FIELD REPORT

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Field work in Wahlenberg fjorden	AT-211, Ice Mechanics, Loads on Structures and Instrumentation Date 10-17. April 2015
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Summary

Field work was conducted on ice over a period of 3 days (12-14 April 2015), in Wahlenberg fjorden located on "Nordaust landet", an island north-east of Spitsbergen.

We travelled by a boat called "Bjørkhaug", and the entire "boat cruise" lasted for 8 days.

We conducted several TDS measurements on the ice, but concentrated more about physical properties of a small iceberg nearby. We did CTD, ADCP and permeability measurements, as well as scanning and underwater photographing of the iceberg.

The results from the field work will be presented in the report.

Keywords, English:
Ice mechanics
Ice berg investigations
ADCP (Acoustic Doppler Current Profiler), CTD (Conductivity Temperature Density), TDS (Temperature Density Salinity)

Abstract

This report covers field investigations conducted over three days, on the ice in Wahlenbergfjorden on Nordaust landet (Svalbard). The field investigations was conducted during a boat cruise in the course AT-211, “Ice mechanics, Loads on structures and instrumentation”, planned by the University center of Svalbard (UNIS).

The purpose of the field work was to obtain knowledge about ice structures (Ice berg), physical properties and typical instrumentation used during ice investigations. Temperature, salinity and density profiles of layer ice were measured. An iceberg was scanned and mapped, CTD and ADCP measurements were done around the iceberg. Permeability tests were conducted.

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1. Introduction

An investigation on formation of sea ice is important to constructional engineering and estimations of loads on ice. Depending on given speed, wind speed/direction, salinity, temperature, density and conductivity, it is possible to map certain ice features. We have been focused mainly on an Iceberg located in the Ice sheet in Wahlenberg fjorden. We made current, temperature and salinity profiles of the water underneath the iceberg. The Iceberg was scanned, and also measured underneath the ice by photographing. It is of special interest to know the depth of the iceberg, because such features are potentially dangerous to offshore structures, as well as ship trafficking.

The report contains descriptions and data from the mentioned methods we used, and we will try to describe the size and different features of the iceberg. We will also present some salinity, temperature, permeability and density measurements done on the ice in Wahlenberg fjorden.

1.1 Background

On April, 12-14 we performed the following field investigations on the ice in Wahlenbergfjorden:

- Termistorstring profiling (not included in report)
- Temperature core sampling (TDS), two core samples
- Salinity and density core sampling (TDS), two core samples
- Scanning of iceberg
- Ice thickness profiling
- Preparing ice cores for studying in laboratory
- Conducting experiments on measuring permeability
- Assisting an ice freezing experiment (not included in the report)
- Acoustic Doppler Current Profiling (ADCP instrumentation)
- Conductivity Temperature Density profiling (CTD)
- Photographing and filming underneath the iceberg with a GoPro camera.
- Measuring Salinity on the boat with salinity meters (cores taken from first day)

1.2 Site information

We conducted the ice investigation in Wahlenberg fjorden, located on Nordaust landet north east of Svalbard. The coordinates were 79.655N and 19.956E. Nordaust landet are cut off from Spitsbergen by “hinlopenstredet”, and are the second largest island on Svalbard.

In figure 1.2.1, the “red dot” marks were we did the ice investigations.

Figure 1.2.1 - Location of Wahlenbergfjorden where we did our investigations. (Marked with red dot). Image adopted from wikipedia

2. Field investigations

2.1 TDS measurements

13.04.2015 TDS measurements were performed on the sea ice in Wahlenbergfjorden. Three core samples were taken, where the first was used for temperature measurements, and the two other was used for salinity and density measurements. We drilled the core samples with a Kovacs drill, and used a core cutter for density and salinity core sections.

For the temperature measurements, we used a thermometer. We took temperature measurements from the top of the core, 5 cm apart, to the bottom of the core. The snow depth was 14 cm, and the total core depth was 52 cm.

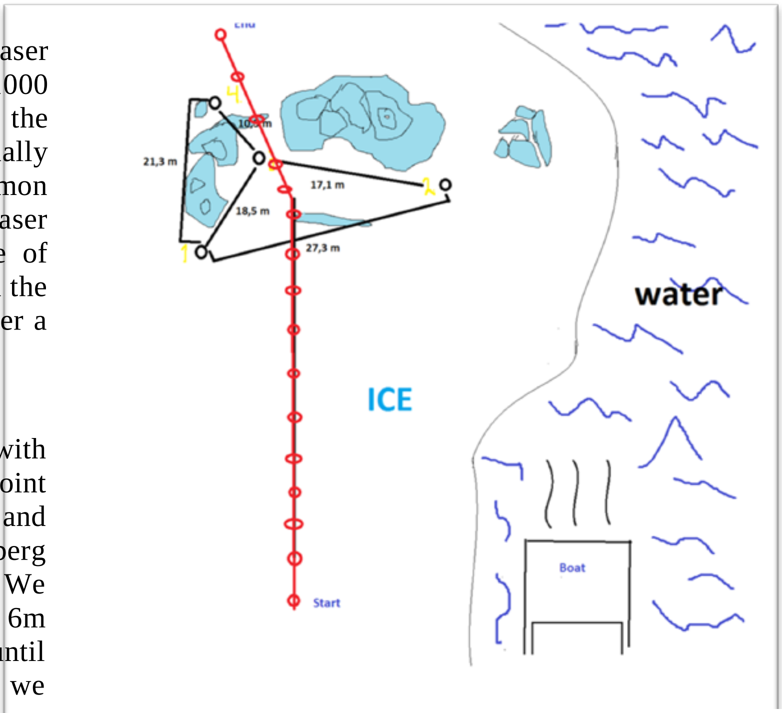
For density and salinity measurements, we cut the core sample in sections of 6.2 cm length. We measured weight, length and diameter of the cores to calculate the densities. The core sections, was then put in salinity boxes, melted, and measured with two salinity meters.

2.2 Scanning of Iceberg

The Iceberg was scanned by a laser scanner called Riegel VZ-1000 from 5 different points around the iceberg. The 5 scans were manually registered to each other by common points in each scan. The laser scanner gave points of surface of the ice berg, and then calculated the surface volume triangulation over a plane.

2.3 Ice thickness profiling

27 holes were drilled in the ice with an auger drill, from a start point located next to the boat, and through the part were the iceberg was located (see figure 2.3.1). We started with approximately 6m distance between the holes, until we reached the iceberg, where we drilled with 2-3m distance. Figure 2.3.1 is not up to scale, and is merely an illustration, to better understand the procedure.



Figur 2.3. 1 - Ice thickness profiling. (The red line shows the drilling path)

2.4 Acoustic Doppler Current Profiling (ADCP)

An Acoustic Doppler Current Profiling instrument measures water currents using acoustic waves and the Doppler effect. The instrument sends out acoustic waves that can be reflected with particles of the water, and returns to the instrument. Higher sound frequency means that the water is moving towards the instrument, while water particles moving away from the instrument gives lower frequency sound waves. The difference between frequencies of outgoing and incoming acoustic waves is called the Doppler shift, and the instrumentation uses this to calculate the water current speed.

4 holes was drilled with the Mora drill (diameter 35cm), around the iceberg (see figure 2.5.1).

The ADCP instrument was set in a hole, under the ice surface, and left in each hole for approximately 30 minutes.

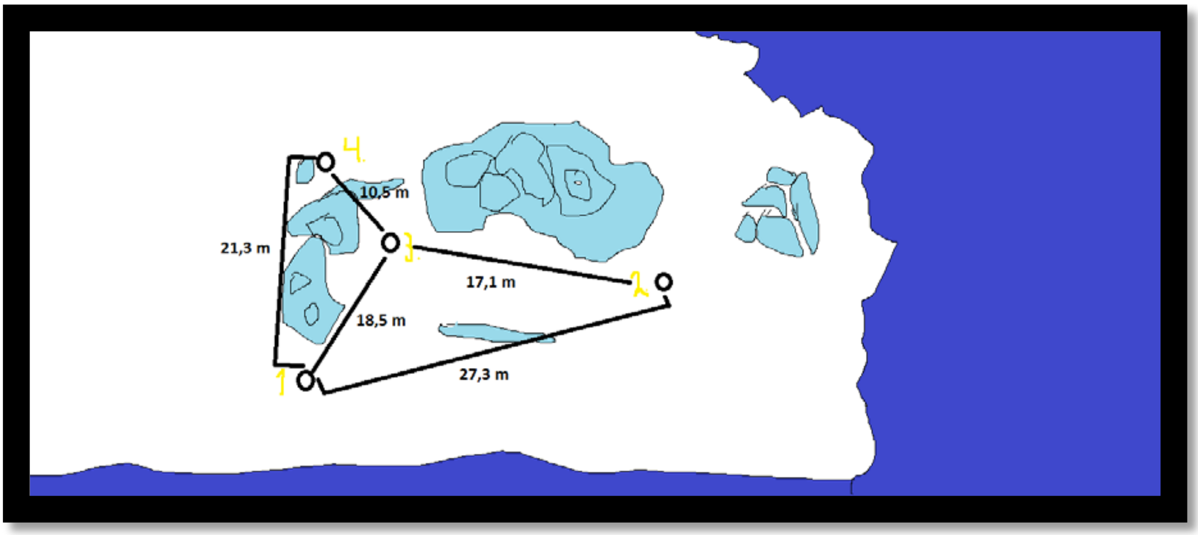


Figure 2.5.1 - Illustration of Iceberg. Showing the location of the 4 drill holes, and the distance between the holes.

Table 2.5.1 - Latitude and longitude coordinates for our 4 bore holes. (') is minutes, and ('') is seconds.

Hole number:	Coordinates latitude	Coordinates Longitude
1	79 39'18.0"N	19 57'27.0"E
2	79 39'18.8"N	19 57'24.2"E
3	79 39'18.2"N	19 57'23.6"E
4	79 39'17.9"N	19 57'22.6"E

2.5 Conductivity Temperature Density measurements (CTD)

Being lowered down The Conductivity Temperature Depth instrument is measuring conductivity, temperature and density of water. We lowered the instrument 190 m down, in each hole, and dragged it up. The device did measurements 4 times per second. The entire measurement took approximately 9 minutes in each hole. From this method, the salinity in each hole was calculated, from the conductivity data. Temperature and depth data were also obtained.

2.6 Photographs taken underneath the iceberg

A Go Pro camera was attached to a pole and lowered down into the 4 holes, taking pictures in different directions. We also tried to take pictures underneath the larger ice berg (ice bit), to estimate the thickness, with a rope/probe lowered in another hole closer to the iceberg. It was difficult to capture the entire iceberg in the pictures, so we also filmed underneath the ice. Before the filming started, a rope was lowered down with knots on each 2 meters. On the movie it is possible to observe the rope, and determine the depth by the knots.

2.6.1 Iceberg theory

An Iceberg is a large piece of freshwater ice that is broken of a calving glacier or an ice shelf, and is floating in open water. Because of the density difference between pure ice (ca 920 kg/m^3) and seawater (ca 1025 kg/m^3), typically one-tenth of the volume of the iceberg is above water. Ice berg is driven by wind and currents to the shore, and may very well freeze into the shore ice.

Icebergs are classified by size and shape. The latter is divided in tabular and non-tabular. Tabular icebergs have steep sides and a plateau at the top. Non-tabular icebergs are subdivided into: dome (Rounded top), pinnacle (one or more spires), wedge (steep edge and a slope on the other side), dry-dock, (eroded to form a slot or a channel), and blocky (steep vertical sides and a flat top, like a block).

2.7 Permeability measurements

The permeability experiment was conducted as a separate experiment, and we have explained the procedure and results in chapter [3.7].

3. Results

3.1 TDS measurements

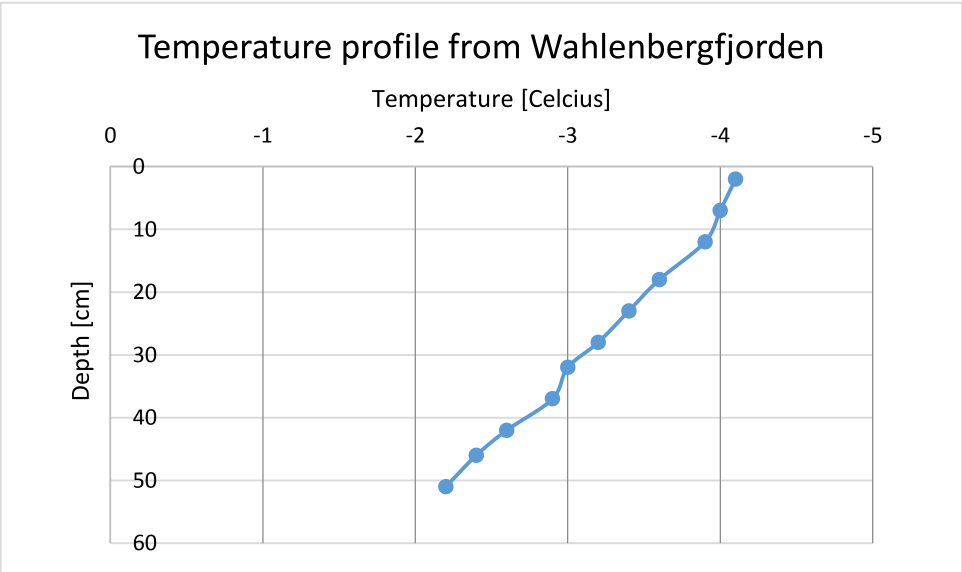
3.1.1 Temperature measurements (see chapter 2.1 for description)

The total core depth was 52 cm, with 14 cm of snow on top.

Table 3.1.1 - Temperature measurements conducted 12.04 on ice in Wahlenbergfjorden

Depth from top [cm]	2	7	12	18	23	28	32	37	42	46	51
Temperature [℃]	-4,1	-4,0	-3,9	-3,6	-3,4	-3,2	-3,0	-2,9	-2,6	-2,4	-2,2

The temperature increases from -4,1℃ at the top of the core, to -2,2℃ at the bottom. These results seem reasonable, because water freezes from the top and down. Sea water freezes at approximately -1,9℃, and the temperature is therefore lower at the bottom of the ice. A temperature profile is made in figure 3.1.1.



Figur 2.1.1 - Temperature profile from the Ice in Wahlenbergfjorden, with depth.

3.1.2 Salinity and Density measurements

We measured each section of the core that we cut, regarding weight, height (depth) and diameter. Density was calculated, and Salinity was measured. We made two core samples, and therefore we will present results for both of them.

Table 3.1.2.1 - First core sample. Shows measured weight, height, diameter and density.

Core	Depth from top [cm]	Weight [kg]	height [m]	Diameter [m]	Area [m^3]	Density [kg/m^3]
1	2 cm - 8,2 cm	0,21	0,062	0,07	0,000239	880,12
2	11,5 cm - 17,7 cm	0,238	0,062	0,07	0,000239	997,47
3	18 cm - 24,2 cm	0,238	0,062	0,07	0,000239	997,47
4	25 cm - 31,2 cm	0,237	0,062	0,07	0,000239	993,28
5	32 cm - 38,2 cm	0,236	0,062	0,07	0,000239	989,09
6	38,5 cm - 44,7 cm	0,236	0,062	0,07	0,000239	989,09
7	45 cm - 51,2 cm	0,236	0,062	0,07	0,000239	989,09
8	51,2 cm - 55 cm	x	x	x	x	x

The salinity was measured by two salinity meters, marked [41] and [42]. They showed different values, of temperatures and salinity, so it is hard to determine which value is the best. We made a salinity-depth and density-depth profile, to see how this varied. (figure 3.1.2.1).

Table 3.1.2.2 - First core sample. Shows core depth, and temperature, salinity measured by two salinity meters (41 and 42)

Salinity meter		**41**	**42**	**41**	**42**
Core	**Depth from top [cm]**	**Temp 1 [℃]**	**Temp 2 [℃]**	**Salinity 1 [ppt]**	**Salinity 2 [ppt]**
1	2 cm - 8,2 cm	21,7	23,8	9,37	9,05
2	11,5 cm - 17,7 cm	21,5	21,9	9,27	9,29
3	18 cm - 24,2 cm	21,2	21,8	8,01	7,93
4	25 cm - 31,2 cm	20,7	20,3	6,27	6,42
5	32 cm - 38,2 cm	22,2	24,1	5,89	5,68
6	38,5 cm - 44,7 cm	22,7	24,5	4,62	4,46
7	45 cm - 51,2 cm	21,9	22,1	3,94	3,98
8	51,2 cm - 55 cm	21,3	24	4,31	4,09

From the second core sample we got following results:

Table 3.1.2.3 - Second core sample. Showing weight, height, diameter and density of core sections

Core	Depth from top [cm]	Weight [kg]	height [m]	Diameter [m]	Area [m³]	Density [kg/m³]
1	2 cm - 8,2 cm	0,202	0,062	0,07	0,000239	846,59
2	12 cm - 18,2 cm	0,226	0,062	0,07	0,000239	947,18
3	19 cm - 25,2 cm	0,236	0,062	0,07	0,000239	989,09
4	26 cm - 32,2 cm	0,233	0,062	0,07	0,000239	976,51
5	36 cm - 42,2 cm	0,231	0,062	0,07	0,000239	968,13
6	42,2 cm - 48,4 cm	0,237	0,062	0,07	0,000239	993,28
7	50 cm - 54 cm	x	0,04	0,07	x	x

Table 3.1.2.4 - Second core sample. Showing depth, and temperature, salinity from the two salinity meters.

Salinity meter		**41**	**42**	**41**	**42**
Core	**Depth from top [cm]**	**Temp 1 [℃]**	**Temp 2 [℃]**	**Salinity 1 [ppt]**	**Salinity 2 [ppt]**
1	2 cm - 8,2 cm	20,6	22,3	6,65	6,44
2	12 cm - 18,2 cm	20,8	22,6	7,44	7,17
3	19 cm - 25,2 cm	22,2	24,2	5,76	5,52
4	26 cm - 32,2 cm	21,9	23	6,71	6,63
5	36 cm - 42,2 cm	22,6	23,8	5,26	5,18
6	42,2 cm - 48,4 cm	20,8	20,2	4,01	4,15
7	50 cm - 54 cm	20,7	24,5	5,17	4,79

The mark “X” in the tables above, means that the parameters was impossible to measure. The reason is that these cores were partly slushy, or was fractured, so that density calculations would be wrong.

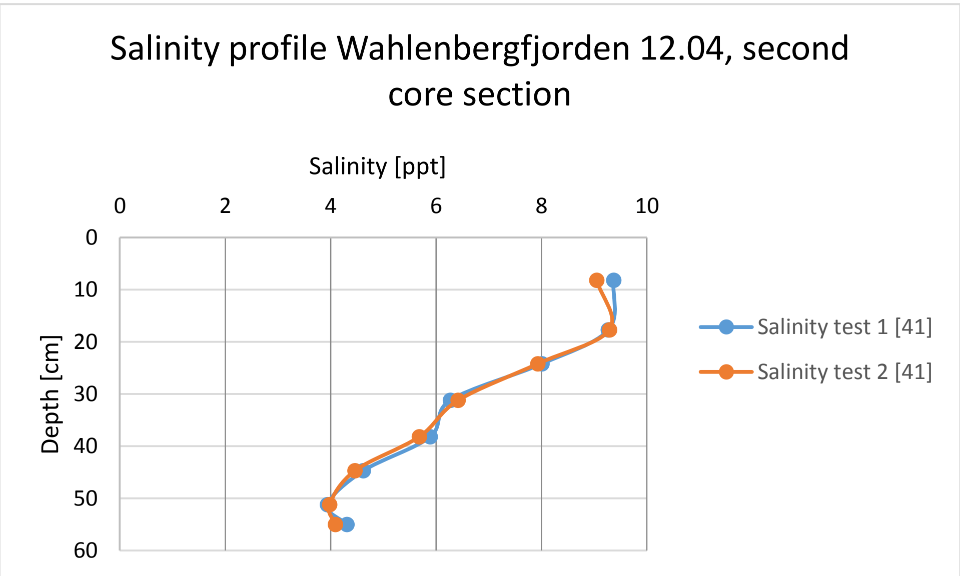


Figure 3.1.2.1 - Salinity profile taken from ice in Wahlenberg fjorden, first core.

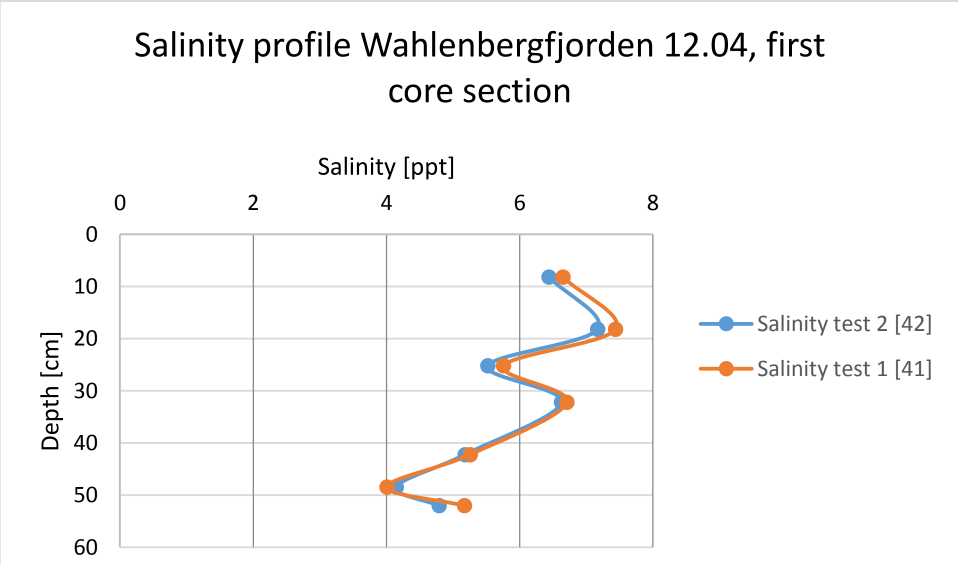


Figure 3.1.2.2 - Salinity profile from Ice in Wahlenberg fjorden, second core.

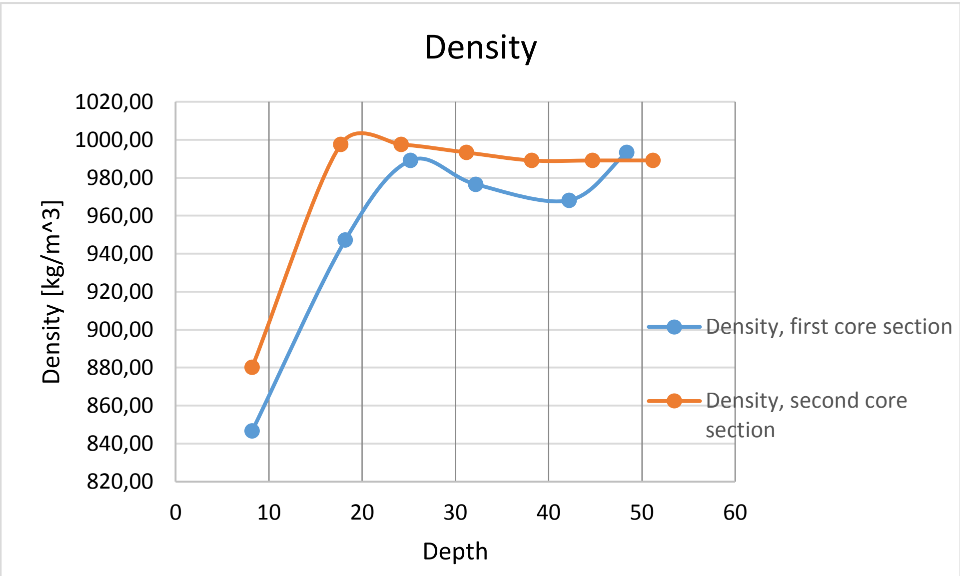


Figure 3.1.2.3 - Density profile calculated for ice in Wahlenberg fjorden

We made salinity and density profiles for the ice cores taken in Wahlenbergfjorden. From the first core (Figure 3.1.2.1), the salinity fluctuates quite a bit, but it is decreasing from the top and down. From the second core (Figure 3.1.2.2), the salinity are more stable, and decreases gradually from the top to the bottom. The salinity is probably high at the top of the ice, due to fast freezing. This traps the salt present in the water, during freezing. Deeper in the ice, the freezing process of water gradually becomes slower. The salt will “escape” the ice, which then results in lower salinity deeper down in the ice.

The density profile for the two cores (Figure 3.1.2.3), shows that the density is low at the top of the ice. This is because a lot of brine was trapped during the fast freezing process. Later brine drained out downwards under gravity and therefore has leaved a lot of air channels in the top layer of ice. The density increases with depth due to increase of brine content and decrease of air content. Porosity of bottom ice can be lower because of slower freezing process. Density values measured are pretty high, and this might be because of high brine content. Errors in weight, height and diameter values can also influence the results.

3.2 Scanning of Iceberg

The Ice berg was scanned from 5 different points. We got a graphic picture of the entire ice berg (Figure 3.2.2), the small bergy bit (Figure 3.2.4), and the large bergy bit (Figure 3.2.3). The surface area of the iceberg was given by the Riegel VZ-1000 laser scanner, and the surface volume was calculated. The volume and area of the ice berg is only estimates, and is presented in the table below.

Table 3.2.1 - Data estimations of ice berg surface area and volume. Data taken from the scanning

Part of ice berg	Surface volume [m^3]	Surface area [m^2]
Small half (small bergy bit)	198 m^3	459 m^2
Big half (large bergy bit)	558 m^3	1037 m^2
Total ice berg	784 m^3	1617 m^2

Figure 3.2.1 - Picture taken from above by a drone. Shows the ice berg that was scanned. Picture taken from Sebastian Sikora.

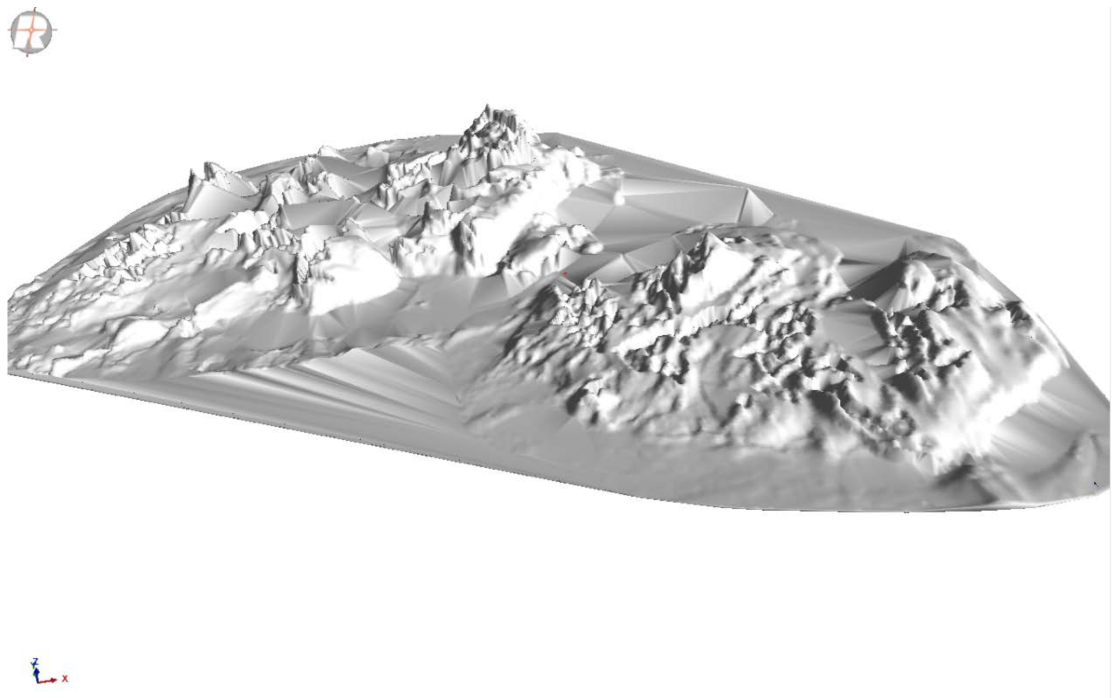


Figure 3.2.2 - Scanning result of the ice berg

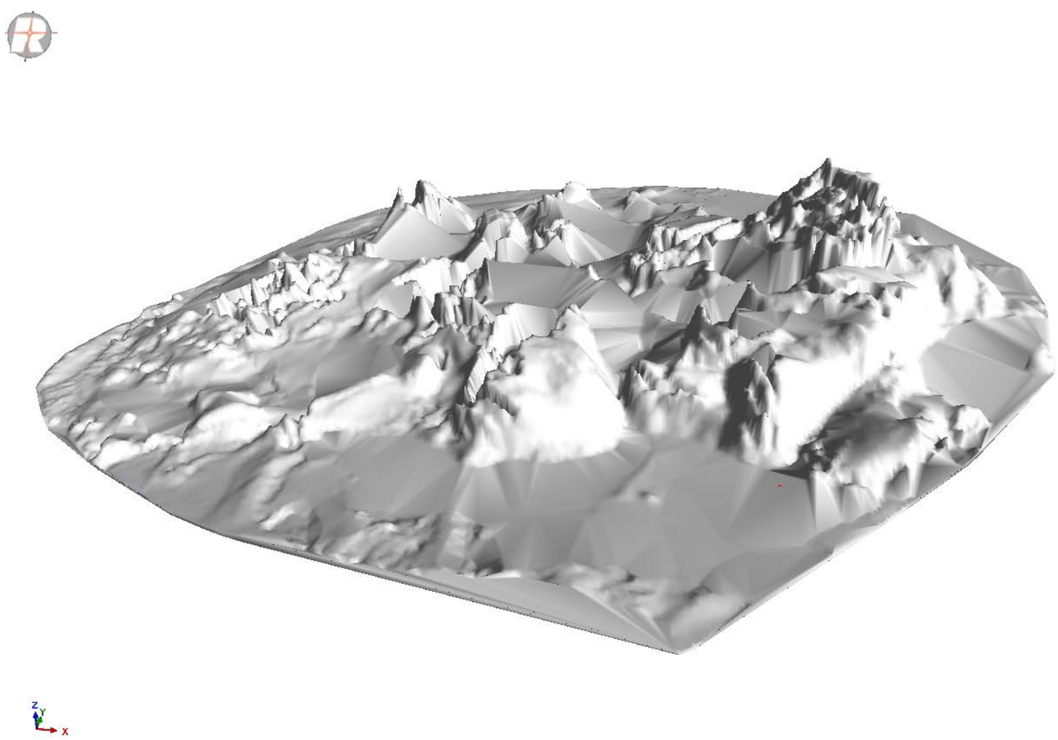


Figure 3.2.3 - Scanning result of the big half (large bergy bit), of the ice berg

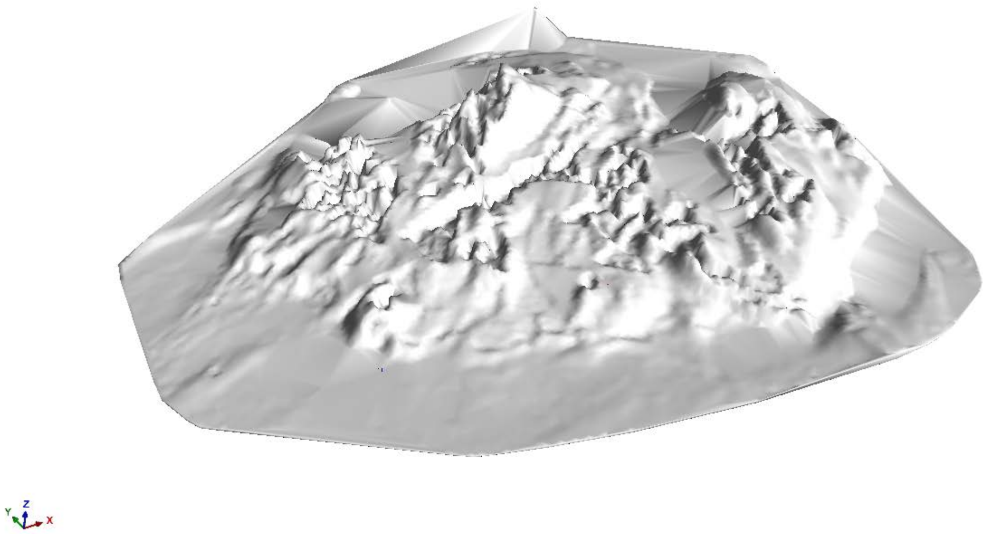


Figure 3.2.4 - Scanning of the small half (small bergy bit), of the ice berg

3.3 Ice thickness profiling

We drilled in total 27 holes over 111 m, and noted the ice depth. See Figure 2.3.1 for illustration of procedure.

Table 3.3.1 - Ice thickness profiling data.

Distance from start point [m]	0	6	12	18	24	30	36	42	48
Ice thickness [cm]	53	41	51	67	72	33	59	58	60
Distance from start point [m]	54	60	66	72	75	78	81	84	86,5 (ice berg starts)
Ice thickness [cm]	60	57	57	35	60	70	59	41	347
Distance from start point [m]	88,5	90,5	92,5	94,5	98,5	102,5	105	107	111
Ice thickness [cm]	283	57	64	60	63	140	467	70	26

The ice thickness is plotted versus distance in Figure 3.3.1.

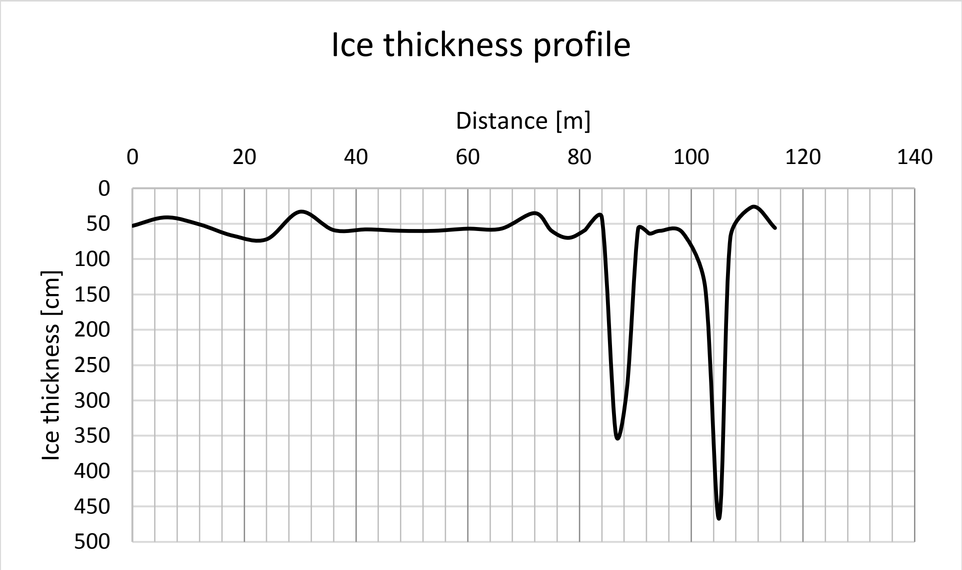


Figure 3.3.1 - Ice thickness plotted against distance.

We observe from Figure 3.3.1, that the ice thickness varies to some small degree on the level ice. This however, is a small variation, and is because of uneven ice surface at the bottom. At (86-88) m from the start point, there is 3.5 m ice depth, because this is where we meet the edge of the Ice berg (small bit). We also have another big ice thickness at 105 m from start, which are 4.7 m deep. It is possible to observe that the ice thickness is smaller to some degree around the ice bits. This might be because the ice berg is melting at the top because of radiation from the sun, and the melt water is running down the sides, and subsequently melting some of the ice.

3.4 Acoustic Doppler Current Profiling (ADCP)

After the “boat cruise”, we processed the data. The data was showing how the currents in the four holes were aligned. The points described in the figures, coincide with our 4 drilled holes.

Figure 3.4.1 shows the water currents for each of the four drilled holes (Figure 3.6.1) with north-east coordinates. Positive x-axis means that the water particles are moving in east direction and negative x-axis means movement in west direction. Positive y-axis gives north direction, and negative gives south direction. Each arrow at the 4 points is measurements at 1 meter depth. Subsequently, the color of the arrows becomes darker with increasing depth. The currents in points 1, 3 and 4 are moving in a western direction, and point 2 in an eastern direction.

In Figure 3.4.2 the vertical velocity is plotted against depth. Positive x-axis means that the current is moving up, while negative x-axis means that the current is moving down.

The measurement for point 3 (red line), at depth of 7.5 meters is probably wrong, because we only have 3 values from 15 profiles. This value should not be taken into account. At point 2 current is moving downward, under the big half of the iceberg, and current moves up in points 1, 3 and 4.

In the table 3.4.1 ADV data taken by another group at some distance from the iceberg is presented. ADV (Acoustic Doppler Velocimetry) uses the Doppler Effect to measure velocity of water particles at one point with high frequency. These measurements were taken at approximately same time with ADCP profiling near the iceberg. The direction of water currents taken by ADV and ADCP is quite different, but the absolute values are of the same order.

Time, hh-mm	East velocity, cm/s	North velocity, cm/s	Vertical velocity, cm/s
11-08	2.92	7.27	-0.44
11-28	6.42	6.78	-0.11
11-48	2.67	3.33	-0.51
12-08	8.14	0.37	0.4

Table 3.4. 1 ADV data

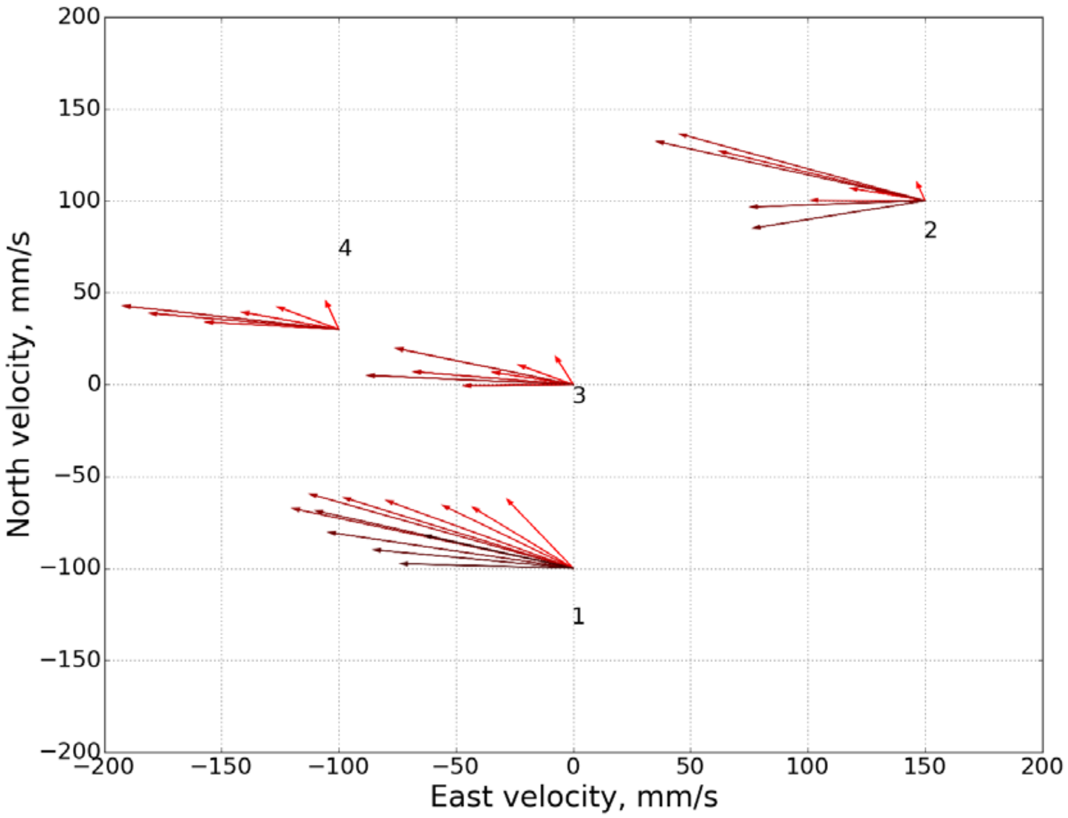


Figure 3.4.1 - Current velocity plotted in east and north coordinates

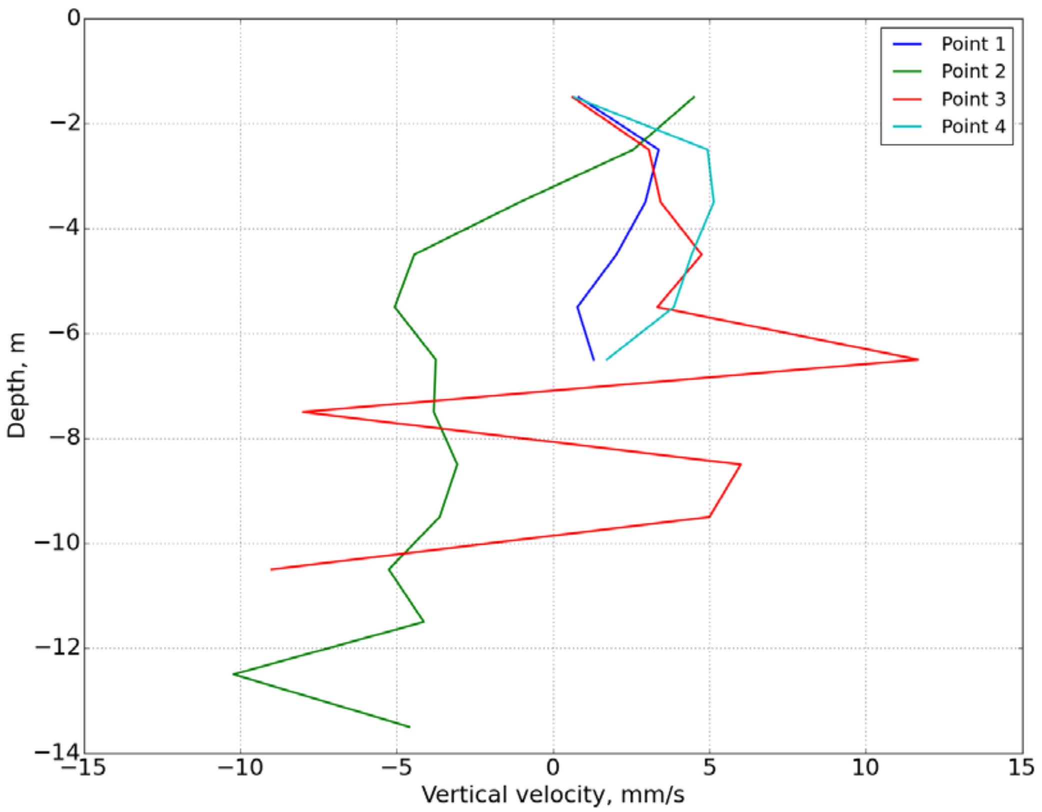


Figure 3.4.2- Vertical velocity of water currents vs depth

3.5 Conductivity Temperature Depth measurements (CTD)

We got Conductivity, temperature and depth data from the CTD device. From this, the Salinity, depth and temperature, was of importance.

Figure 3.5.1 - Picture of setup. CTD device is lowered down in the hole attached to the green rope.

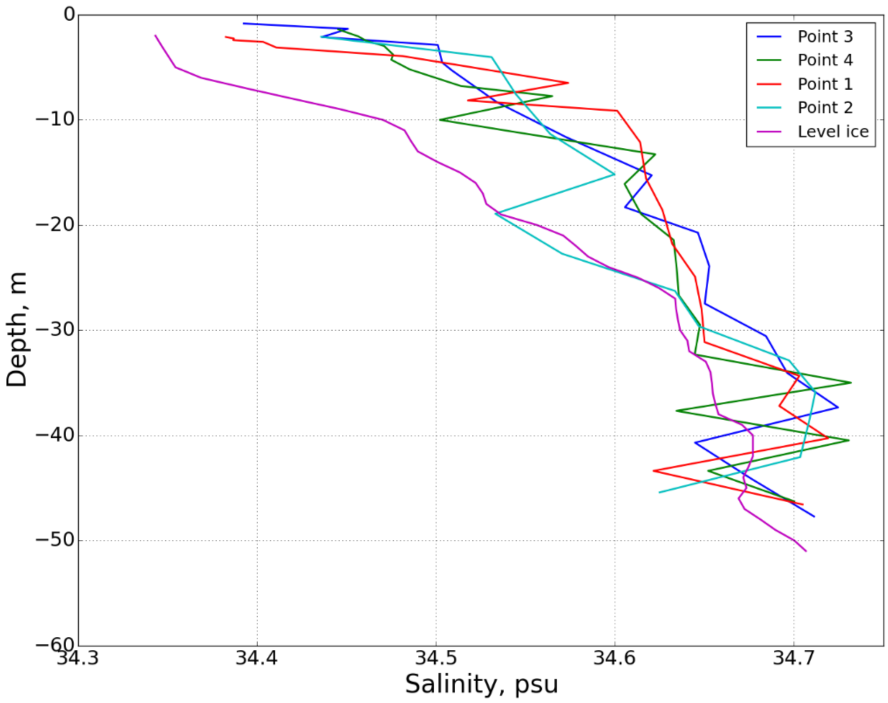


Figure 3.5.2 – Salinity vs depth measurements from top of the ice. CTD

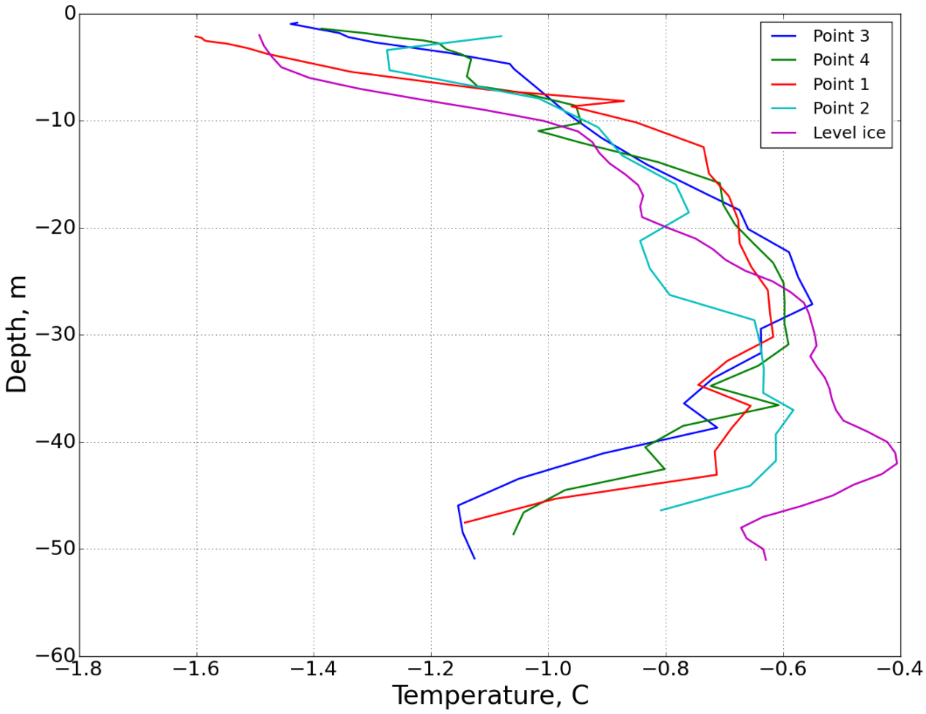


Figure 3.5.3 - Temperature vs depth measurements from top of the ice. CTD

The purple line, called “level ice” in figure 3.5.3, is the salinity taken by AGF students on another location under the same ice sheet, performing CTD measurements. The Figure 2.5.1 shows location of 4 holes around the “Ice berg”, which CTD measurements were taken from.

Figure 3.5.2 shows that salinity is increasing with water depth. The salinity profile is fluctuating for every point, probably because of temperature fluctuations. But, at approximately 15 meters depth, there is a small salinity decrease for point all the points except point 1 (Figure 3.6.1). In figure 3.5.3 we observe that the temperature is increasing at the same depth. This might be because the iceberg is melting. The Iceberg is made of glacier ice (fresh water), and when this melt water is mixing with the sea water, the salinity decreases.

3.6 Photographs taken under the Ice berg

We used a Go Pro camera, attached to a stick, to take pictures and movies under the ice. From Figure 3.6.1, the different holes are mapped, as well as holes that pictures were taken from and probe/rope for reference depth (X and Y).

We had two “Ice bergs”, the small bergy bit, and the large bergy bit. Our objective was to find the depth of the ice keel, by photographing/filming under the ice, with some sort of depth reference. We tried using an avalanche probe, that was approximately 2,5m, and a rope was also used. As shown by the pictures (Figure 3.6.2a and b), it was easier to determine depth of “ice berg”, using the rope with knots at every 2 meters. The probe (Figure 3.6.4 and Figure 3.6.6) was located to far from the iceberg, to estimate depth. The rope was located approximately 2,5 meters (hole X in figure 3.6.1) from the ice berg, and the GoPro camera was lowered down some distance from the hole X in hole Y (Figure 3.6.1).

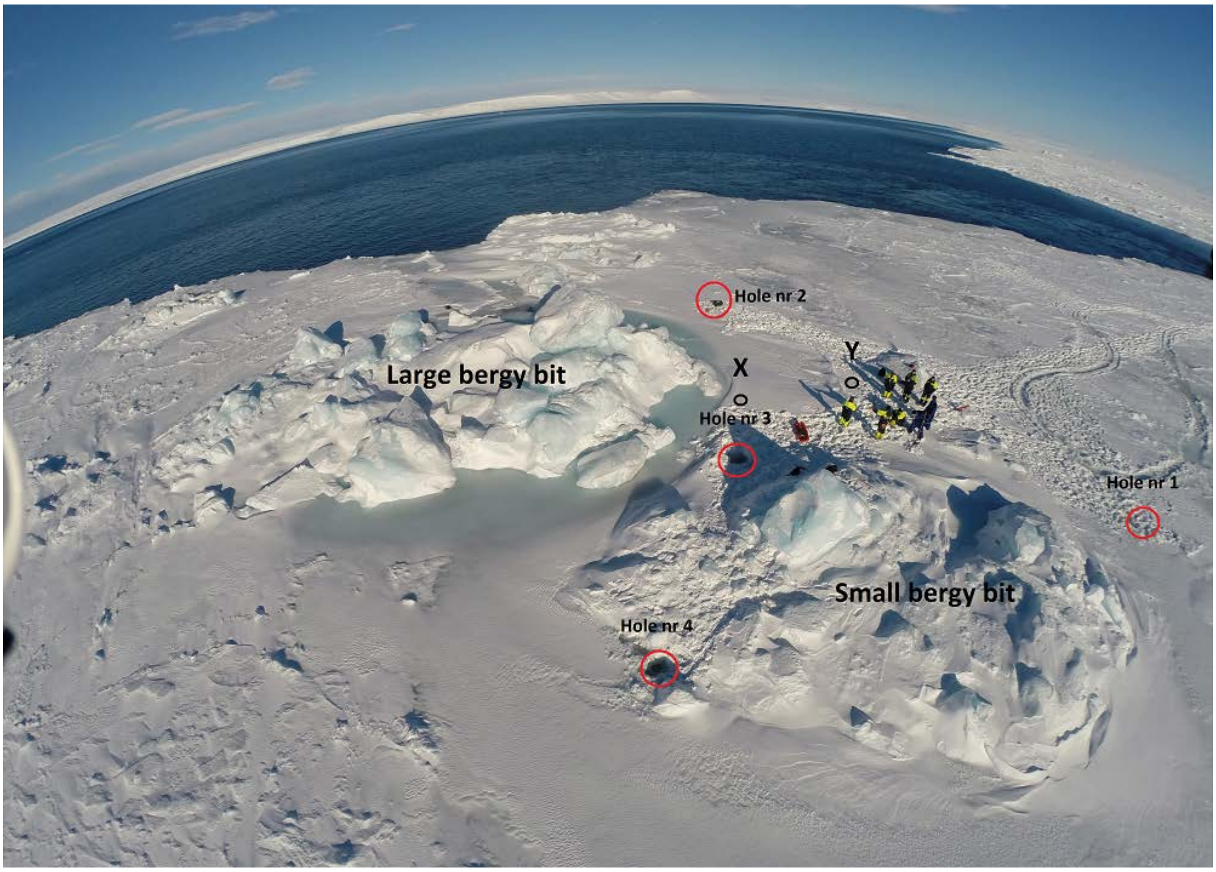


Figure 3.6.1 - Photo of "Ice berg", taken from above by a drone. Shows the setup, and location of drilled holes. Picture taken by Sebastian Sikora.

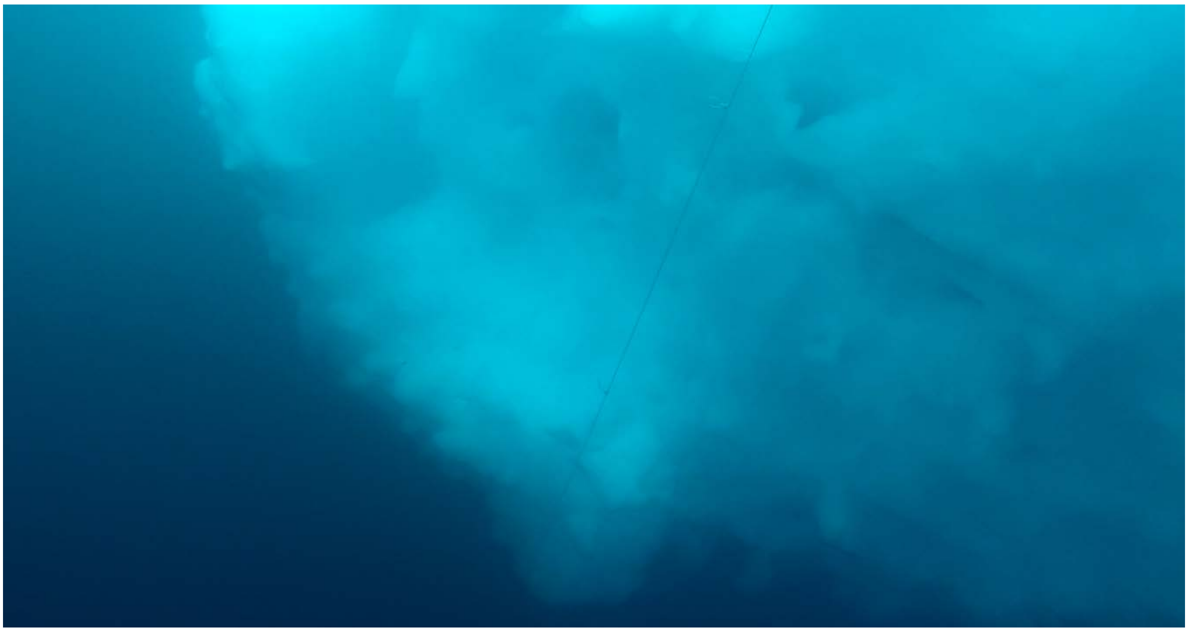


Figure 3.6.2a) - Picture taken from hole Y, with the rope hanging down from hole, towards the large bergy bit.

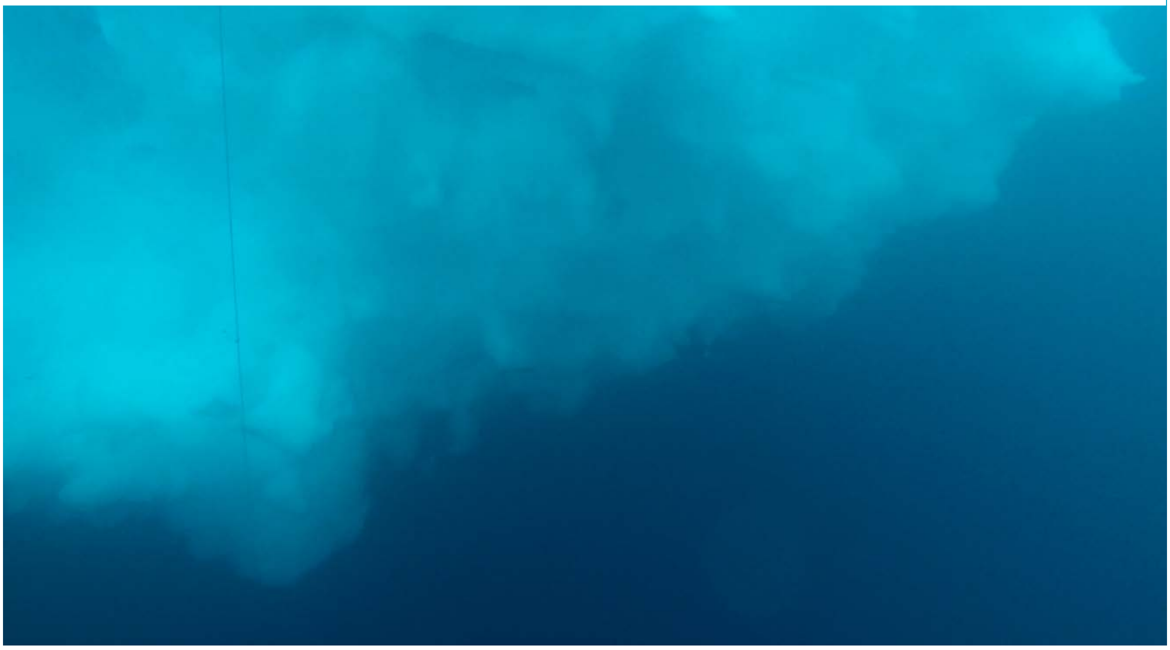


Figure 3.6.2b) - Picture taken from hole Y, with rope hanging down from hole X, towards the large bergy bit.

Pictures shown in Figure 3.6.2 a) and b), are taken from a movie made underneath the large bergy bit of the iceberg. On these figures, it is possible to see the ice keel (bottom of the ice berg). For every 2 meters, there are a knot attached to the rope, and the ice berg depth can be roughly estimated to be at least 7 meters deep. This is only an estimation, because there will be an angle between the rope knot and the iceberg keel. This angle is possible to determine, and calculations of the true depth, will be shown later in this chapter.

Figure 3.6.3 - Large bergy bit observed in the background. Reference picture

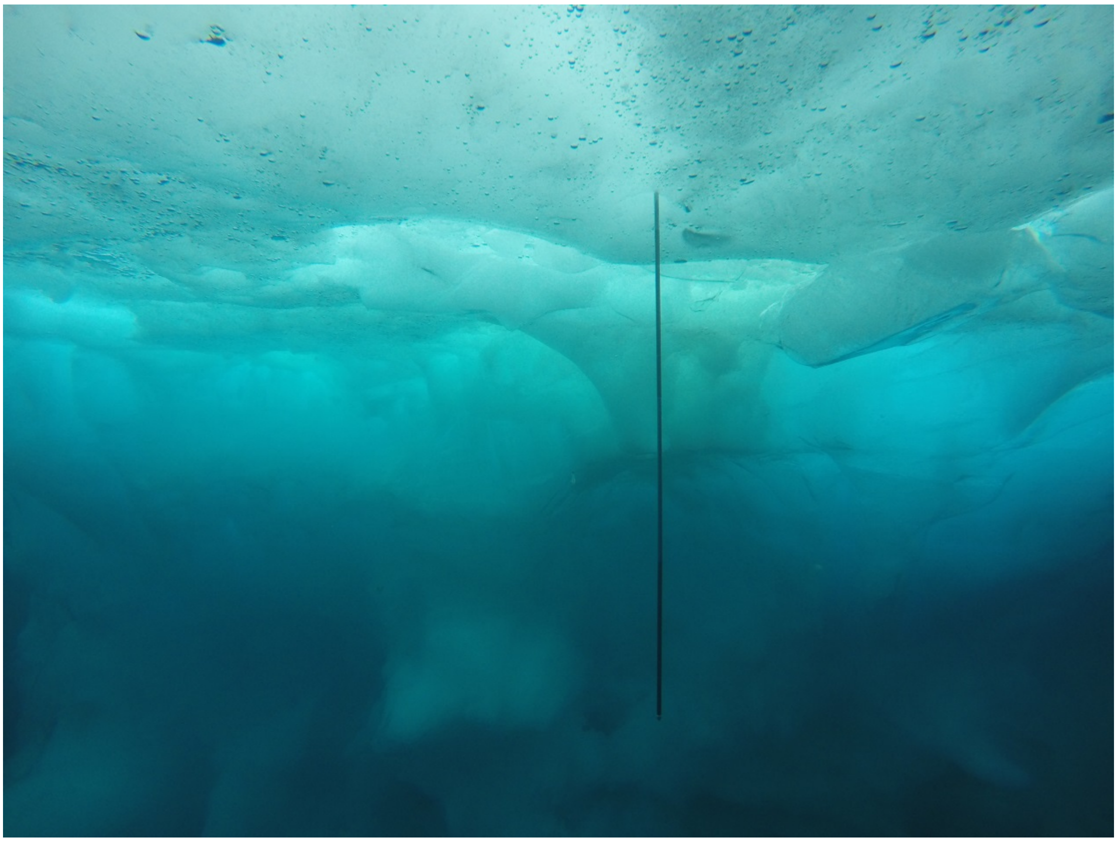


Figure 3.6.4 - Picture taken underneath the Large bergy bit, from hole Y. Avalanche probe as reference (2 m)

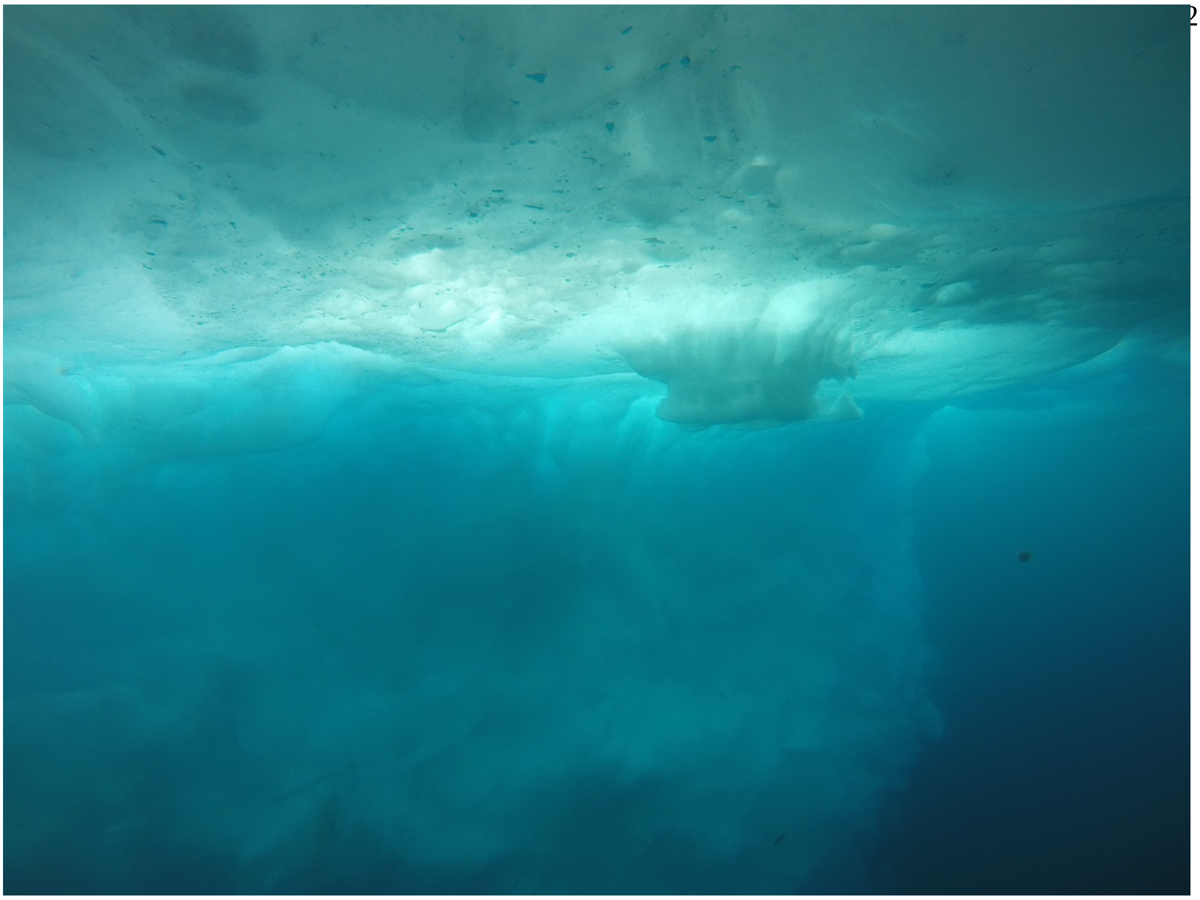


Figure 3.6.5 - Picture taken from hole 2, towards the large bergy bit.

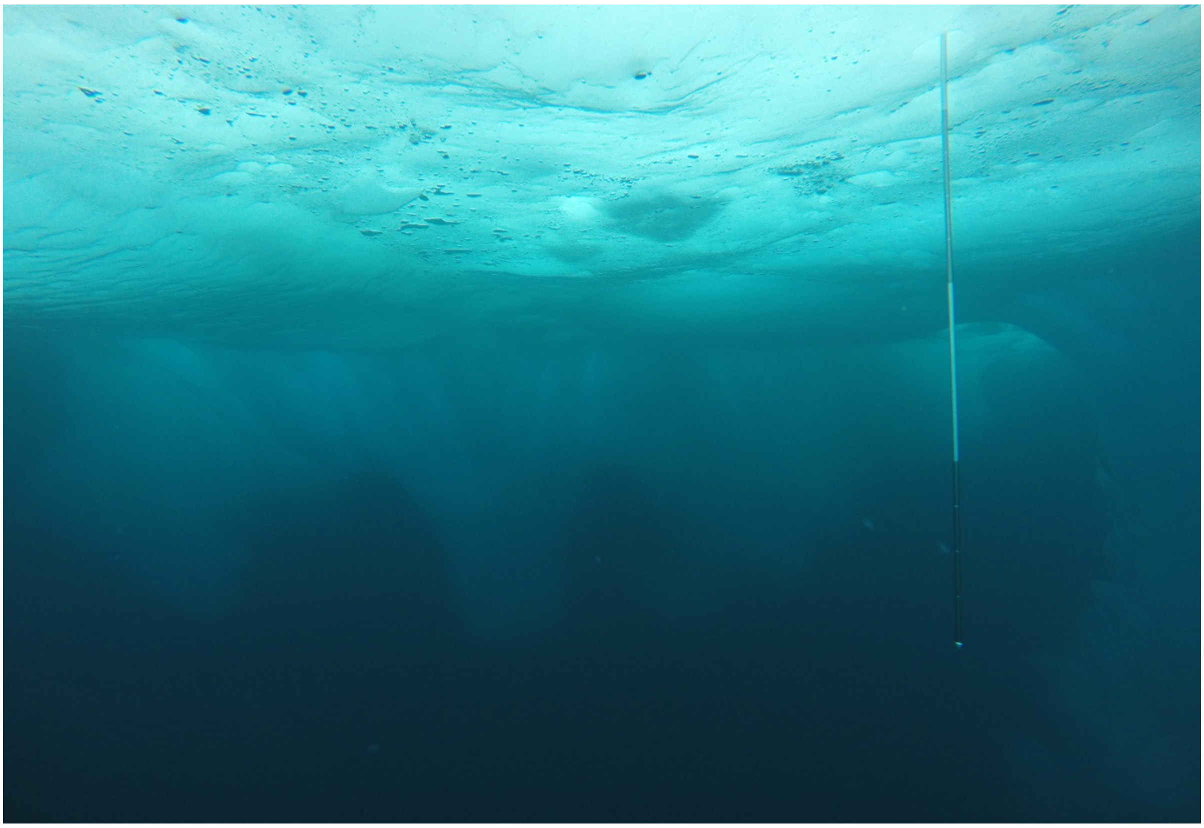


Figure 3.6.6 - Picture taken from hole Y, towards the "small bergy bit". Probe is located to far from bergy bit, to be a reference.

It is difficult to estimate the exact depth and shape of the iceberg, based on photos taken. We can however make some approximations, and try to make a sketch of how it possibly could look like. In Figure 3.6.7, we have made an easy sketch of how the ice berg might look like, underneath. This sketch is not up to scale, but only an approximation.

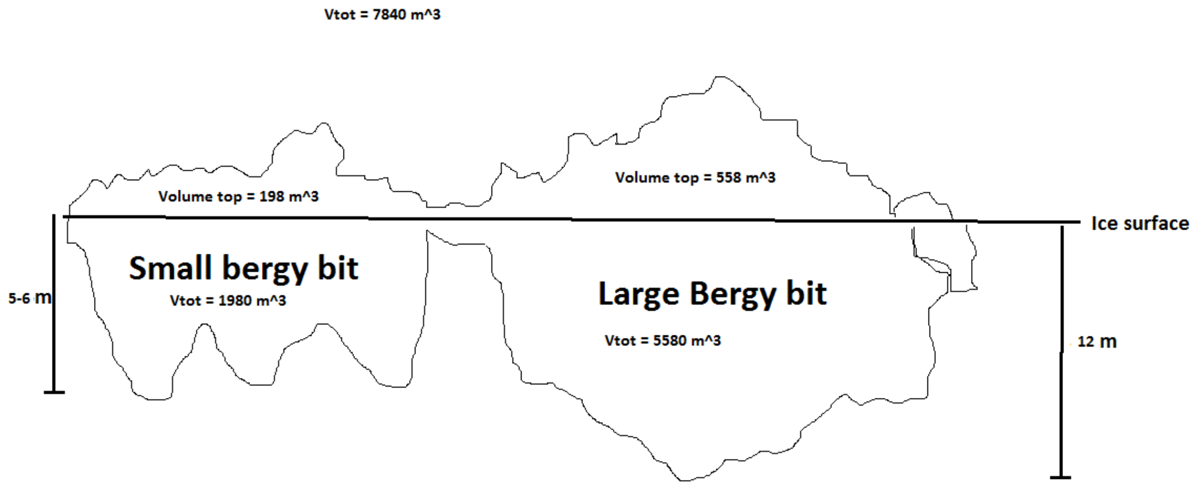


Figure 3.6.7 - Sketch of possible Ice berg appearance. Approximate volume and depth are included.

To estimate the volume of the Ice berg, we did some calculations, to see how much ice is underneath the water.

$$V_{bottom} * \rho_w = V_{total} * \rho_{ice} \qquad \text{(Eq 3.6.1)}$$

And we know that the total volume is

$$V_{total} = V_{top} + V_{bottom} \qquad \text{(Eq 3.6.2)}$$

$$V_{bottom}(\rho_w - \rho_i) = V_{top} * \rho_i \qquad \text{(Eq 3.6.3)}$$

$$V_{total} = V_{top} * \left(1 + \frac{\rho_i}{\rho_w - \rho_i}\right) = V_{top}\left(1 + \frac{900\frac{kg}{m^3}}{100\frac{kg}{m^3}}\right) \qquad \text{(Eq 3.6.4)}$$

$$V_{total} = 10 * V_{top} \qquad \text{(Eq 3.6.5)}$$

So we know that the volume of the iceberg submerged in water is ten times higher than the volume of the top approximately. From this we can estimate an approximately estimation of the volume of the entire iceberg.

Table 3.6.1 - Data of iceberg volume. Approximations based on equations 3.6.5

Piece of iceberg	Volume, top [m^3]	Total volume [m^3]	Total mass [kg]
Large bergy bit	558	5580	$5022 * 10^3$
Small bergy bit	198	1980	$1782 * 10^3$
Total Iceberg	784	7840	$7056 * 10^3$

To calculate the mass of the iceberg, we use the density of pure glacier ice, which is approximately 900 kg/m3.

$$m_{tot} = V_{tot} * \rho_{glacier\ ice} \qquad \textit{(Eq 3.6.7)}$$

The mass of the different icebergs are presented in table 3.6.1. The total mass is almost 7000 tons, in comparison a passenger plane weighs about 4.5 tons.

To determine the true depth of the iceberg, we have to take the angle of the camera into account.

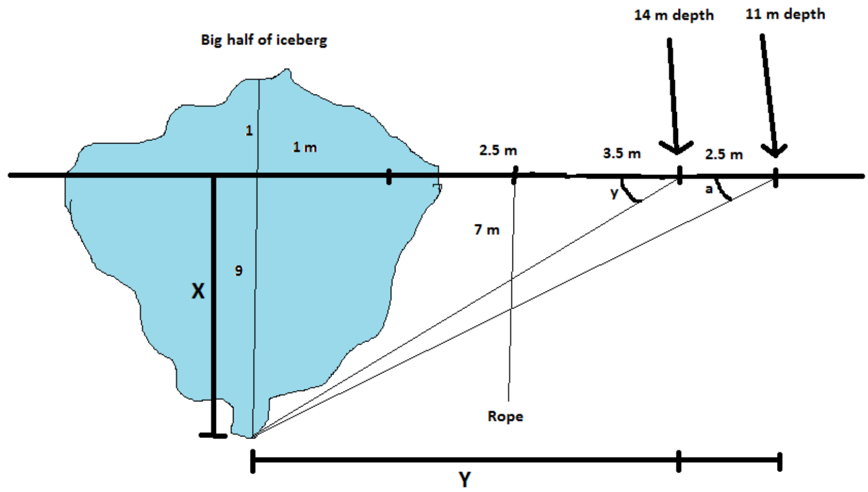


Figure 3.6.7 - Sketch of estimation of iceberg depth (Big half).

We drilled one hole for the reference rope 2,5 meters from the foot of the iceberg, and two more holes 3,5 and 6 meters from the rope. We assume that the distance from the foot of the iceberg (big half) to the highest top is about 1 meter. We observed on the video (Figure 3.6.2 a and b), that the depth seemed to be around 7 meters. It was unclear, which hole we lowered the GoPro camera into, so we have calculated the depth seen from both of these holes, and made an average approximation. We used the following equation: a and y is the angles in figure 3.6.7.

$$\tan(a, y) = \frac{X}{Y} \qquad \textit{(Eq 3.6.8)}$$

Where $\tan(a, y)$ is the same as 7/3.5 or 7/6. We find X (depth of ice keel) for angle a:

$$X = \frac{7m}{6m} * 9{,}5m = 11m$$

The average calculated depth for the two holes will be 12.5 meters, which seems reasonable.

3.7 Permeability Experiment

3.7.1 Setup

The aim of the experiment is to estimate sea ice permeability. Cylindrical holes 30-40 cm deep were drilled in the level ice, so we had 10-25 cm of ice below bottom of holes. The hole was filling with saline water from underneath of the ice as well as from walls. Water flowing from walls influenced mainly in the beginning of the experiment, so we didn't take into account first seconds of experiments. Water level was measured with SeaBird-39. Knowing dependence of water level from time, permeability of ice can be calculated.

3.7.2 Theory

Sea ice contains pockets with liquid brine as well as with air. These cells can be connected forming channels. Therefore saline ice can be considered as porous media. Under pressure applied, brine can filter though ice. This process can be described with Darcy's law (equation 3.7.2.1)

$$\vec{v} = -\frac{k}{\mu}\nabla p \qquad \textit{(Eq. 3.7.2.1)}$$

Where $\vec{v}$ is filtration rate, k – permeability of media, μ – viscosity of fluid, p – pressure applied.

Let's consider a cylindrical hole made in level ice (figure 3.7.2.1). R is ice thickness between water and bottom of hole. H is depth of hole.

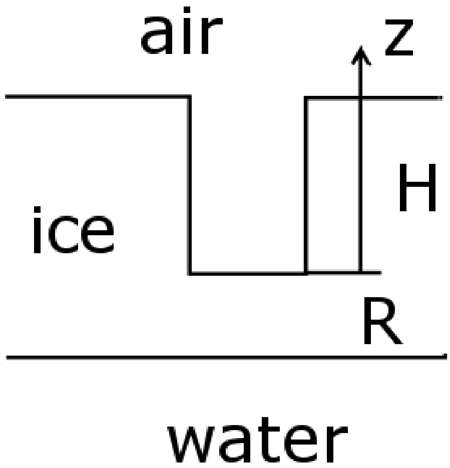


Figure 3.7.2.1 - Illustration of experiment setup.

Water can penetrate through bottom and walls. Assuming than water flows from underneath only rate filling velocity is given by equation 3.7.2.2

$$u(t) = n\frac{dz}{dt} \qquad \textit{(Eq. 3.7.2.2)}$$

Sea water penetrates according to Darcy's law, where ∇p is linear and can be found from equation 3.7.2.3

$$\nabla p = \frac{\Delta p}{\Delta z} = \rho g\left(\frac{H-z(t)}{-R}\right) \qquad \textit{(Eq. 3.7.2.3)}$$

Thus from equation 3.7.2.2 and equation 3.7.2.1 taking into account equation 3.7.2.3 formula for z(t) can be written as follows:

$$n\frac{dz}{dt} - \frac{k}{\mu}\rho g\left(\frac{H-z(t)}{-R}\right) = 0 \qquad (Eq.\ 3.7.2.4)$$

Solution of the equation 3.7.2.4 is

$$\ln\left(\frac{H-z(t)}{R}\right) = -\frac{k}{n\,\mu}\rho g\, t \qquad (Eq.\ 3.7.2.5)$$

Therefore z(t) equals to

$$z(t) = H - R\, e^{-\frac{k}{n\,\mu}\rho g\, t} \qquad (Eq.\ 3.7.2.6)$$

From equation 3.7.2.5 permeability can be calculated using equation 3.7.2.7

$$k = \frac{n\,\mu}{\rho g t}\ln\left(\frac{H-z(t)}{R}\right) \qquad (Eq.\ 3.7.2.7)$$

3.7.3 Results

Four experiments were performed. In the first experiment hole was 32 cm deep, total ice thickness was 52 cm, so we observed saline water filtrating though 20 cm of ice. Second experiment was conducted close to first one, hole was 42 cm deep, 10 cm of ice left below bottom of the hole. Oscillations in pressure can be due to influence of hole from first experiment. Third and fourth experiments were done with same parameters: 35 cm hole made in 60 cm thick ice. Water penetrated through 25 cm of ice. Data which we took for analysis is shown on figure 3.7.3.2. We have not taken first seconds of experiments due to possible influence of water going from walls. Raw data is shown on the figure 3.7.3.1.

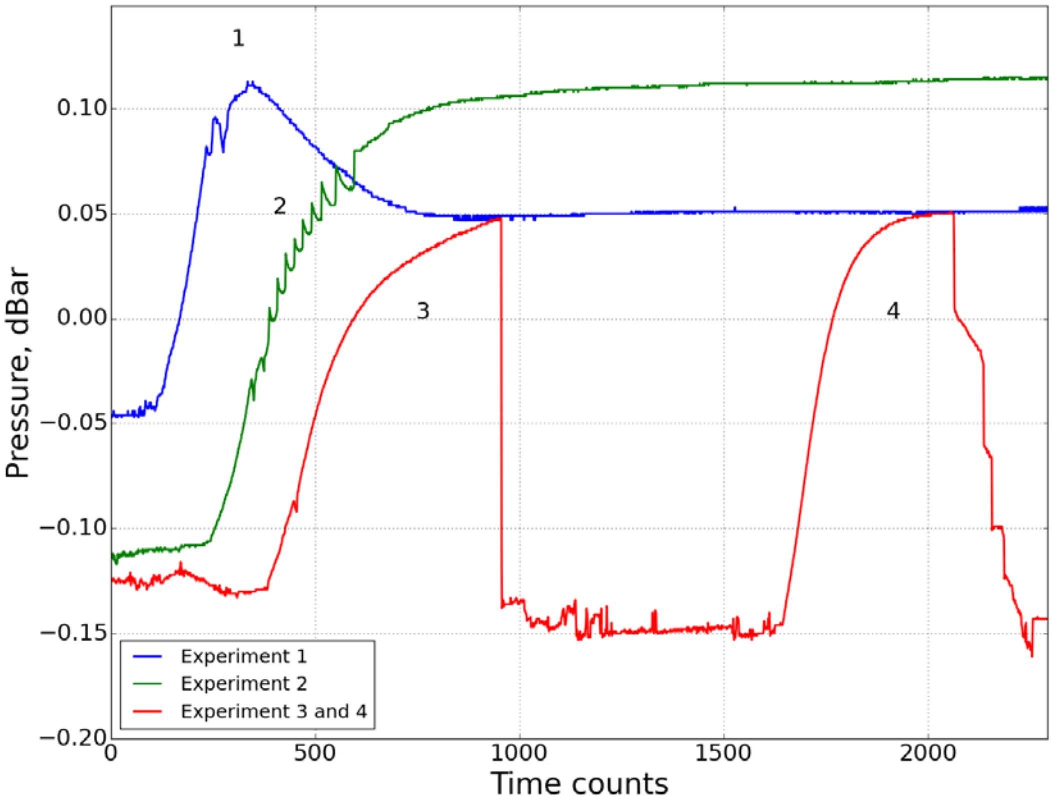


Figure 3.7.3.1 - Pressure change with time

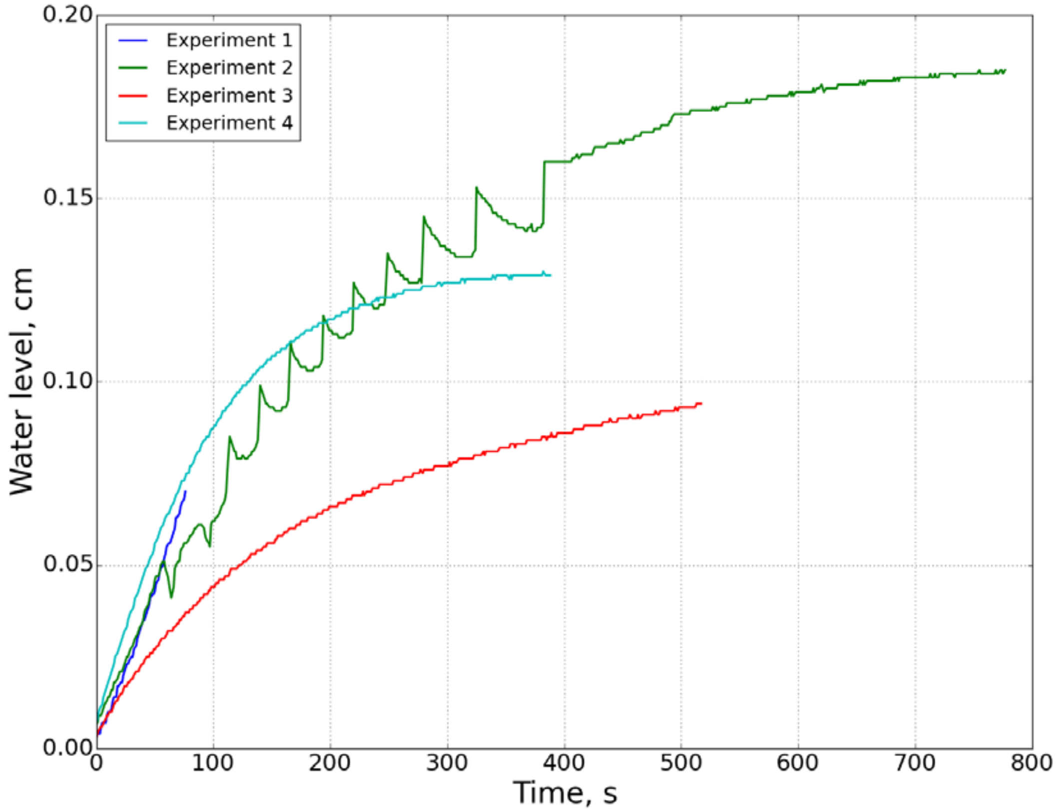


Figure 3.7.3.2 - Data taken for analysis

To find permeability according to equation 3.7.2.5 we took logarithm from data shown on figure 3.7.3.2. Curves received were fitted with linear functions as it's shown of figure 3.7.3.3.

Knowing inclination angle, permeability can be calculated using equation 3.7.2.5.

$$\tan\alpha = -\frac{k}{n\,\mu}\rho g \qquad \textit{(Eq. 3.7.3.1)}$$

$$k = -\frac{n\,\mu\,\tan\alpha}{\rho g} \qquad \textit{(Eq. 3.7.3.2)}$$

Porosity of ice at temperature -2.3 C, salinity 4.5 ppt, density 990 $\frac{kg}{m^3}$ is about n = 0.12 according to [Knut, 2014].

Considering $\mu = 2 * 10^{-3}\ Pa\ s$ (for -4 C), $\rho = 10^3\ \frac{kg}{m^3}$, $g = 10\ \frac{m}{s^2}$

$$k_1 = \frac{0{,}12 * 2 * 10^{-3} * 0.03}{10^3 * 10} = 7{,}2 * 10^{-10}\ [m^2]$$

$$k_2 = \frac{0{,}12 * 2 * 10^{-3} * 0.005}{10^3 * 10} = 1{,}2 * 10^{-10}\ [m^2]$$

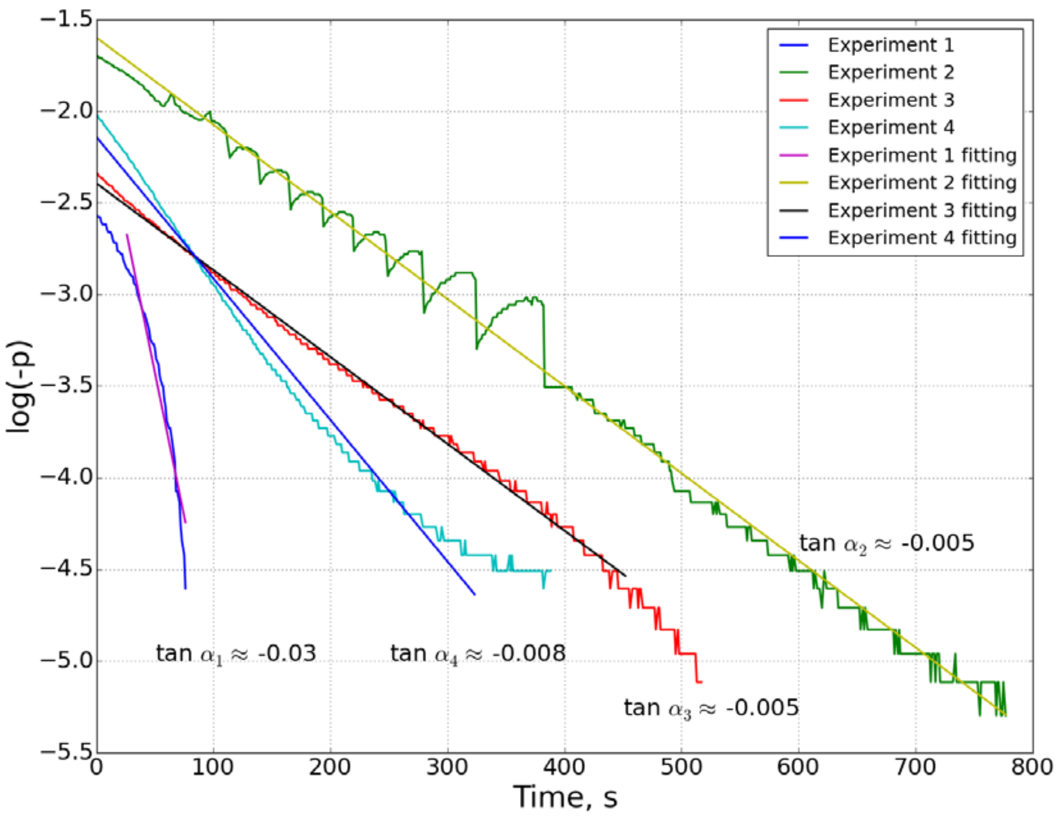


Figure 3.7.3.3 - Dependence of Log(-p) from time

$$k_3 = \frac{0{,}12*2*10^{-3}*0.005}{10^3*10} = 1{,}2*10^{-10}\ [m^2]$$

$$k_4 = \frac{0{,}12*2*10^{-3}*0.008}{10^3*10} = 1{,}9*10^{-10}\ [m^2]$$

Values received for permeability of sea ice are in accordance with data described in articles [1], [2], [3].

In ends of experiments we observed deviation from linear functions. This can be a result of water penetration in tops of walls.

In addition to pressure, SeaBird-39 also measures temperature of water. In our experiments temperature of water inside holes was approximately -4 C. We have measured salinity of water sample taken after experiment. It was approximately 65 ppt, and the freezing point for water with this salinity is about -4 C, so water in the holes was at the freezing point.

4. Discussion

Our TDS measurements were taken on the sea ice near the boat, and were done for the beam test group. Our results seem reasonable, the temperature and salinity are decreasing with increasing ice depth. The density is lower at the top of the ice, because this part has more porosity and is less compacted. The density is increasing with increasing depth, because of compaction and more columnar ice. However, the weight and area measurements of the ice cores have a lot of uncertainties, and are therefore not completely reliable.

By scanning the Iceberg with the Riegel VZ-1000 laser scanner, we got estimates of surface area and then calculated the surface volume of the iceberg by triangulating over a plane. This was used to calculate the total volume of the iceberg (7840 m^3).

By ice thickness profiling, we could observe that the ice thickness was a bit smaller around the ice berg (ice bits). This might be because of surface melting of the ice berg, making the ice around the ice berg thinner and less saline. There are some uncertainties connected to the ice depth measurements, but these are negligible.

The permeability test was conducted at another location on the ice. The first and second holes had a 20 cm and 10 cm ice buffer to the water. Water was penetrating through both of the holes, but the oscillations in pressure observed for the second hole, was mainly because of influence from the first hole (close distance). The third and fourth hole had both 25 cm of ice buffer, and water was observed to penetrate through the ice. Temperature was measured to be -4 degrees Celsius with high salinity. Because of the high salinity the freezing point of this water was shifted to about -4 degrees Celsius, and the water was therefore close to its freezing point.

ADCP profiling showed that water currents were flowing from east to north mainly. In front of the iceberg it went down (point 2), and went upwards at points 1, 3, 4. Velocity of the current was directed into a different direction comparing with ADV data measured at some distance from the iceberg. Absolute values of velocities are, however, of the same order.

At point 2 we observed temperature and salinity drops at the depth of 10-20 meters. Since the iceberg consists of fresh water and some energy is needed for phase change, the decreasing of temperature and salinity can be related to melting of the iceberg under influence of ingoing water current.

Our objective was to map the iceberg, by taking pictures and video, as well as volume calculations from the scanning. We found from our video that the largest half of the iceberg was between 7-8 meters deep, while the smaller half might be 4-5 meters (observation). After taking the camera angle into account, we calculated that the deepest ice keel might be at 12.5 meters depth. However, there are a lot of uncertainties about this calculation, and the depth value should be handled as an approximation. We calculated the total volume of the iceberg to be 7840 m^3, by estimate calculations of the bottom volume of the ice berg. All of our results have uncertainties, because we used observational measurements.

5. Conclusions

From the theory, we can conclude that the iceberg we investigated is a small pinnacle iceberg, formed from a glacier, and frozen in the icepack we investigated. We have obtained results for all of our field investigations, and these are as following:

- TDS measurements showed that the temperature was decreasing with increasing ice depth. The salinity was decreasing with increasing depth because of the freezing process of sea water. The density was increasing with increasing depth.
- Ice thickness is lower around the iceberg, because melting water from the top of the iceberg is accumulated around the bergy bits.
- Total volume of the ice berg was estimated to 7840 m^3
- Depth of biggest iceberg keel is estimated to 12.5 meters deep.
- Total mass of the iceberg was calculated to be 7056 tons.
- ADCP and CTD data might support that the iceberg is partly melting, causing salinity decrease.

In conclusion, we have acquired estimations of iceberg size and shape, but with our tools it is difficult to get precise results.

6. References

Bergman, J. (2001, December 13). *Windows to the Universe*. Retrieved from http://www.windows2universe.org/earth/Water/CTD.html

J.Freitag, H. (n.d.). Meltwater circulation and permeability of Arctic summer sea ice. [1]

K.M.Golden, H. A. (n.d.). Thermal evolution of permeability and microstructure in sea ice. [3]

Ocean Instruments. (n.d.). *Ocean Instruments*. Retrieved from http://www.whoi.edu/instruments/viewInstrument.do?id=819

Toshiyuki Kawamura, M. I. (n.d.). Measurements of Permeability of Sea Ice. [2]

Knut(2014), The air and brine volume of ice

7. Appendix A

List of figures and tables