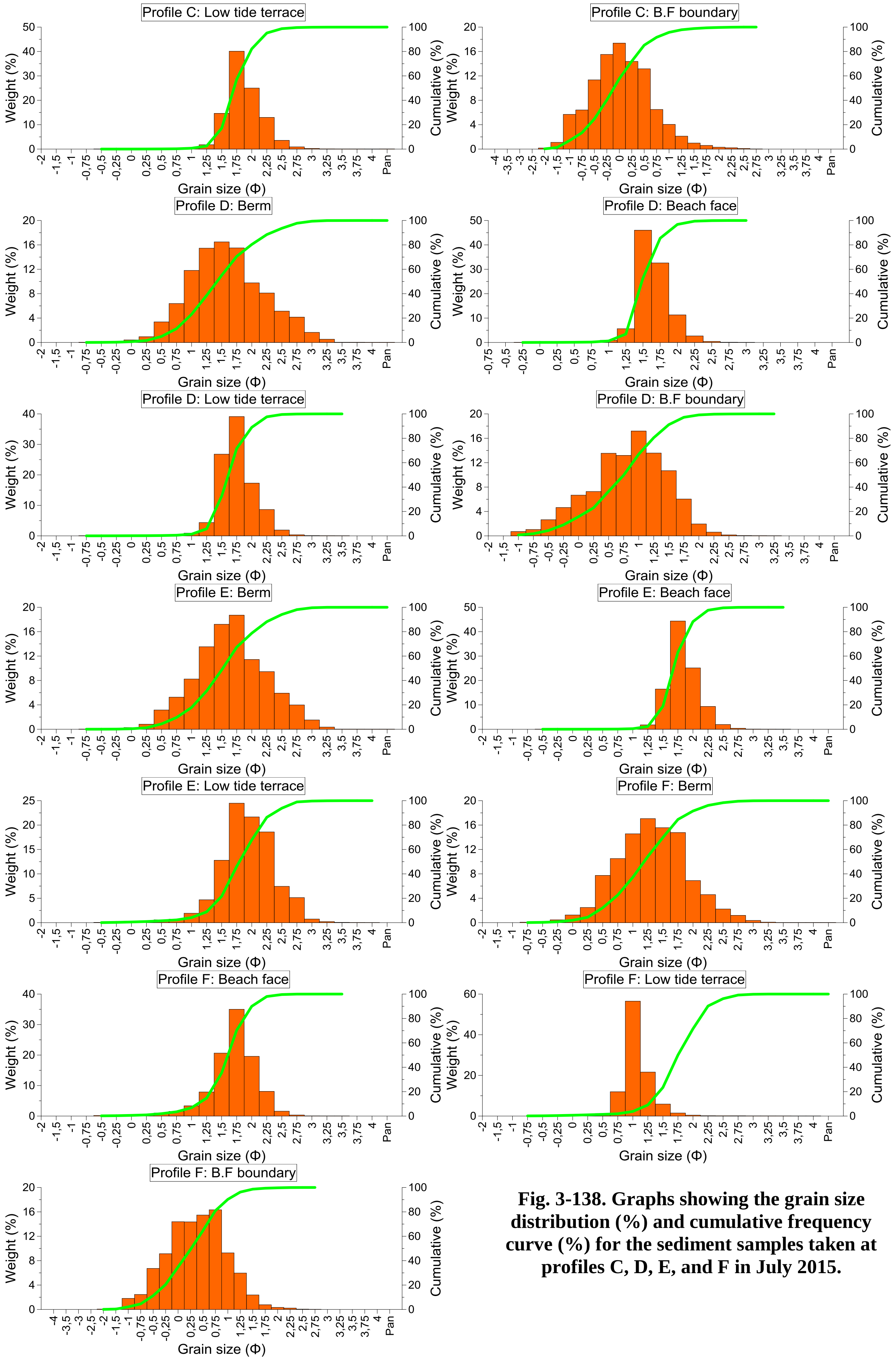

Fig. 3-138. Graphs showing the grain size distribution (%) and cumulative frequency curve (%) for the sediment samples taken at profiles C, D, E, and F in July 2015.

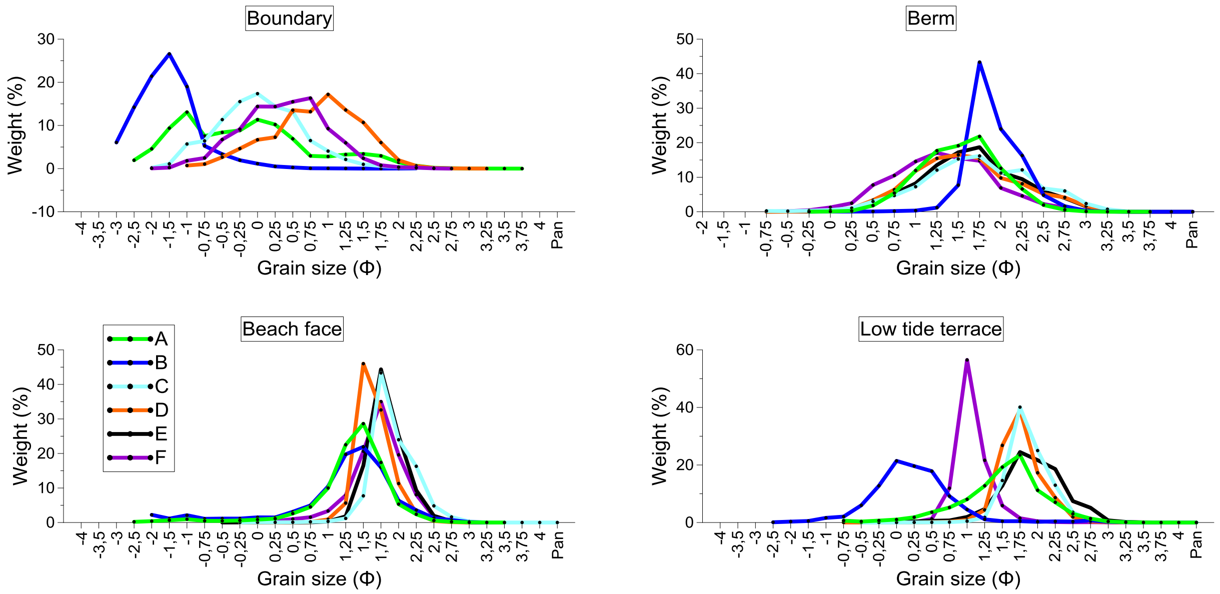

Fig. 3-139. Graphs compering the grain size distribution at every sample location in July, at each beach profile, to each other.

When the grain sizes at the same sampling locations, at different profiles, are compared to each other a similar trend can be observed (fig. 3-139). The beach face had coarse sand at Profiles A and B, while there was medium sand present on the other Profiles. At the boundary, Profiles A and B had the coarsest material as well, very fine gravel and fine gravel respectively, while the grain size decreases from Profile C to D and from D to E, before increasing again at Profile F. A similar trend is present on the terrace, where the sample from Profile B was the coarsest or very coarse sand, while the grain size is smaller at profiles C, D, and E before increasing again at Profile F. The relatively fine material found on the terrace at Profile A is most likely due to the present of the sandbar there, as it both decreases wave power on the terrace and could also be a source for fine material to be brought on to the terrace. These grain size distribution over the beach could suggest that there is a longshore current running from the north to the south at the beach, halting somewhere in the vicinity of Profile E. The coarser grain size at Profile F could be due to either increased wave energy there, as it is more exposed to northern storms than the other profiles, or that Filma stream brings sediments to the beach and the sediments then gets re-distributed along the beach near Profile F. The samples from the berm were all similar in grain size and all are characterized as medium sand, but the sample from Profile F was the coarsest, followed closely by the samples form profiles A and D. The samples from E, C, and B were similar as well, but E and C were slightly coarser than the sample from Profile B.

Table 8. Textural characteristics of sediments from the beach profiles for July 2015

	Profile A				Profile B				Profile C			
	Berm	B. Face	Boundary	Terrace	Berm	B. Face	Boundary	Terrace	Berm	B. Face	Boundary	Terrace
Mean (M_Z)	1,396	0,498	-1,063	1,393	1,784	0,655	-2,425	-0,674	1,590	1,784	-0,111	1,734
Sorting (σ)	0,466	0,482	0,946	0,568	0,293	0,749	0,421	0,487	0,651	0,293	0,602	0,284
Skewness (S_K)	-0,032	-0,225	0,134	-0,177	0,279	-0,347	0,050	0,057	0,012	0,279	0,011	0,175
Kurtosis (K_G)	0,998	1,526	0,956	1,237	1,015	1,855	1,159	1,056	0,985	1,015	1,078	1,024

	Profile D				Profile E			Profile F			
	Berm	B. Face	Boundary	Terrace	Berm	B. Face	Terrace	Berm	B. Face	Boundary	Terrace
Mean (M_Z)	1,454	1,497	0,690	1,620	1,528	1,691	1,790	1,162	1,589	0,237	0,936
Sorting (σ)	0,629	0,231	0,646	0,295	0,603	0,262	0,433	0,578	0,363	0,588	0,225
Skewness (S_K)	0,103	0,164	-0,127	0,125	0,028	0,142	0,014	0,003	-0,087	-0,029	0,188
Kurtosis (K_G)	1,023	1,020	0,994	1,087	1,042	1,101	1,083	0,987	1,217	0,977	1,273

Table 9. Description of the textural characteristics of the sediments samples from the beach profiles for July 2015

	Profile A				**Profile B**			
	Berm	**B. Face**	**Boundary**	**Terrace**	**Berm**	**B. Face**	**Boundary**	**Terrace**
Mean (M_Z)	Medium Sand	Coarse Sand	Very Fine Gravel	Medium Sand	Medium Sand	Coarse Sand	Fine Gravel	Very Coarse Sand
Sorting (σ)	Well Sorted	Well Sorted	Moderately Sorted	M. Well Sorted	Very Well Sorted	Moderately Sorted	Well Sorted	Well Sorted
Skewness (S_K)	Symmetrical	Coarse Skewed	Fine Skewed	Coarse Skewed	Fine Skewed	Very Coarse Skewed	Symmetrical	Symmetrical
Kurtosis (K_G)	Mesokurtic	Very Leptokurtic	Mesokurtic	Leptokurtic	Mesokurtic	Very Leptokurtic	Leptokurtic	Mesokurtic
Mode	Bimodal	Unimodal	Trimodal	Unimodal	Unimodal	Unimodal	Unimodal	Bimodal
	Profile C				**Profile D**			
	Berm	**B. Face**	**Boundary**	**Terrace**	**Berm**	**B. Face**	**Boundary**	**Terrace**
Mean (M_Z)	Medium Sand	Medium Sand	Very Coarse Sand	Medium Sand	Medium Sand	Medium Sand	Coarse Sand	Medium Sand
Sorting (σ)	M. Well Sorted	Very Well Sorted	M. Well Sorted	Very Well Sorted	M. Well Sorted	Very Well Sorted	M. Well Sorted	Very Well Sorted
Skewness (S_K)	Symmetrical	Fine Skewed	Symmetrical	Fine Skewed	Fine Skewed	Fine Skewed	Coarse Skewed	Fine Skewed
Kurtosis (K_G)	Mesokurtic	Mesokurtic	Mesokurtic	Mesokurtic	Mesokurtic	Mesokurtic	Mesokurtic	Mesokurtic
Mode	Bimodal	Unimodal	Unimodal	Unimodal	Bimodal	Unimodal	Unimodal	Unimodal
	Profile E			**Profile F**				
	Berm	**B. Face**	**Terrace**	**Berm**	**B. Face**	**Boundary**	**Terrace**	
Mean (M_Z)	Medium Sand	Medium Sand	Medium Sand	Medium Sand	Medium Sand	Coarse Sand	Coarse Sand	
Sorting (σ)	M. Well Sorted	Very Well Sorted	Well Sorted	M. Well Sorted	Well Sorted	M. Well Sorted	Very Well Sorted	
Skewness (S_K)	Symmetrical	Fine Skewed	Symmetrical	Symmetrical	Symmetrical	Symmetrical	Fine Skewed	
Kurtosis (K_G)	Mesokurtic	Mesokurtic	Mesokurtic	Mesokurtic	Leptokurtic	Mesokurtic	Leptokurtic	
Mode	Unimodal	Unimodal	Unimodal	Bimodal	Unimodal	Bimodal	Unimodal	

3.3.4 August

18 samples were collected in August (fig. 3-140), from the berm, the beach face, and the low tide terrace.

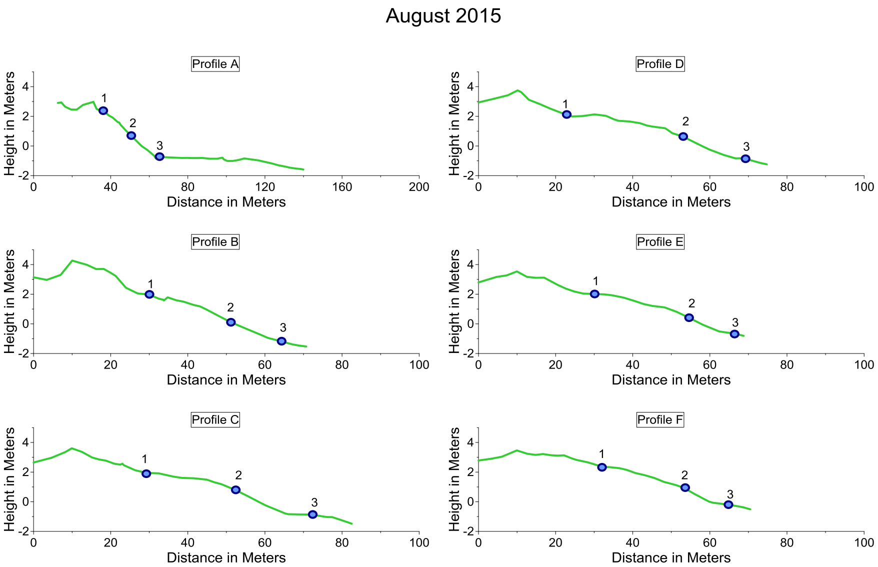

Fig. 3-140. The location of where each sample was taken on the beach profiles in August. Four samples were taken at each profile, from the berm (1), the beach face (2), and the low tide terrace (3).

At Profile A the coarsest sample was from the berm, with coarse sand, while the beach face and the terrace had medium sand. The berm and the terrace samples were m. well sorted and the beach face was very well sorted. The samples ranged from symmetrical to coarse skewed, where the berm was fine skewed, the beach face symmetrical, and the terrace coarse skewed. The kurtosis of the samples varied from platykurtic to mesokurtic, where the berm was platykurtic and the other two mesokurtic. The berm and the terrace samples were bimodal, while the beach face sample was unimodal. At Profile B the berm had the coarsest sediment, or medium sand, while the beach face and the terrace had fine sand. The sorting was worst at the berm, or m. well sorted, while the other two were well sorted. The berm and the beach face samples were symmetrical and the terrace sample was coarse skewed. The berm was mesokurtic and unimodal, the beach face platykurtic and trimodal, and the terrace was leptokurtic and unimodal. At Profile C, both the berm and the terrace had medium sand, while the beach face had fine sand. The sorting was best at the beach face, or very well sorted, while the terrace was well sorted and the berm was m. well sorted. All three samples were mesokurtic, and the berm sample was symmetrical and bimodal, the beach face sample was symmetrical and unimodal, and the terrace was fine skewed and unimodal. At Profile D the berm and the terrace samples were medium sand, while the beach face was fine sand. The berm and the beach face samples were well sorted and the terrace sample was m. well sorted. All three samples were symmetrical, where the berm sample was leptokurtic and unimodal, the beach face sample was mesokurtic and unimodal, and the terrace sample was mesokurtic and trimodal. At Profile E, both the berm and the terrace samples were medium sand, while the beach face sample was fine sand. The berm sample was m. well sorted and fine skewed, and the beach face and the terrace samples were very well sorted and symmetrical. The three samples were all unimodal, and the berm was platykurtic, the beach face mesokurtic, and the terrace was leptokurtic. At Profile F all three samples were medium sand, where the berm sample was m. well sorted and the other two were very well sorted. The berm and the terrace samples were symmetrical, while the beach face sample was fine skewed, and the three samples were all mesokurtic and unimodal. The Grain size distribution (%) and cumulative frequency curve (%) for the 24 sediment samples taken in May 2015 can be seen in fig. 3-141 and fig. 3-142, a while the grain sorting statistics can be seen in Table 10 and in statistical terms in Table 11.

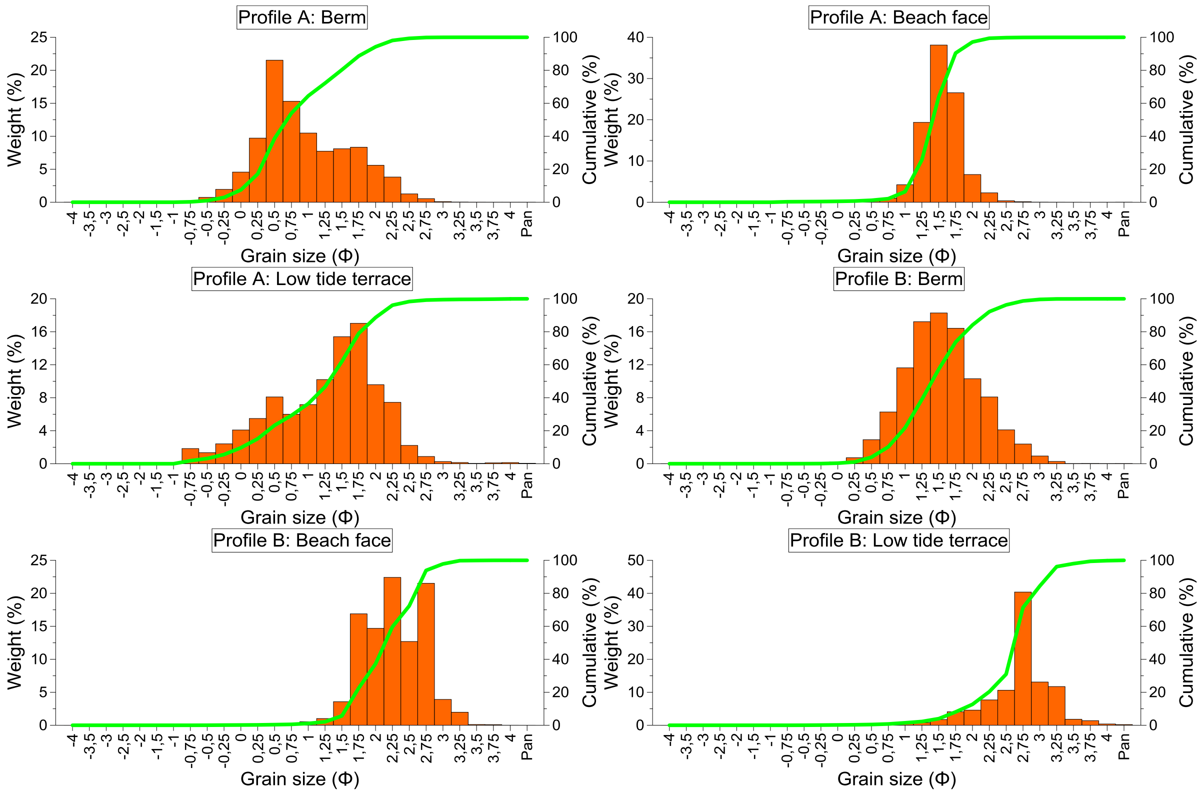

Fig. 3-141. Graphs showing the grain size distribution (%) and cumulative frequency curve (%) for the sediment samples taken at profiles A and B in August 2015

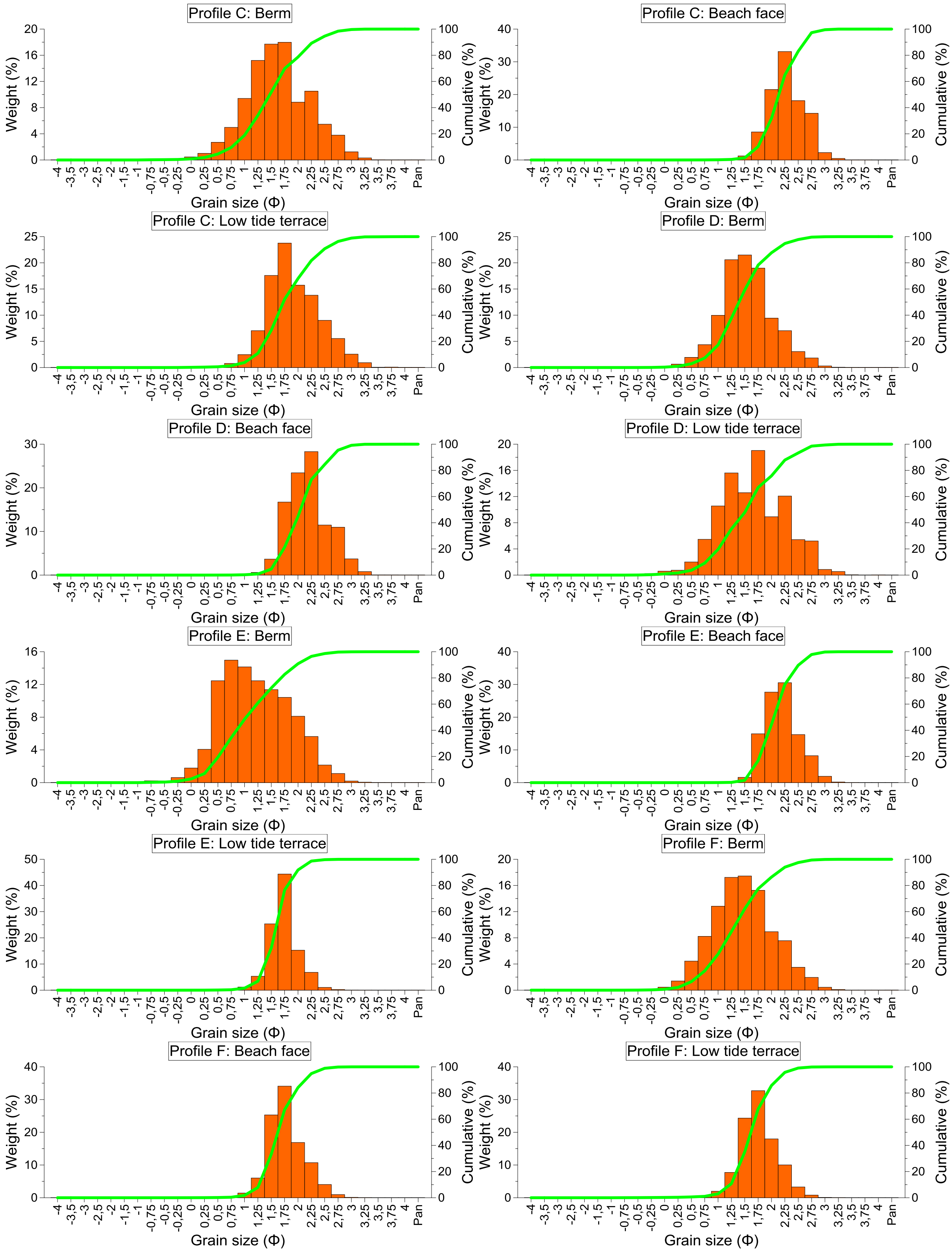

Fig. 3-142. Graphs showing the grain size distribution (%) and cumulative frequency curve (%) for the sediment samples taken at profiles C, D, E, and F in August 2015.

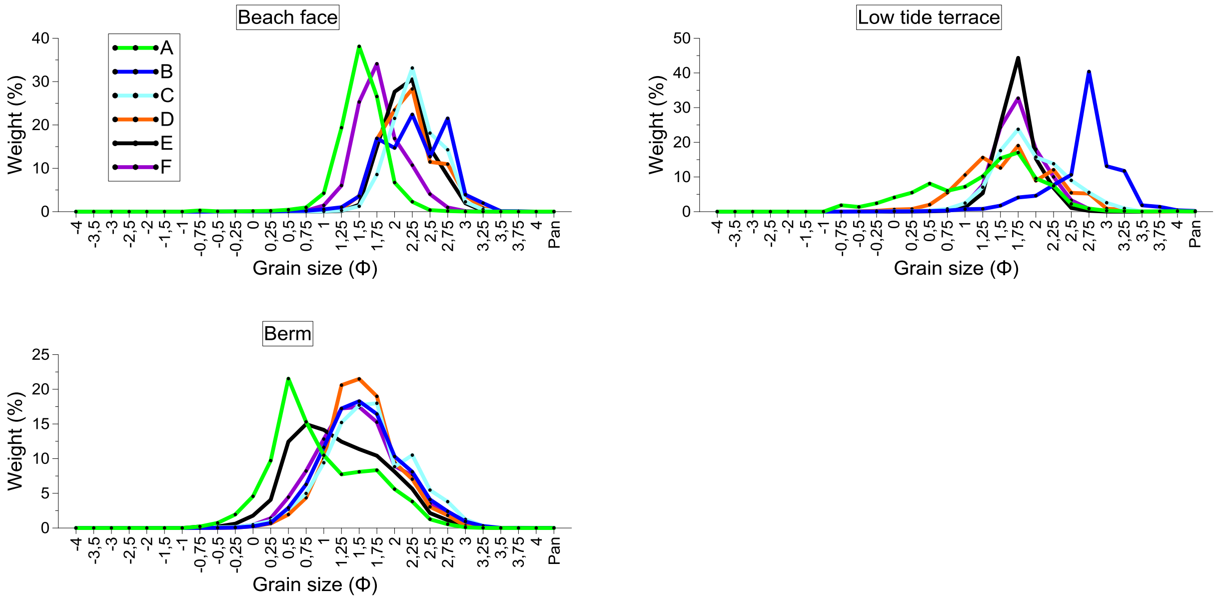

Fig. 3-143. Graphs compering the grain size distribution at every sample location in August, at each beach profile, to each other.

When the grain sizes at the same sampling locations, at different profiles, are compared to each other (fig. 3-143) a similar distribution of grain sizes over the beach face can be seen as were observed in July. The samples from the beach face were coarsest at profiles A and F, or medium sand, while the rest of the samples were fine sand. The samples from the terrace do however not show this trend, as all the samples were medium sand, except from Profile B which was fine sand. At the berm the sample from Profile A was coarse sand while the other samples were medium sand.

Table 10. Textural characteristics of sediments from the beach profiles for August 2015

	Profile A			Profile B			Profile C		
	Berm	B. Face	Terrace	Berm	B. Face	Terrace	Berm	B. Face	Terrace
Mean (M_Z)	0,827	1,398	1,141	1,418	2,131	2,564	1,502	2,144	1,774
Sorting (σ)	0,678	0,292	0,782	0,565	0,450	0,473	0,601	0,339	0,494
Skewness (S_K)	0,296	0,011	-0,275	0,079	-0,011	-0,186	0,064	0,038	0,177
Kurtosis (K_G)	0,896	1,108	0,920	1,054	0,772	1,450	1,019	1,003	0,988
	Profile D			Profile E			Profile F		
	Berm	B. Face	Terrace	Berm	B. Face	Terrace	Berm	B. Face	Terrace
Mean (M_Z)	1,415	2,057	1,530	1,077	2,051	1,595	1,335	1,644	1,623
Sorting (σ)	0,482	0,387	0,617	0,649	0,331	0,280	0,579	0,340	0,347
Skewness (S_K)	0,087	0,079	0,028	0,113	0,064	0,051	0,052	0,128	0,070
Kurtosis (K_G)	1,113	1,004	0,917	0,865	1,065	1,275	1,039	1,029	1,042

Table 11. Description of the textural characteristics of the sediments samples from the beach profiles for August 2015

	Profile A			Profile B		
	Berm	**B. Face**	**Terrace**	**Berm**	**B. Face**	**Terrace**
Mean (M_Z)	Coarse Sand	Medium Sand	Medium Sand	Medium Sand	Fine Sand	Fine Sand
Sorting (σ)	M. Well Sorted	Very Well Sorted	Moderately Sorted	M. Well Sorted	Well Sorted	Well Sorted
Skewness (S_K)	Fine Skewed	Symmetrical	Coarse Skewed	Symmetrical	Symmetrical	Coarse Skewed
Kurtosis (K_G)	Platykurtic	Mesokurtic	Mesokurtic	Mesokurtic	Platykurtic	Leptokurtic
Mode	Bimodal	Unimodal	Bimodal	Unimodal	Trimodal	Unimodal
	Profile C			**Profile D**		
	Berm	**B. Face**	**Terrace**	**Berm**	**B. Face**	**Terrace**
Mean (M_Z)	Medium Sand	Fine Sand	Medium Sand	Medium Sand	Fine Sand	Medium Sand
Sorting (σ)	M. Well Sorted	Very Well Sorted	Well Sorted	Well Sorted	Well Sorted	M. Well Sorted
Skewness (S_K)	Symmetrical	Symmetrical	Fine Skewed	Symmetrical	Symmetrical	Symmetrical
Kurtosis (K_G)	Mesokurtic	Mesokurtic	Mesokurtic	Leptokurtic	Mesokurtic	Mesokurtic
Mode	Bimodal	Unimodal	Unimodal	Unimodal	Unimodal	Trimodal
	Profile E			**Profile F**		
	Berm	**B. Face**	**Terrace**	**Berm**	**B. Face**	**Terrace**
Mean (M_Z)	Medium Sand	Fine Sand	Medium Sand	Medium Sand	Medium Sand	Medium Sand
Sorting (σ)	M. Well Sorted	Very Well Sorted	Very Well Sorted	M. Well Sorted	Very Well Sorted	Very Well Sorted
Skewness (S_K)	Fine Skewed	Symmetrical	Symmetrical	Symmetrical	Fine Skewed	Symmetrical
Kurtosis (K_G)	Platykurtic	Mesokurtic	Leptokurtic	Mesokurtic	Mesokurtic	Mesokurtic
Mode	Unimodal	Unimodal	Unimodal	Unimodal	Unimodal	Unimodal

3.3.5 September

In September (fig. 3-144) samples were collected from four locations at each profile from the berm, the beach face, the boundary, and the low tide terrace, resulting in 22 samples.

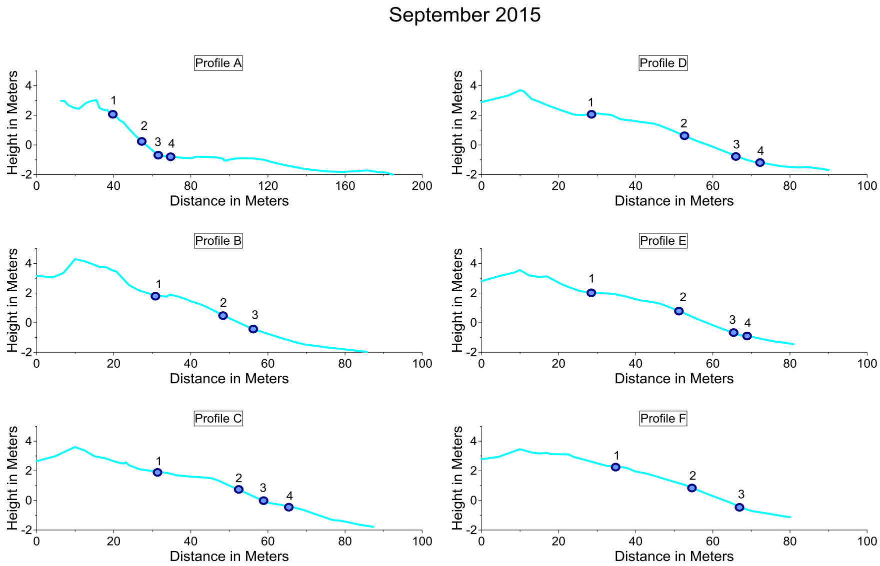

Fig. 3-144. The location of where each sample was taken on the beach profiles in September. Four samples were taken at each profile, from the berm (1), the beach face (2), the boundary between the beach face and the low tide terrace (3), and the low tide terrace (4).

At Profile A the coarsest sample was from the boundary, with very fine gravel, while the berm and the beach face were coarse sand and the terrace medium sand. The sorting ranged from m. well sorted to very well sorted, with the beach face sample being very well sorted, the berm moderately sorted and the boundary and the terrace samples m. well sorted. The berm sample was fine skewed, mesokurtic, and bimodal, the beach face sample was symmetrical, leptokurtic, and unimodal, the boundary sample was fine skewed, mesokurtic, and bimodal, and the terrace sample was coarse skewed, leptokurtic, and bimodal. At Profile B the berm had m. well sorted coarse sand while the beach face and the boundary had medium sand where the beach face was well sorted and the boundary was m. well sorted. The berm sample was fine skewed, mesokurtic, and bimodal, the beach face sample was symmetrical, platykurtic, and bimodal, and the boundary sample was very coarse skewed, mesokurtic, and trimodal. At Profile C the berm sample had the coarsest sediment, or coarse sand, while the beach face, the boundary, and the terrace were all medium sand. The beach face sample was very well sorted and the other three were well sorted. The berm and the terrace samples were symmetrical and mesokurtic, where the berm sample was unimodal while the terrace sample was bimodal. The beach face and the boundary samples were fine skewed, mesokurtic, and unimodal. At Profile D the berm sample was the coarsest, with coarse sand, while the beach face, the boundary and the terrace samples were medium sand. The sorting varied from moderately sorted at the terrace, to well sorted at the berm and the boundary, and very well sorted at the beach face. The berm sample was symmetrical, mesokurtic, and unimodal, the beach face sample was coarse skewed, leptokurtic, and unimodal, the boundary sample was fine skewed, mesokurtic, and trimodal, and the terrace sample was fine skewed, platykurtic, and trimodal. At Profile E the berm had the coarsest grain size, or coarse sand, while the beach face, the boundary, and the terrace had medium sand. The boundary was m. well sorted while the other three samples were well sorted. The berm and the beach face samples were symmetrical, while the boundary sample was fine skewed, and the terrace sample was coarse skewed. All four samples were mesokurtic and the boundary sample was bimodal while the other three were unimodal. At Profile F the berm sample was m. well sorted coarse sand, the beach face was very well sorted medium sand, and the boundary sample was well sorted medium sand. The berm sample was symmetrical while the beach face and the boundary samples were fine skewed. The berm and the beach face samples were mesokurtic and unimodal, while the boundary sample was leptokurtic and bimodal. The Grain size distribution (%) and cumulative frequency curve (%) for the 24 sediment samples taken in May 2015 can be seen in fig. 3-145, fig. 3-146, and fig. 3-147m, while the grain sorting statistics can be seen in Table 12 and in statistical terms in Table 13.

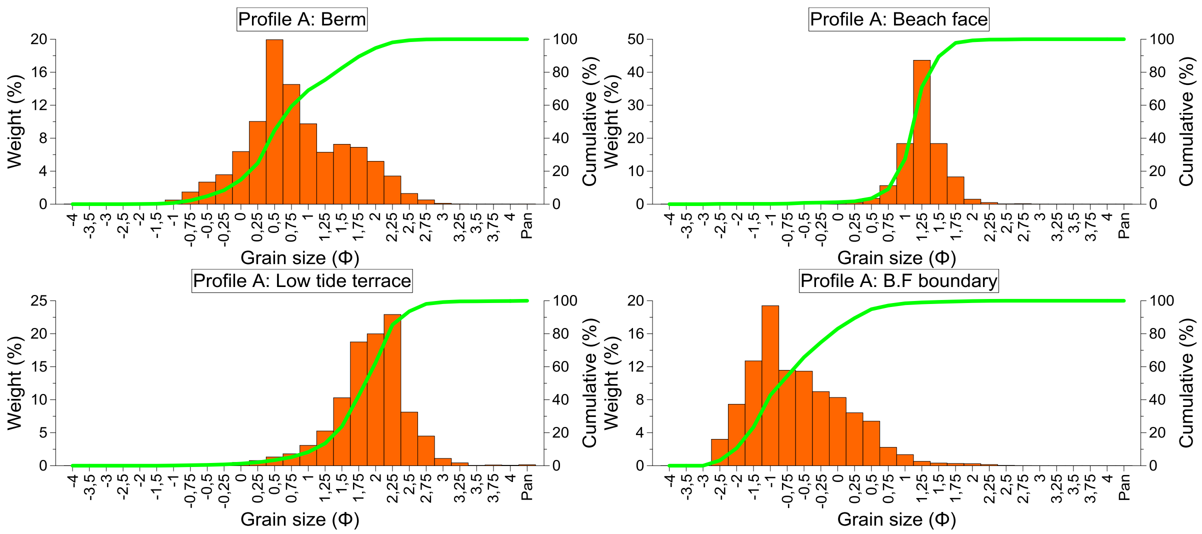

Fig. 3-145. Graphs showing the grain size distribution (%) and cumulative frequency curve (%) for the sediment samples taken at profile A in September 2015.

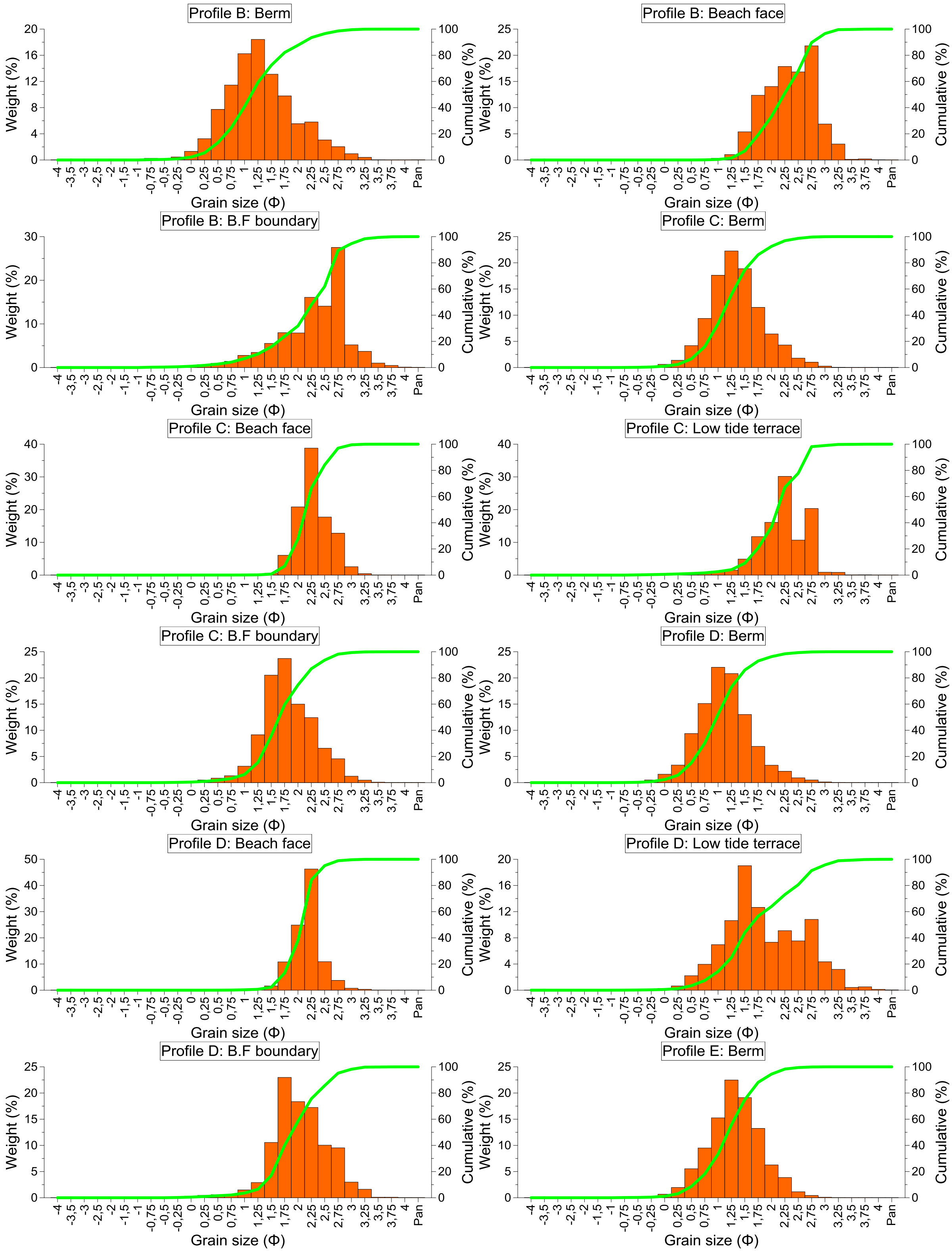

Fig. 3-146. Graphs showing the grain size distribution (%) and cumulative frequency curve (%) for the sediment samples taken at profiles B, C, D, and E in September 2015.

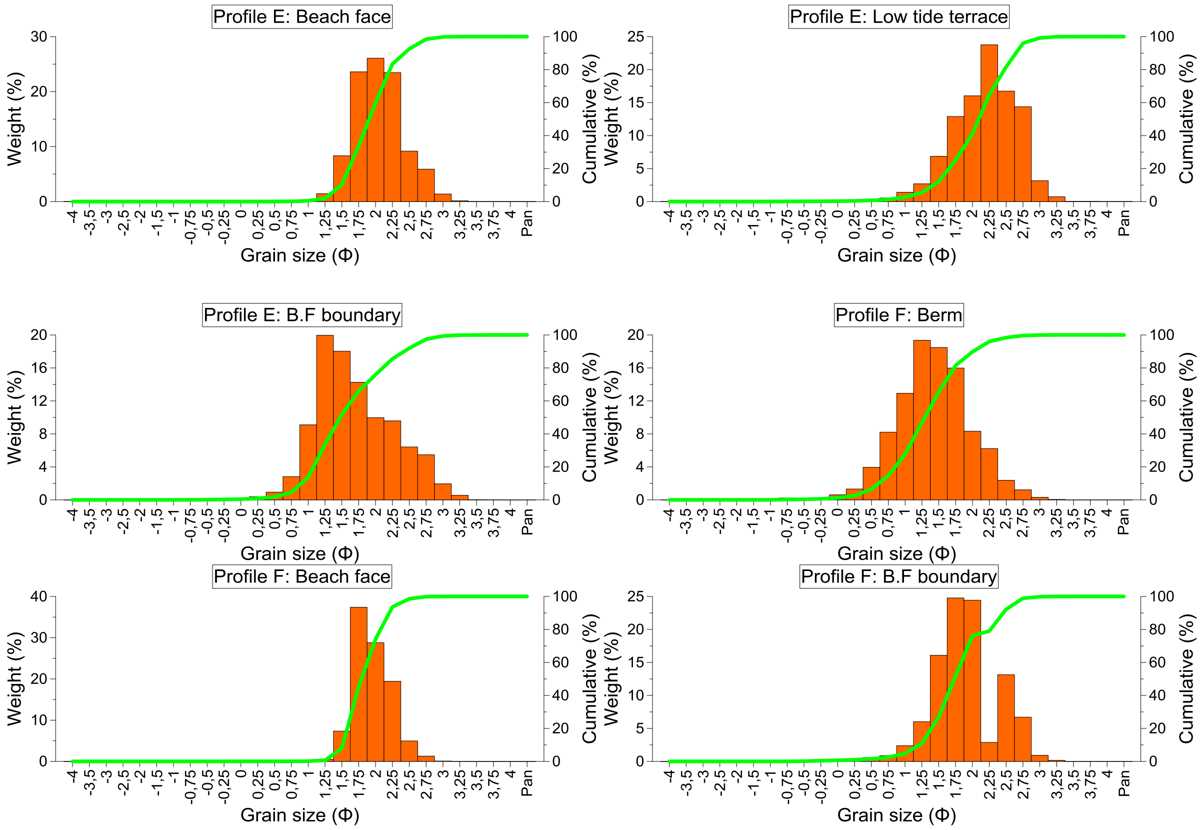

Fig. 3-147. Graphs showing the grain size distribution (%) and cumulative frequency curve (%) for the sediment samples taken at profiles E and F in September 2015.

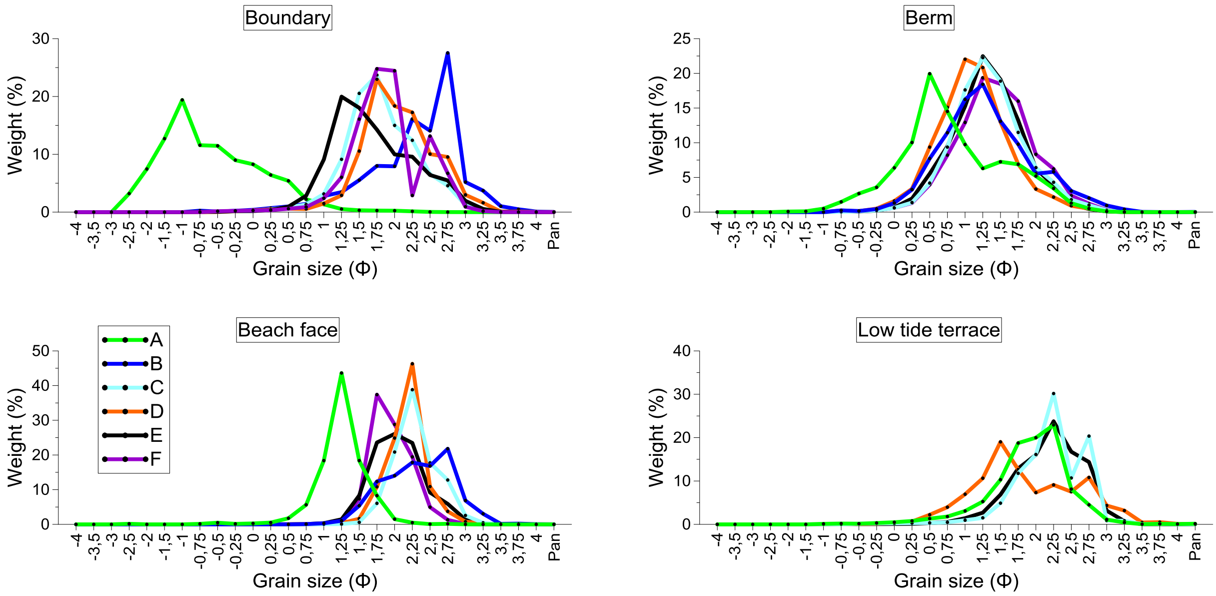

Fig. 3-148. Graphs compering the grain size distribution at every sample location in September, at each beach profile, to each other.

When the grain sizes at the same sampling locations, at different profiles, are compared to each other (fig. 3-148) the grain size trends observed in July and August continue. The sample from Profile A had the coarsest material of the boundary, or very fine gravel, while there was medium sand at the other five. The beach faced showed the same distribution of grain size by profiles, where the sample from Profile A was coarse sand while the other five were medium sand. The terrace did not show any change along the beach, with medium sand at the four profiles that were sampled. The grain size of the berm had increased and was now coarse sand at every profile, indicating removal of finer material by wind. This process seems to have started between July and August, as before August all berm samples had been medium sand, but by July the berm grain size had increased at Profile A. The reason for this increase in grain size could be linked to increased wind speeds in the latter part of the summer season, between July and August, and August and September, where an increase in southerly winds, compared to the earlier months of the summer season, was also observed.

Table 12. Textural characteristics of sediments from the beach profiles for September 2015

	Profile A				Profile B			Profile C			
	Berm	**B. Face**	**Boundary**	**Terrace**	**Berm**	**B. Face**	**Boundary**	**Berm**	**B. Face**	**Boundary**	**Terrace**
Mean (M_Z)	0,225	0,624	-1,224	1,284	0,665	1,691	1,657	0,700	1,660	1,188	1,604
Sorting (σ)	0,756	0,313	0,694	0,512	0,640	0,479	0,627	0,499	0,319	0,488	0,448
Skewness (S_K)	0,212	0,003	0,222	-0,177	0,145	-0,085	-0,320	0,097	0,108	0,133	-0,069
Kurtosis (K_G)	1,070	1,342	0,936	1,248	1,066	0,841	1,062	1,104	1,055	1,074	0,923
	Profile D				**Profile E**				**Profile F**		
	Berm	**B. Face**	**Boundary**	**Terrace**	**Berm**	**B. Face**	**Boundary**	**Terrace**	**Berm**	**B. Face**	**Boundary**
Mean (M_Z)	0,481	1,519	1,436	1,240	0,672	1,403	1,065	1,564	0,784	1,314	1,292
Sorting (σ)	0,491	0,260	0,491	0,740	0,500	0,366	0,580	0,472	0,534	0,281	0,496
Skewness (S_K)	0,070	-0,152	0,121	0,190	0,005	0,072	0,228	-0,113	0,020	0,183	0,160
Kurtosis (K_G)	1,109	1,166	1,026	0,898	1,064	1,029	0,923	0,938	1,049	0,946	1,276

Table 13. Description of the textural characteristics of the sediments samples from the beach profiles for September 2015

	Profile A				Profile B		
	Berm	**B. Face**	**Boundary**	**Terrace**	**Berm**	**B. Face**	**Boundary**
Mean (M_Z)	Coarse Sand	Coarse Sand	Very Fine Gravel	Medium Sand	Coarse Sand	Medium Sand	Medium Sand
Sorting (σ)	Moderately Sorted	Very Well Sorted	M. Well Sorted	M. Well Sorted	M. Well Sorted	Well Sorted	M. Well Sorted
Skewness (S_K)	Fine Skewed	Symmetrical	Fine Skewed	Coarse Skewed	Fine Skewed	Symmetrical	Very Coarse Skewed
Kurtosis (K_G)	Mesokurtic	Leptokurtic	Mesokurtic	Leptokurtic	Mesokurtic	Platykurtic	Mesokurtic
Mode	Bimodal	Unimodal	Bimodal	Bimodal	Bimodal	Bimodal	Trimodal

	Profile C				Profile D			
	Berm	**B. Face**	**Boundary**	**Terrace**	**Berm**	**B. Face**	**Boundary**	**Terrace**
Mean (M_Z)	Coarse Sand	Medium Sand	Medium Sand	Medium Sand	Coarse Sand	Medium Sand	Medium Sand	Medium Sand
Sorting (σ)	Well Sorted	Very Well Sorted	Well Sorted	Well Sorted	Well Sorted	Very Well Sorted	Well Sorted	Moderately Sorted
Skewness (S_K)	Symmetrical	Fine Skewed	Fine Skewed	Symmetrical	Symmetrical	Coarse Skewed	Fine Skewed	Fine Skewed
Kurtosis (K_G)	Mesokurtic	Mesokurtic	Mesokurtic	Mesokurtic	Mesokurtic	Leptokurtic	Mesokurtic	Platykurtic
Mode	Unimodal	Unimodal	Unimodal	Bimodal	Unimodal	Unimodal	Trimodal	Trimodal

	Profile E				Profile F		
	Berm	**B. Face**	**Boundary**	**Terrace**	**Berm**	**B. Face**	**Boundary**
Mean (M_Z)	Coarse Sand	Medium Sand	Medium Sand	Medium Sand	Coarse Sand	Medium Sand	Medium Sand
Sorting (σ)	Well Sorted	Well Sorted	M. Well Sorted	Well Sorted	M. Well Sorted	Very Well Sorted	Well Sorted
Skewness (S_K)	Symmetrical	Symmetrical	Fine Skewed	Coarse Skewed	Symmetrical	Fine Skewed	Fine Skewed
Kurtosis (K_G)	Mesokurtic	Mesokurtic	Mesokurtic	Mesokurtic	Mesokurtic	Mesokurtic	Leptokurtic
Mode	Unimodal	Unimodal	Bimodal	Unimodal	Unimodal	Unimodal	Bimodal

4 Discussion

4.1 The affect that snow and ice have on the beach profile at Sandbukt Beach

The effects of ice on beaches has been studied in great detail over the decades, especially on ice piling and ice ridges, as well as the freezing of sediments on the beach face (Rosen, 1978; Taylor, 1978; Nielsen, 1988; Rodzik and Zagórski, 2009; Short and Wiseman, 1974; Zumberge and Wilson, 1953; Nielsen, 1988; Reinson and Rosen, 1982; Lantuit and Pollard, 2008). The effects of these ice structures and processes include increased erosion of the beach face, decreased erosion where ice foots are formed, decrease in aeolian activity, and formation of different morphological features. At Sandbukt, from November 2014 to April 2015, snow and ice was present on the beach. The snow and ice cover was mostly confined to the backshore, but reached the berm crest and the upper beach face on several occasions during neap tides. Frost plaid a large part as well, as the upper sediment layers of the backshore, the beach face, and the low tide terrace were often frozen during the winter season. Three snow and ice processes that were in play during the winter season 2014 - 2015 at Sandbukt Beach are, (I) formation of thick layers of snow and ice on the berm and the berm crest that possibly reduce erosion, (II) freezing of the top sediments of the beach face and the low tide terrace during low tides, and subsequent thawing of the sediments once the tide starts to rise again, and (III) sediment accumulation on the snow and ice cover.

(I) The formation of the ice cover started most likely once the first permanent snow had fallen on the backshore, between November and December. At December the 9th, the snow cover was still fairly thin, but had started to grow in thickness and the snow front on the upper beach face had been eroded slightly by the last high tide. By January the thickness of the snow and ice cover had increased significantly, and a large erosional scarp had been formed at the ice front on the berm crest. The scarp seems to have been created by run-up on the beach face, as the ice had collapsed in front of it. Since the snow does not accumulate in great quantity below the berm crest, it is likely that waves reach the snow and ice cover only during storms or very high tides. During the one year cycle, five storms from the north hit Sandbukt beach, and caused extensive erosion during three of those storms. Three of these storms hit Sandbukt beach while there was a thick snow on the berm and a ice-step on the berm crest, while the other two hit when there was no snow or ice on the beach. Of the three storms that caused erosion, only one was during a time where ice-step was present on the beach, in March, but by that time the snow and ice on the beach had started to recede slightly. The other two storms in January hit the beach during the time when there was a thick layer of snow and ice on the berm and the berm crest. The storms in March and July did not occur during high tide, and therefore had little chance of effecting the backshore.. The latter of the two storms in January occurred during high tide, much like the storm in November, but caused no erosion on the upper beach face or the berm as had occurred in November. Instead, the erosional scarp in the ice front that had formed between December and January, was increased, but the scarp was more vertical and not undercut (fig. 4.2). The lack of undercutting and the vertical scarp might suggest that waves had broken on the ice front, instead of wave run-up reaching it. Sand was also intergraded into the ice, further suggesting that waves broke on the ice front, as sand is often intergraded into ice on the shore when waves break at the ice (Zumberge and Wilson, 1953). This suggest that during the storm in late January waves reached the berm crest and would have possibly eroded parts of the berm, like occurred during the storm in November, if it had not been for the snow and ice cover. Another example of this process can be seen clearly at profile A, where erosional scarp in the ice was formed on the berm crest (fig. 4.1), while the beach face was lowered by a few cm. The storm in November caused some erosion of the berm at Profile A, but during both the storms in January, the berm seems to have remained stable. This is most likely due to the ice found there and the freezing of sediments underneath the ice. Studies have shown that ice formed on beaches can play an important role in reducing wave action during the winter (Zumberge and Wilson, 1953; Rosen, 1978; Rodzik and Zagórski, 2009). It is therefore possible, under certain circumstances, that the ice cover reduces the wave energy that the berm at Sandbukt Beach would otherwise be subjected to during storms, preventing or reducing the erosion that might occur. This would have to be study further to confirm such an effect, with more frequent measurements during the winter season.

(II) When the top part of sediment is frozen on the beach face during low tide, it can be covered with sediment or be broken up and eroded away when the tide starts to rise again (Short and Wiseman, 1972; Reinson and Rosen, 1982). In January and February 2015 an erosion of the low tide terrace and the beach face was observed when the top few mm of sediments were frozen. The sediments were frozen solid, but once the tide started to rise again, the frozen layer was broken up and removed by the swash, causing a lowering in elevation by a few millimeters. No measurements were made of the extent of the erosion, as the GPS is not accurate enough to measure such a small change. This erosion caused by

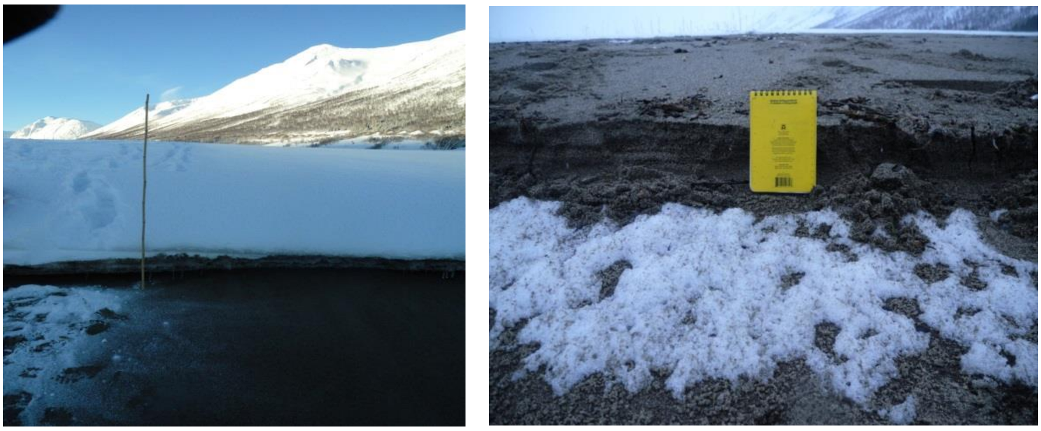

Fig. 4.1. Photos showing the erosional scarp at Profile A. In February (on the left) the berm was still covered with snow and ice, but by March 31st (on the right) the snow and ice had been removed and the scarp was visible.

Fig. 4.2. Photos showing the erosional scarps in January (on the right) and in February (on the left). Pieces of ice that have collapsed as the ice front was undercut can be seen on the photo from January, while there is very litle undercutting in February.

freezing could play a significant part in the erosion of the beach face and the low tide terrace during the winter months, that is if the eroded layer is not immediately deposited again once the tide rises. This process, although small in scale, could cause extensive erosion over long periods of time as the beach is exposed to this kind of erosion frequently. It would therefore be quite interesting to compare the erosion rate of the beach face when the temperature is well below zero and when it is above freezing, and to see if the erosion on the beach face lasts.

(III) The snow and ice cover prevents aeolian erosion on the berm during most of the winter season, but some accretion occurs as sand is deposited on top of the snow at the berm. The top layer of the beach face and the low tide terrace are often frozen, which decreases the available material that can be reworked by aeolian processes and brought up on the ice cover. The sand that is deposited on the snow cover forms thin layers and these layers then get interbedded when snow is added on top of it. Once the ice starts to recede during the spring, the sand accumulates on top of it and gets deposited on the berm once the ice has been completely removed. The features created by this process seem not to be permanent and play little to no role in beach profile change, apart from the few mounds that remained at Profile B and altered the morphology of the berm slightly (see c. 4.2).

4.1.1 Summary

Snow and ice is a large part of the beach system at Sandbukt Beach, since the beach is has snow on it for large parts of the year. The snow and ice seems to have had some influences on the beach profile, but the effects were not long lasting and the beach recovered from its winter state quickly. In order to fully ascertain the range of the effects snow and ice have on Sandbukt Beach, the beach should be studied in greater detail during the winter season, as well as a daily monitoring of the ice cover on the beach before and after storms and when spring thaw begins.

4.2 The welding of sandbars as a possible factor in spit, berm, and beach ridge building at Sandbukt Beach

The movement of sandbar near beaches have been studied extensively (Sallenger et al., 1985; Lippmann and Holman, 1990; Brander, 1999; Masselink et al., 2006; Masselink et al., 2008; Price et al., 2014), where sandbars tend to migrate offshore during storms and onshore during calmer conditions. The results at Sandbukt indicate that, at least the small sandbar in front of Profile A, does not behave in the same manner during storms, as there were no indications of offshore movement of the bar throughout the one year cycle, even during storms from both the north and the south. The onshore migration of the sandbar seems to have been continuous. During the one year cycle, the sandbar in front of the beach at Profile A migrated closer to the beachface and in doing so raised the low tide terrace. It is not entirely accurate to say that the sandbar migrated, but rather that material from the bar was transported over it as a large sand dune, and the area that has been designated as the low tide terrace in this paper might just be a runnel, but will be referred to as the low tide terrace here for continuation. These sand dunes were then welded to the beach, at first on the low tide terrace and later on the beach face.

In November 2014 the sandbar had one large dune close to the low tide terrace. By January, a large part of the dune had been transported on to the terrace, and had raised it by about 25 cm, and was almost at the same height as the sandbar at that time (fig.4.3 A). From January to March the remaining parts of the dune was transported onto the terrace and the lower part of the beach face, extending the beach facer further outward and decreasing the width of the low tide terrace and increasing the gradient of it, so it was dipping a little towards the sandbar. By April the low terrace had been lowered again, to the level it had in January, and another sand dune had started to move in (fig. 4.3 B). Between April and June, the dune continued to migrate closer to the beach face, while there were no major changes to the position of the beach face or the low tide terrace. Between June and August the sand dune migrated even closer to the beach face, and was split into two by the drainage channel. The drainage channel had been in a similar position between April and June, but now began to migrate along with the dune (fig. 4.3 C). In September the dune was still migrating closer, and another dune can be seen on the end of the profile measured then (fig. 4.3 D). By October the dune was almost at the beach face, but the dune in September cannot be seen as the profile line in October did not extend far enough out. The position of the dune in October 2015 is almost exactly the same as it was in November 2014, but is considerable higher in elevation (fig. 4.3 E).

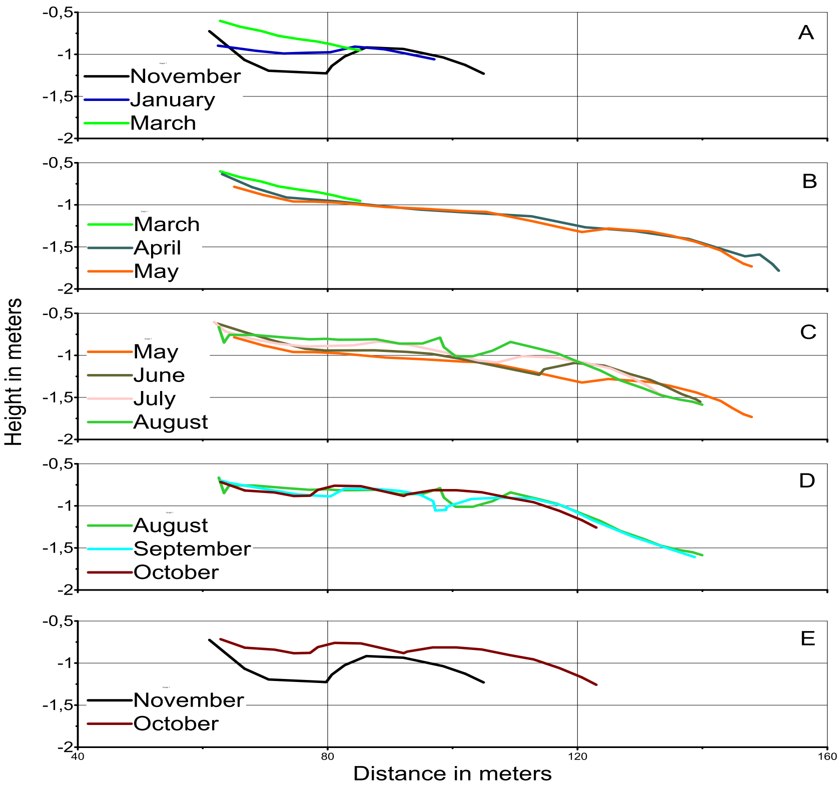

Fig. 4.3. The migration of sand dunes on the sand bar, from November 2014 to October 2015.

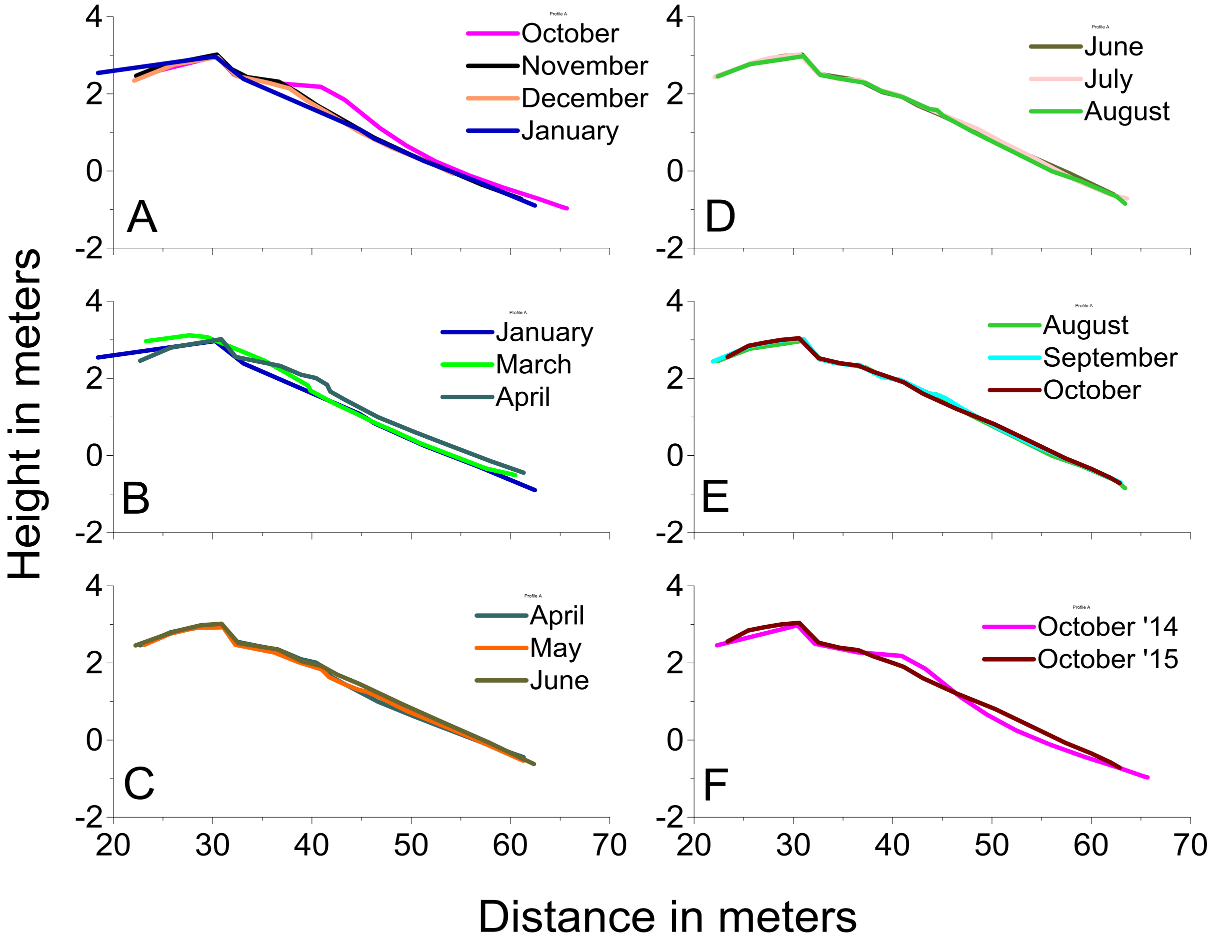

Fig. 4.4. The beach face at Profile A during the one year cycle.

The beach face did not show the same accretion as the low tide terrace during the one year cycle but the beach width increased during the cycle and the overall profile of the beach face lies higher in October 2015 than it did in October 2014 (fig. 4.4 F). After the erosion of early November 2014, the beach face was stable until March (fig. 4.4 A and B). Between March and April, both the berm and the beach face were raised, at the same time as the sand dune was migrating up the beach face, and continued to be raised until June (fig. 4.4 B and C). After April the beach face remained mostly stable until October, with small areas of both erosion and accretion (fig. 4.4 D and E). It seems clear that the material from the sand dune is brought in to the low tide terrace, raising it, and then is moved up the beach face, adding material as high as at the berm, increasing both the width of the berm and the beach face. The only time during the one year cycle that material was added to the berm at Profile a was in April, shortly after the sand dune had been moved onto the low tide terrace.

It seems therefore clear that the small sandbar is causing accretion on the beach near Profile A, by raising the low tide terrace, or filling in the runnel, and pushing material up the beach face. The one year cycle is however not long enough period of time to follow the completion of this sandbar welding and its effect on the upper part of the profile there. If aerial photographs are examined, similar events seem to have happened in the past.

An aerial photograph was taken over Sandbukt Beach on the 23rd of July in 2004 (fig. 4-5). The exposure of the sandbars in Breivika River, and outside the spit, indicate that the photo was taken during a low tide. On the photo, a collection of sandbars can be seen on the north-eastern part of the spit and extend out some distance from the beach. The main outlet of Breivika River was along the left side of the valley and the transport of suspended material is clearly visible. A small sandbar (1) was in front where profile A is, and the small sandbar is almost identical to the one that is there today, both in size and layout. The larger sandbar (2), to the north of the small one, is unlike the sandbar that is today at Sandbukt, but the location of the outer parts are similar. When this photo is compared with a aerial photograph, taken in August in 2006 (fig 4-5), large changes in the position and the size of the sandbar has occurred. By 2006 the sandbars seem to have been pushed up onto the beach, and increased the width near profile A, and created a small spit (2). The smaller spit (2), which was present in 2004 as well, seems to have diminished in size. The welding of the small sandbar (1), and the southern part of the larger sandbar, on to the beach could be responsible for the increased width of the beach in the area and the creation of the small beach ridge that is in front of the modern beach ridge, but ends just north of Profile A (see chapter 4.1.1.1). The two aerial photographs were taken during different tide height and therefore the size of the beach in 2006 seems smaller, as the tide is higher on the photo from 2006, but there does not seem to be any signs of large sandbars to the east of the spit, as well as less material in suspension outside the beach. By 2011, both of the spits (2 and 3) have been altered, where the smaller spit (3) had decreased considerably in size and has almost disappeared. The larger spit (2) is similar in size as it was in 2006, but is bent more to the west than it used to be. Between 2011 and October 2014, it seems that the sandbars have grown again, to a similar size and extent as they were in 2004. The larger spit also seems to have been bent more to the west (fig. 4.6), much like between 2004 and 2011, but it is hard to tell if that is the case when comparing an aerial photograph to a photograph taken at similar height as the spit itself.

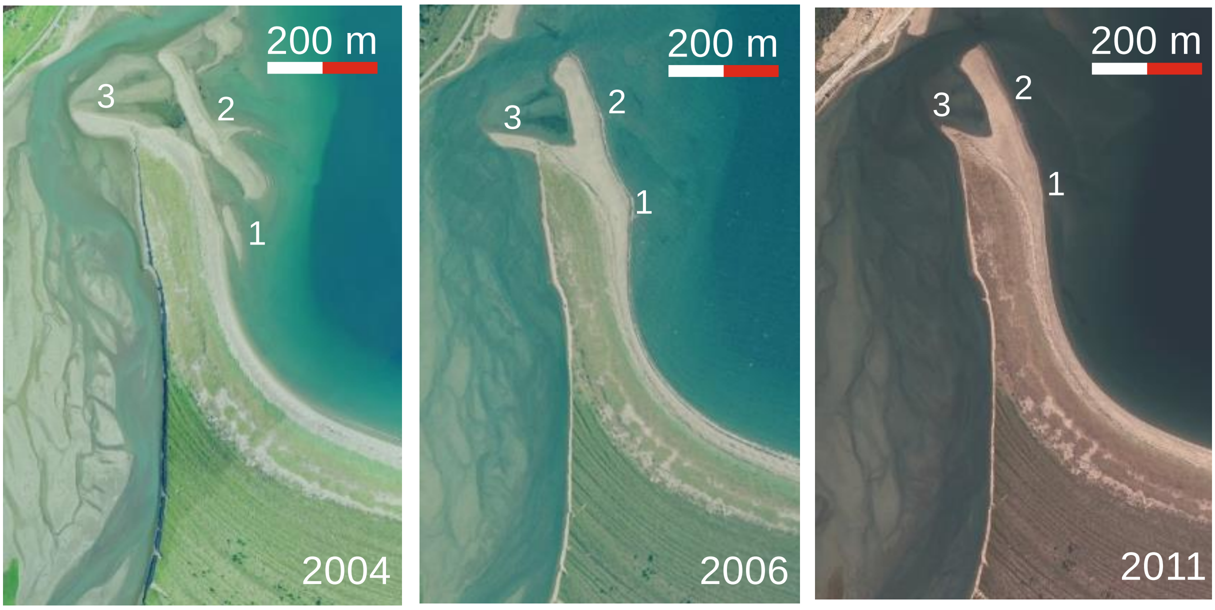

Fig. 4.5. Aerial photographs of the spit at Sandbukt Beach, taken in 2004 (on the left), 2006 (in the middle), and 2011 (to the right). Large changes in the size and location of both the sandbars (1 and 2) and the two small spits (2 and3) can be seen, with decreasing size in the sandbars and both decrease and increase in the size of the smaller spits.

Fig. 4.6. Photo of the spit, taken north of it in March 2015. The larger sandbar can be seen, as well as the end of the larger spit and the smaller spit. The curve of the larger spit is well evident.

A similar pattern emerged if aerial photographs from the mid to late 20th century are examined. In 1968, the beach shape is different than it is compared to 2004 (fig. xx). The top of the beach is more „pointy“ than it is in the decades following, and both the eastern and western sides are almost straight. There is a large sandbar on the eastern side, similar in shape and size to that of the sandbar in 2004, but further to the south. By 1986 (fig. 4-7), the top of the beach has become wider, and the eastern side of it has a bulge on it, making it less straight than in 1968. There is also a sandbar present on the eastern side of the spit in 1968, and a small sand spit on the north-west side of the beach end. There seems to have been mild erosion on the western side of the beach end as well, as the western side is no longer straight but has small bends in it. This could possibly be due to the tide level, as it seems to have been much higher when the photo was taken in 1986 than in 1968. The increase tidal height does however not explain the increase in the width at the eastern side, It is therefore likely that a

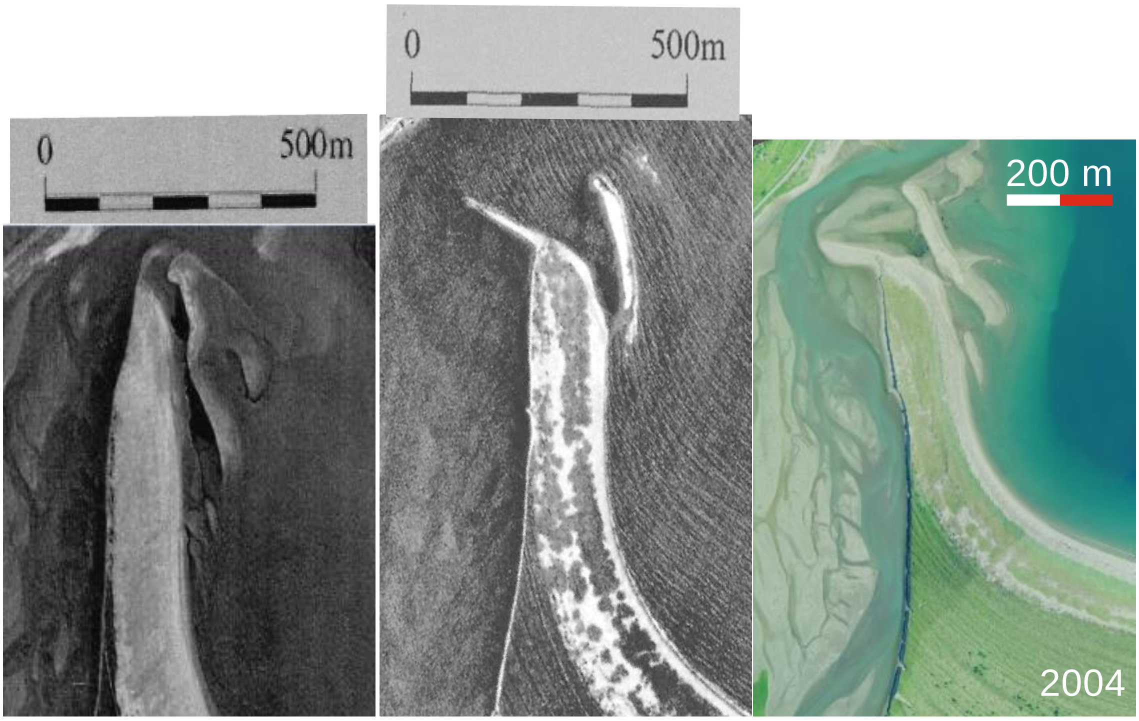

Fig. 4-7. Aerial photographs of the spit at Sandbukt Beach in 1968 (on the left), 1986 (in the middle) and 2004 (on the right).

similar welding occurred to the sandbar in 1968, as it seems to have occurred between 2004 and 2006. It is possible that the sandbar in 1986 was also welded to the beach, and subsequent sandbars that might have formed between 1986 and 2004, as the spit in 2004 has undergone changes since 1986. Fjalstad (1986) went over five aerial photographs from 1952-1979, and found that the small spit had grown and moved further to the west and north-west during that period (fig. 4-8).

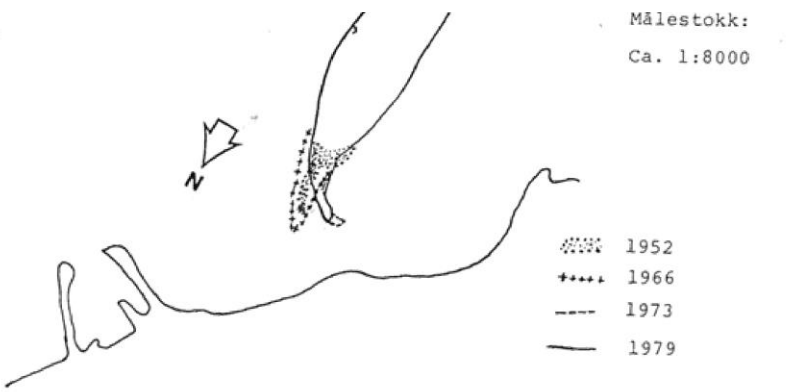

Fig. 4-8. The evolution of the sand spit at Sandbukt Beach from 1952 to 1979. From Fjalstad, 1986.

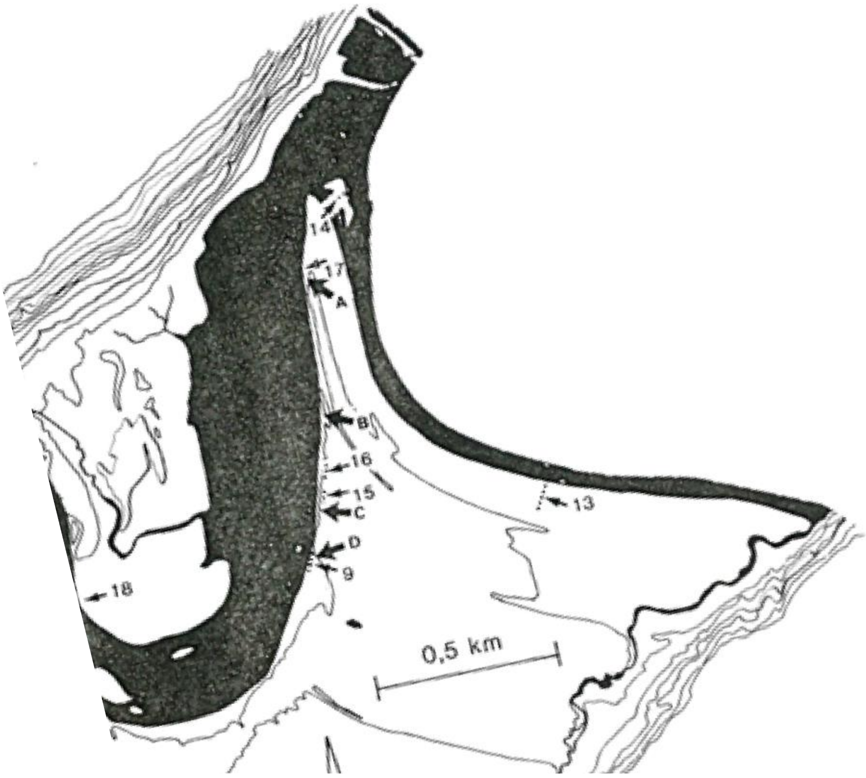

Fig. 4-9. Map of Sandbukt Beach, showing the four locations (A, B, C, and D) where erosion was measured from 1984-1985. From Fjalstad, 1986.

While the northern and eastern sides of the beach at the outlet of Breivika River are growing, the western part is being eroded by the river. Fjalstad (1986) observed erosion by Breivika River in 1984 and 1985, on its eastern side, eroding into the field of raised beach ridges. He observed four locations (fig. 4-9) and two of them are on the northern part of the beach. There the erosion was 0,8 m in 1984 and 0,6 m in 1985 at location A, while the erosion was 0,65 m in 1984 and 0,35 m in 1985 at location B. There was erosion at location C and D as well, eroding parts of the field of raised beach ridges. Despite the extensive erosion, the thickness of the beach near the outlet of Breivika River seems to have remained similar, this suggest that the amount of material that is added to the eastern side of the beach is similar to the amount eroded on the western part. The erosion and the accretion have, over the last few thousand years, have caused the northern part of the beach to bend to the east. The formation of the sandbars is presumably caused by the sediment brought in by the river, where the highest amount of sediments is brought in during spring thaw. The creation of the sandbars could therefore occur either by continual increase in sediments in the area during a few years in succession, or when there is unusually thick snow cover in Breivika valley which results in larger spring flood than during a normal year.

The presence of a sandbar near the spit, and welding of said sandbar in the following years, removal of most of the sandbars from the area, and then reappearance of a new sandbar, suggest cycles of creation and welding of the sandbars in front of Breivika Rivers mouth. The larger spit that is currently at Sandbukt, is more likely to be the remnants of an sandbar that has been welded on the beach, rather than a spit created by longshore current. It would also seem that sandbars that have been formed in the past have been welded on to the beach in similar fashion, and cause growth of the beach both to the north and to the east. The spits at Sandbukt beach are therefore likely not spits in its general term, but rather the remnants of sandbars that have been welded on to the beach. Once the sandbars have been welded on the beach, they are compressed which increases their height and a new berm and possible a new beach ridge is formed behind the newly formed beach part. The sandbars that are currently present at Sandbukt Beach should therefore be welded up on to the beach in the coming year, a process that has already started as seen at profile A. This could explain the high number of small, poorly developed, beach ridges on the beach near Profile A. The number of raised beach ridges in the immideate area behind the modern day beach ridge are equall at all profiles, except at profile A (fig. xx) where they are more numerous and smaller. In the 120 meters behind the modern beach ridge, there are two raised ridges behind profiles B, C, D, and E, while there are at least four, and arguably six. The ridge which is closest to the modern ridge at Profile A, has three peaks, and is either one large ridge with three minor ridges on it, or they are three seperate ridges with only small swales between each. These small ridges that are near Profile A could have been eroded away behind the other profiles, as the large swale behind the modern beach ridge at profile B, C, D, E, and F has been linked with aeolian erosion there during the little ice age (Fjalstad, 1986). The width and depth of the swale is quite similar to the next swale, with a ridge inbetween them that is similar in size as the one before that , and therefore the erosion does not seem to have been extensive, at least not so that it created a uniqely large swale. It also fails to explain why there would have been erosion in the swale behind most of the beach, but not at the spit. The higher number of beach ridges near Profile A, and being less in size than the other parts of the modern ridge, could explain why the ridge in Profile section A is smaller than at the rest of the beach (fig. 4-10). If indeed the beach ridge formation is escalated in Profile section A due to the welding of sandbars, the beach ridge there does not have the same amount of time to grow as another ridge is formed in front of it, depriving the older ridge of sand brought in by both waves and aeolian processes.

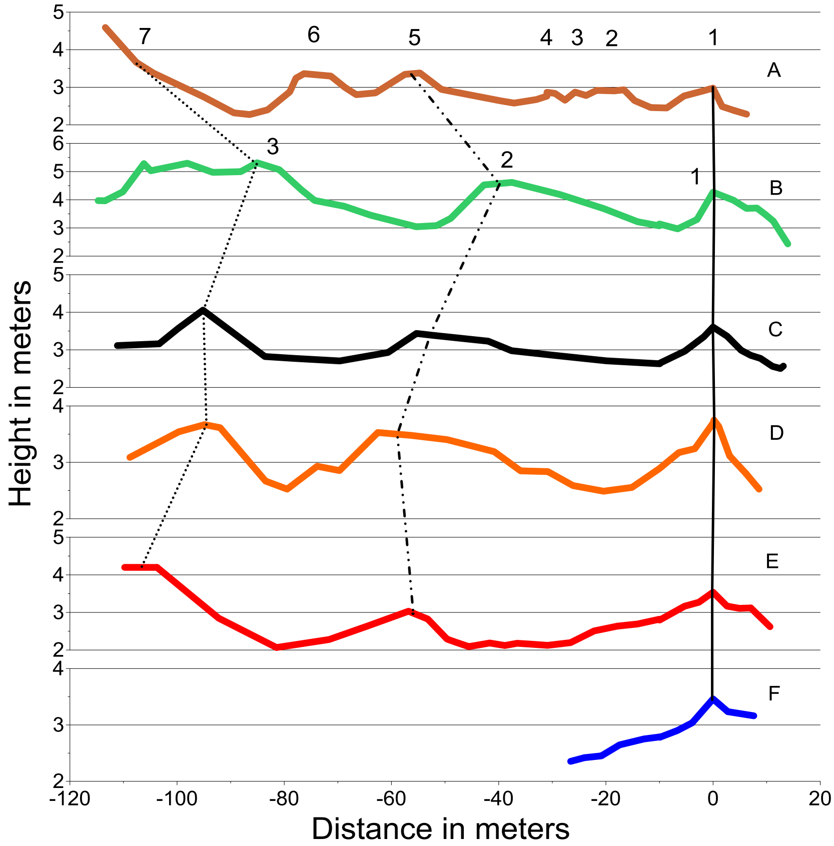

Fig. 4-10. The field of raised beach ridges behind each profile at Sandbukt Beach. The 0 m point is at the top of the modern beach ridge at each profile. The number of beach ridges in the near vicinity of the modern ridge is similar for profiles B, C, D, and E, but behind Profile A there are at least two, if not four, more beach ridges.

5 Conclusions

The monthly profile measurements at Sandbukt Beach showed a greater tendency for erosion during the winter season than the summer season, and the beach profile was less stable. The beach width and volume was decreased during the winter season, but was increased during the summer season. From October 2014 to October 2015, the beach volume increased at every profile, resulting in a net accretion on the beach during the one year cycle.
The shoreface morphology at Sandbukt Beach reflects the deltaic input on the northern part of the beach, as the shoreface has a steep slope on the northern side, while the shoreface slope gradient is less steep on the southern side. It also suggests that sediments on the southern part of the shoreface are more heavily reworked than sediments on the northern side.
Erosion of the beach profile mainly occurs during storms with northerly winds that hit when the tide is high. The southern part of the beach is more exposed to waves, and erosion is greater there than on the northern side of the beach. The tidal height during the storms plays a significant role in the erosion of the beach, as it controls where the erosion will occur on the beach profile. A runnel is formed on the beach as a response to beach face erosion during storms. Waves can only reach the backshore when storms coincide with high tide levels, and when that occurs, the berm may be completely removed on the middle- and the southern-part of the beach. When storms occur at, or near low tide, the beach face is eroded and a runnel and a swash bar is formed where the erosion occurred. Storms with southerly winds do not have the same effect on the beach profile as storms with northerly winds, as the winds do not facility greater wave height at the beach.
Snow and ice may play a large role in reducing the amount of wave energy the backshore is exposed to during storms at high tide. This results in less erosion of the backshore, allowing the berm to be built up further.
The grain size distribution showed potential longshore current at the beach, running from the north to the south. The grain size at Profile F is often greater than at Profile E, suggesting that coarser sediments are brought on to the beach there either by waves or Filma Stream.
The grain size at the berm increased during the summer season, most likely due to removal of finer sediments by aeolian processes during predominantly northern winds in the summer.

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Appendix A

Table 14. The Euref89 UTM33 coordinates of the pegs that were placed at Sandbukt Beach

Profile	A		
	Peg 1	7.735.329.164	680.146.162
	Peg 2	7.735.330.635	680.158.573
Profile	B		
	Peg 1	7.735.026.523	680.208.230
	Peg 2	7.735.031.904	680.216.588
Profile	C		
	Peg 1	7.734.832.185	680.446.863
	Peg 2	7.734.841.289	680.450.911
Profile	D		
	Peg 1	7.734.734.492	680.732.473
	Peg 2	7.734.744.107	680.735.044
Profile	E		
	Peg 1	7.734.678.007	681.033.253
	Peg 2	7.734.687.837	681.034.922
Profile	F		
	Peg 1	7.734.636.606	681.213.423
	Peg 2	7.734.645.940	681.216.885