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Master's thesis

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Dating of NEEM core from visual stratigraphy

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Submitted: 01/11/10

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200885-1959

Contents

Resumé på dansk

Dette speciale handler om datering af NEEM-iskernen fra Grønland baseret på visuel stratigrafi. Der er tale om en metode, hvor man via en særlig skanner registrerer lysets spredning i en del af den udborede iskerne.

Ud fra fotograferinger af iskernen, vil jeg forsøge at identificere årlag og tælle antallet af dem i bestemte sektioner af kernen. Årlagene vil ikke blive bestemt på denne måde i hele kernen, da metoden forudsætter visuelt identificerbare årlag. Der vil på denne måde heller ikke være tale om en "endelig" aldersfastlæggelse, hvilket skyldes, at der ikke sammenlignes med alle andre typer dateringer.

Metoden er i udgangspunktet brugbar i kolde perioder (istider), og ikke anvendelig i varme perioder (mellemistider). Der er i dette speciale forsøgt at tælle årlagene fra en del af NEEM-iskernen, der blev udboret i 2009, samt undesøgt, hvordan denne metode virker i de varme perioder og om den var overførbar til 2010-boringerne.

Det viste sig, at det ikke er lige til at udvikle en metode til at gøre dette indenfor den givne tidsramme, der automatisk kunne tælle lagene baseret alene på data fra NEEM-iskernen, og at denne metode heller ikke umiddelbart kunne implementeres på 2010-boringen.

Der er dog forsøgt at lave en årlagstællingen, og samtidigt er data analyseret med henblik på at finde ud af, hvor problemerne ligger.

Endeligt er der identificeret en uventet anormalitet i data omkring 1570 meters dybde, der formentlig skyldes fejl, idet denne dog optræder på en ikke let forklarlig måde.

Abstract in english

This thesis is about the dating of the NEEM ice core from Greenland based on visual stratigraphy. This is a method is based on data from a special scanner detecting light scattering in the drilled ice core.

From the line scanning of the ice core, I will try to identify and count annual layers in certain sections of the core. Annual layer will not be determined in this manner throughout the core, because the method requires visually identifiable annual layer. There will thus not be a "final" age determination, which is due to be compared with all other types of dates.

The method is basically serviceable in cold periods (ice ages) and not usable in warm periods (interglacials). There is in this thesis tried to count the annual layer from a portion of NEEM ice core was drilled in 2009, and investigate, how this method works in the warm periods and if it were transmissible to the part drilled in 2010.

It turned out that it is not just to develop a method to do this within the given time frame to automatically count the layers based only on data from the NEEM ice core, and that this method does not readily implemented in 2010-well.

There is, however, tried to make an annual counting, and simultaneously, the data analyzed in order to find out where problems lie.

Definitively there is identified an unexpected anomaly in the data around 1570 m depth, probably due to errors, provided this is acting in a not readily explicable way.

1 Introduction

1.1 The ice sheet on Greenland

Most of Greenland is covered by up to 3 km thick ice cap. Over large areas of this ice sheet is temperaturne year round so low that no or only very little melting occurs on the surface. That means the snow that falls on ice accumulates layer by layer as the years pass. The growth of new layers added to will eventually push the snow together. First to firn, (air penetrable ice at the top), which is consistent ice, but still porous, and since the ice where the air in the snow cut into bubbles. These bubbles will gradually as pressure increases with depth, compressed and eventually disappear completely when the air in them embedded in the ice crystal structure in the form of clathrates.

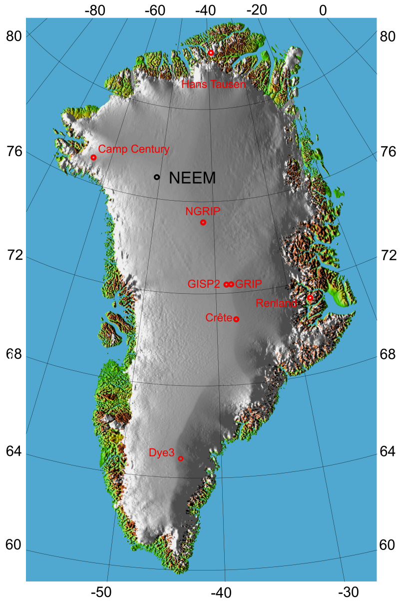

Figure 1.1: Geographic position of the Camp Century, NorthGRIP and NEEM ice cores

When the ice despite the constant rainfall in mass balance due to the fact that ice is plastic and flows out toward the edge where it melts or breaks off into icebergs. In ice divide (which is the boundary between the portion of the ice sheet where the ice flows to the east, and the part where the ice flows to the west) will be least affected by ice horizontal flow. The accumulation will here, in the ideal situation, give a layered structure.

1.2 Previously ice cores

Before the NEEM ice core project, there has been a number of other cores, some of the more important are described below:

- GRIP/GISP: The GRIP and GISP cores, each about 3000 m long, were drilled by European and US teams respectively on the summit of Greenland. Their usable record stretches back more than 100,000 years into the last interglacial. They agree (in the climatic history recovered) to a few metres above bedrock. However, the lowest portion of these cores cannot be interpreted, probably due to disturbed flow close to the bedrock. There is evidence the GISP2 cores contain an increasing structural disturbance which casts suspicion on features lasting centuries or more in the bottom 10 % of the ice sheet.

- NorthGRIP: The NorthGRIP drilling site is near the center of Greenland 75.1°N 42.32°W, 2917 m, ice thickness 3085). Drilling began ran from 1999-2003, where bedrock was reased. The NorthGRIP site was chosen to extract a long and undisturbed record stretching into the last glacial. NorthGRIP covers 5 ka of the Eemian, and shows that temperatures then were roughly as stable as the pre-industrial Holocene temperatures were.
- Beside from these cores, the following cores are also from Greenland: Station Eismitte, Camp VI, Station Central, Site 2, Camp Century, North Site, North Central, Crête, Milcent, DYE-2, Summit Camp, South Dome, Hans Tausen, Camp III, DYE-3 and Renland.

Each core has a kind of target, i.e. a given period, like Eemian for NEEM, other went in to problem with ice flow data. Especially the early and more experimental cores had problems, and their site were chosen after american defense installations and not at scientific optimized position like later cores. A selection of the cores are used to create a composite time scale, GICC05, see section 1.8 for more details.

1.3 The NEEM ice core

North Greenland Eemian Ice Drilling (NEEM) is a project, where an ice core is drilled on the ice divide in the northern part of the greenlandic ice sheet on the following position: 77.45°N 51.06°W, see figure 1.1, [Ice and Climate Group, 2009]. The purpose is to drill an ice core from the last interglacial period, Eem, which ended for around 115,000 years. Earlier ice cores, e.i. Camp Century, DYE-3, GRIP, GRIP2, and NGRIP has not given usuable data from this period, which is caused by melting and disturbance from ice flow close to the bed rock. The climate was around 3-5°C varmer in this period compared with today, which is on the same magnitude of the compared globale warming in the future, where the expectations is 2-4°C.

The precise location is chosed, so the following criteria are full filled[1]:

- The ice must be thick, as large ice thickness implies more annual layers.
- The bedrock most be flat, because uneven bedrock causes irregular ice flow that can disturb the ice layering
- The precipitation should be moderately high. Large annual snowfall results in fast ice flow and thereby fast thinning of the lower, older parts. In contrast, low snowfall will mean that the annual layers become harder to detect and analysed.
- The drill site should be on an ice divide. The ice divide is the line that separates the east-flowing part from the west-flowing part. The oldest ice layers are found near ice divides.

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[1] *http : //neem.nbi.ku.dk/about_neem/*

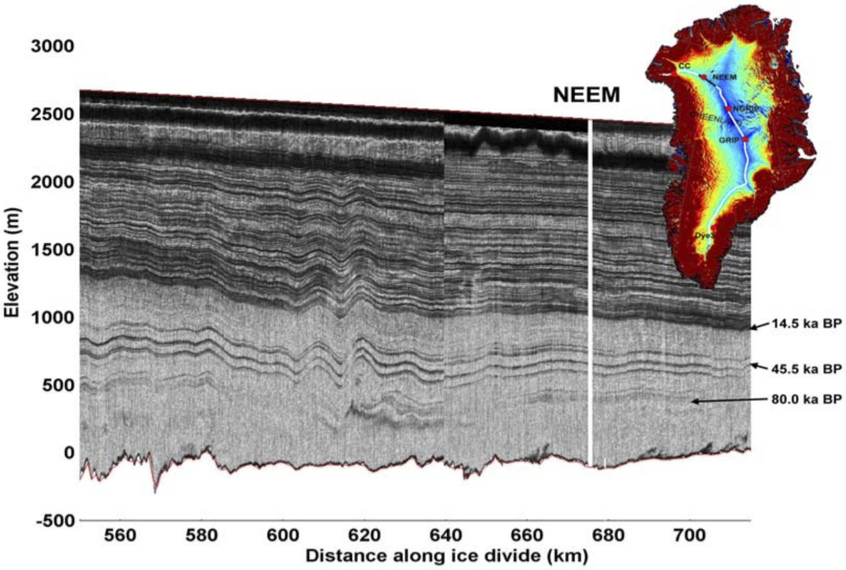


Figure 1.2: Analysis of internal radar reflectors (isochrones). The NEEM site is indicated. The map over Greenland shows surface slope of the Ice Sheet (blue: flat and red: steep). The white line shows the ice divide from Dye-3 in the South to Camp Century (CC) in the North West. The radar image covers the black section of the ice divide, [Ice and Climate Group, 2009].

Figure 1.2 show a map over the surface slope of the ice sheet, and a white and black line representing the ice divide. Before choosing the exact position, this route was traversed, and radar measurement was done under way, with the result shown also in figure 1.2. Based on these data, the exact position was chosen.

The project has been active on the this location since summer 2008, and is still ongoing. In 2008 the camp was built and a test core in the shallow was drilled. 2009 was the first season with focus on drilling the main core, where 1755.60 meters was reached, and processed, except for the brittle zone, see section 1.6.1. In the 2010 season the beck rock was reached.

1.3.1 The NEEM ice core

Beside from the main core, a small number of other cores were drilled at the NEEM Camp. On of these extra cores were a firn core, which is used for studying the air penetration through the firn.

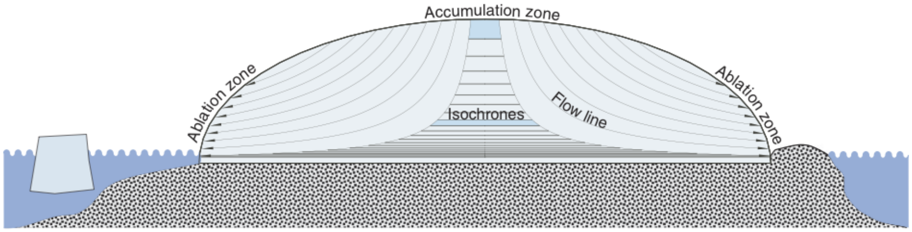


Figure 1.3: Simple ice flow model, [Schwander, 2007].

1.4 Dating methods

There is a number of methods by which the age of an ice core can be dated, as described in [Schwander, 2007]. The main task in annual counting is to find a parameter, which has an annual variation. Visual stratigraphy is based on dust layers, where as other methods can be based radioactivity, physical and chemical properties.

If we look on a simple model for the ice flow in the greenlandic ice sheet, as shown in figure 1.3, [Schwander, 2007], we se the previously mentioned layering, where the layers are thinned out by time. The thickness of one year is described as λ.

1.4.1 Stratigraphy

There are a number of different stratigraphic methods, where visual stratigraphy is one of them. Other methods are "anything" which results in a layered structure based on seasonal variation.

1.4.2 δ^{18}O

Beside the visual stratigraphy, one other important method of tracing seasonal variation in the climate is δ^{18}O and δ^{2}H. Here the ratio in the amounts of $^{18}O/^{16}O$ and $^{2}H/^{1}H$ are measured, since these ratios are strongly relateted to the condensation temperature, which reflects the seasonal variation of temperature.[Schwander, 2007]. Figure 1.4 show a significant similar tendency between then variations i λ and δ^{18}O for the NorthGRIP ice core, [Svensson et al., 2008]. δ^{18}O is defined as:

$$\delta^{18}O = 1000\left(\frac{\left(\frac{^{18}O}{^{16}O}\right)_{sample}}{\left(\frac{^{18}O}{^{16}O}\right)_{standard}} - 1\right)$$

Figure 1.5 shows the NEEM ice core δ^{18}O variation, and as expected, there are clearly distinguishable variation including onsets. The δ^{18}O has at time of writing not been interpreted and published.

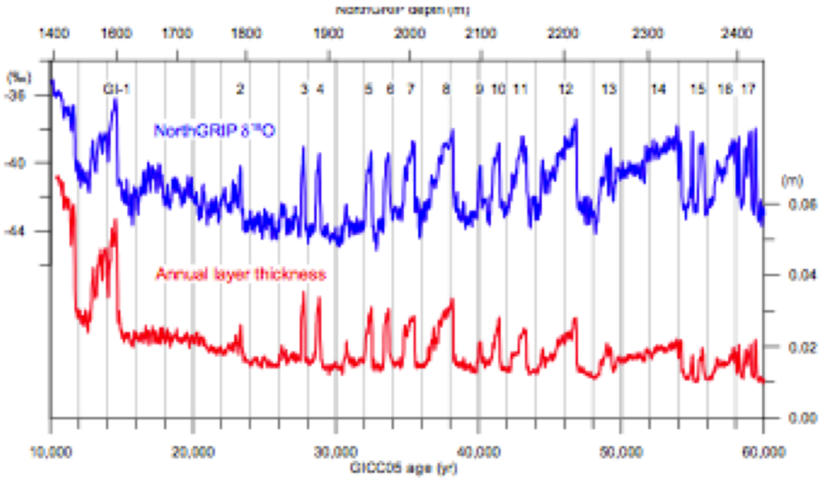


Figure 1.4: Comparison of λ and ^{18}O from NorthGRIP The λ-data is described in the results, [Svensson et al., 2008].

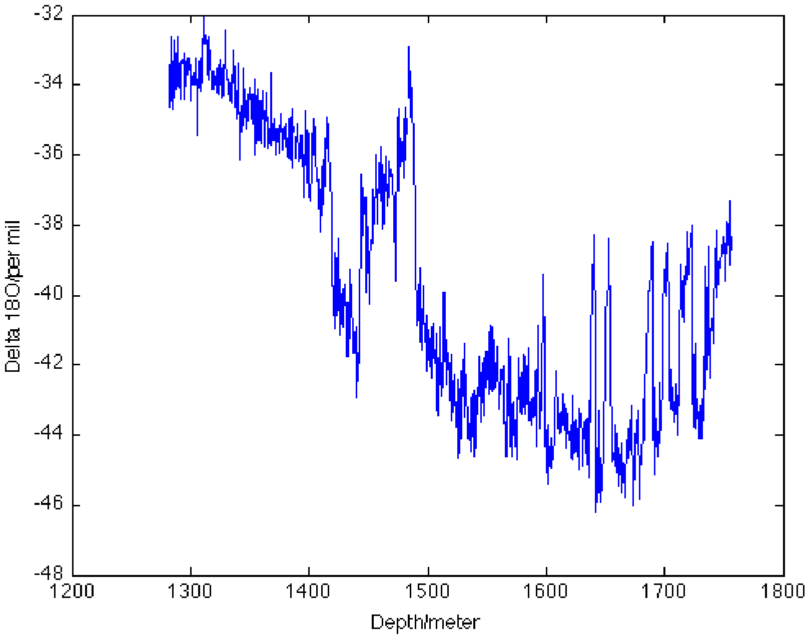


Figure 1.5: The δ^{18}O measurements from NEEM.

1.5 The ice core

Looking at the picture of the ice core will make a series of observations along with the kernel. The most prominent are white band across the nucleus, i.e. in the horizontal direction, and bubbles in the ice.

The white band is most notable in the Ice Age, while the bubbles here are smaller and thus not "disturb" the image to the same degree.

1.5.1 The bag system

The ice core is sectionated in so called bag. If we look at the ice core as one long unbroken core, the uppermost bag has number one. Each bag is 55 cm long, meaning that, measured from, 0.00-0.55 m is containing to bag 1. 0.55-1.10 m is bag 2, and generally bag n has the depth in meters: $[0.55(n-1); 0.55n]$.

1.5.1.1 Threebag A threebag is a bag with three bags in a row. Each threebag is numbered after the uppermost bag, the one with the lowest bagnumber, in the threebag, i.e. threebag 3000 means the threebag with bagnumbers 3000, 3001 and 3002. Ideally the threebags should have been numbered $1, 4, 7, \ldots$. But at least from threebag 639 they are numbered with $3n$, where n is a natural number. I do not have any datas from above bag 639, and therefore I don't know have their corresponding threebags are numbered. Each threebag is 1.65 m long, meaning that, measured from, 1649.45-1651.10 m is containing to bag 3000. Generally threebag n has the depth in meters: $[0.55(n-1); 0.55(n+2)]$.

1.5.1.2 Twobag In 2010 the system was changed to a twobag system. The upper bag in a twobag has an even number, the lower one an odd number, i.e. twobag 3260 contains bag number 3260 and 3261.

1.5.2 Threebags and cutting

The drill head is able to drill around 3 meters of ice cores in each run. The breaks from the drilling are *not* at all coordinated with the bag system. Furthermore there were other breaks in the unprocessed core. These break were normally not close to the point, where the core should be cut in bags. But if the break was close enough to the bag cut, the bag cut was moved in one or the other direction with a hole but few centimeters. The next cut was not moved, so there was not any accumulated shift in the relation between bags and their depth.

1.5.2.1 Uncertainty in the threebag length There was maybe noticed a problem with the cutting in 2009. The core was cut in 1.65 m threebags in the drill trench. In the last process in the science trench, the threebags were remeasured, and here they were up till 5 mm longer. This problem is ignored in this project.

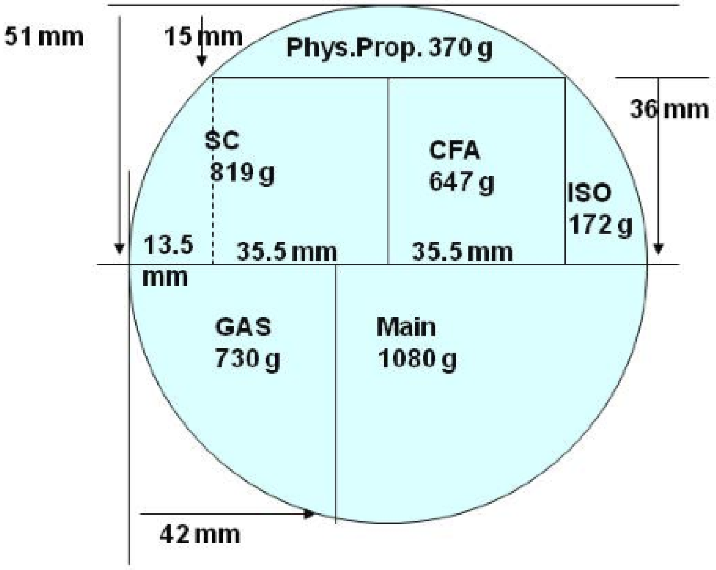


Figure 1.6: Ice core cutting, [Ice and Climate Group, 2009].

1.5.3 Terminology

- Interglacial: The warmer period between two glacial periods
- Stadial: A warmer period during a interglacial period
- Onset: The transition *to* from a stadial period

1.6 Ice core processing

After drilling and cutting into threebags, the core where transferred from the drill trench to the science trench for core processing. Here the core is underwented a number of measurements, where most of them requires the core to be cut in different parts, as shown on figure 1.6. Before cutting, the dielectrophoresis (DEP) are measured. The cutting was done in more steps, first the two horizontal cuts, which gave the upper physical properties part and a larger part containing the combined SC, CFA and ISO parts. This part was first used for the electrical conductivity measurements, and after careful smoothing of the horizontal surfaces, it was used for line scanning. The electrical properties and line scan was done as the first measurements in the science trench because the were non-destructive.

The different parts was used in these ways:

- CFA: This part was used for Countinued Fluid Analysis. By this process the chemical composition and the dust are measured.
- GAS: This part was cut and distributed between several labs for gas analysis.
- ISO: This part wss used for isotopic composition δ^{18}O.
- Main: This part was not processed in the camp, but send unprocessed to Copenhagen.
- Phys.Prop.: Some of this part was processed in warm labs at NEEM. The physical properties is i.e. crystal size.
- SC: Usage of this part was to be decided later by the Steering Committee.

1.6.1 Brittle zone

In 2009 the so called brittle zone was drilled. This is a part of the is core, where the air pressure in the bubbles (with small collection of the atmosphere) is so high, that it cause small explosions when the core reach surface pressure. This caused a lot of breaks, from time to time in a manner, that the ice core was nick named gravel. The brittle zone was decided to reach over bags 1095-2330, corresponding to 601.70-1281.50 meters. Since this part was hard to process, it was stored over the winter to summer 2010, and then processed. Beside from resulting in a gab in the 2009 data, it is not a problem regarding visual stratigraphy, because the brittle zone do not have clearly visible layers useable for this method.

1.7 The NorthGRIP ice core

North Greenland Ice Core Project was an international deep drilling project that has as main objective to provide an uninterrupted series of ice core data from the Eem period. In the ice from the two previous deep drilling, GRIP and GISP2, is the layering in this period violently disrupted by ice float over rocky ground.

The ice core was drilled near the ice divide at 2921 m on the ice divide, [Dahl-Jensen et al., 2002]. After an unsuccessful attempt when drilled sat stuck in the 1310 meters, the ice was the first 1750 meters of the initially NGRIP core drilled in summer 1999. Ice from the 1280 meters and below were stored in NGRIP camp over winter and was treated with the new ice (down to 2930 meters) were drilled following year.

The NorthGRIP ice core covers the past 123 ka and provides the longest continuous Greenland paleo-climatic record (North Greenland Ice Core Project members, 2004). This period includes the Holocene, the last glacial period and the termination of the previous interglacial period, MIS 5e or Before the NEEM-project, there has, as been noted in the Introduction, been drilled other cores.

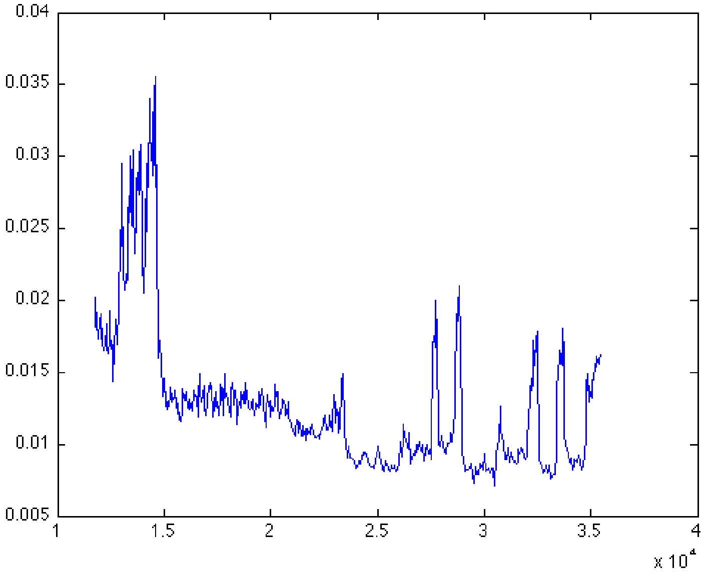


Figure 1.7: NorthGRIP ice core with clearly visible difference between stadial and interstadial periods.

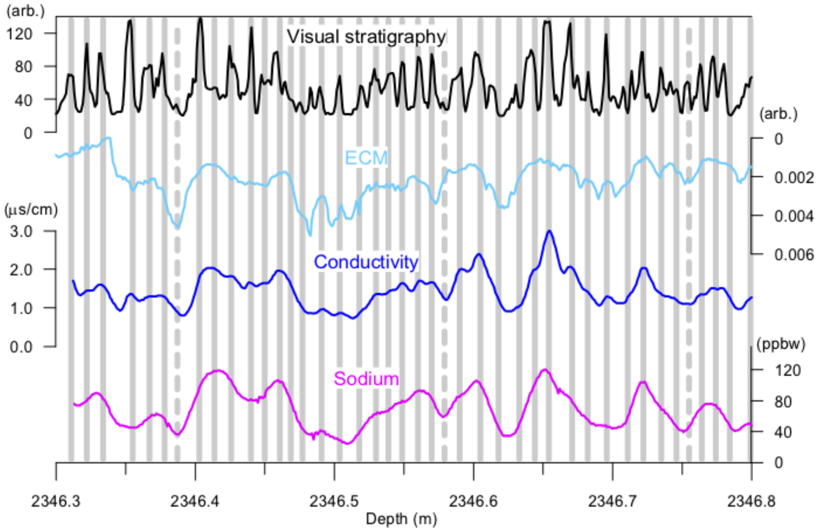


Figure 1.8: Example of annual layer counting within GI-14. The records are visual stratigraphy grey scale, ECM, conductivity, and Na^+-concentration. Annual layers are indicated by grey vertical bars, and uncertain annual layers with dashed bars. Example of annual layer counting within the stadial preceding GI-14. The counting of this section is mostly based on visual stratigraphy and ECM profiles which have the highest resolution. [Svensson et al., 2006]

One of those cores is the North GRIP ice core. The age of this core is well determined, why this core is used as an reference.

It is justifiable to assume, that the onsets are simultaneous events in ice core, meaning that the GI-1 (described later) events are the same age in both ice cores. Therefore they can be used as fix points.

1.8 GICC05 time scale

The Greenland Ice Core Chronology 2005 (GICC05) is a stratigraphic time scale composed on multiple stratigraphic counting of annual layers in three Greenland, DYE-3, GRIP and NorthGRIP ice cores. The 0–7.9 ka section of the time scale is based on counting of annual layers in ^{18}O and ^{2}D from the DYE-3, GRIP and NorthGRIP ice cores [Vinther et al., 2006]. The 7.9–14.8 ka interval is established from Electrical Conductivity Measurements (ECM) of the solid ice and Continuous Flow Analysis records (CFA) of the GRIP and NorthGRIP ice cores [Rasmussen et al., 2006]. The 14.8–41.8 ka section is based on counting of annual layers in ECM, CFA and visual stratigraphy data from NorthGRIP, [Andersen et al., 2006] and [Svensson et al., 2006]. GICC05 provides an uncertainty estimate based on the accumulated number of uncertain annual

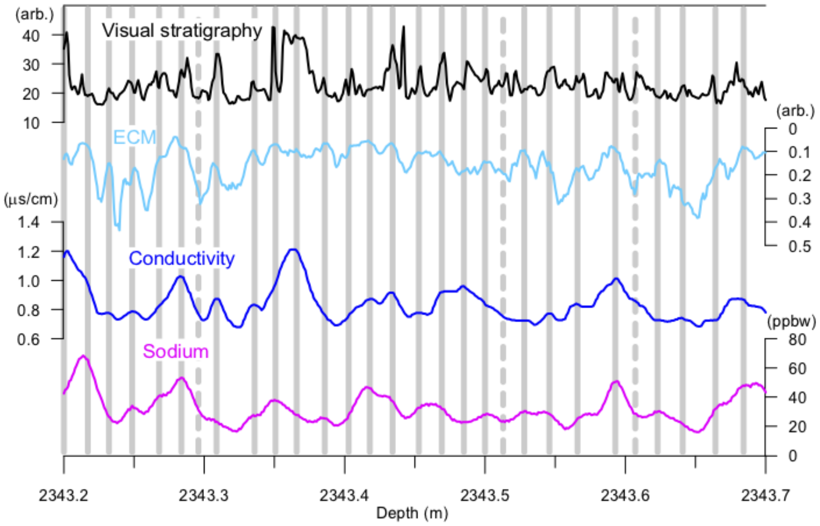


Figure 1.9: The counting of this section is mostly based on the conductivity and Na^+ profiles becauce the other records are known to have multiple peaks within an annual layer during milder climatic periods. Legend identical with figure 1.8. [Svensson et al., 2006]

YD/PB transition	11.702±50
Onset GI-1	14.692±93
Onset GI-2	23.340±298
Onset GI-3	23.780±416
Onset GI-4	28.900±449
Onset GI-5	32.500±566
Onset GI-6	33.740±606
Onset GI-7	35.480±661
Onset GI-8	38.220±725
Onset GI-9	40.160±790
Onset GI-10	41.460±817
Onset GI-11	43.340±868
Onset GI-12	46.860±956
Onset GI-13	49.280±1015
Onset GI-14	54.220±1150
Onset GI-15	55.800±1196
Onset GI-16	58.280±1256
Onset GI-17	59.440±1287

Table 1.1: The identified onset from the NorthGRIP ice core, [Svensson et al., 2008].

layers, detailed discussion in [Andersen et al., 2006] and [Rasmussen et al., 2006].

The GICC05 time scale provides a number of fix point in form of onset, clearly visible on figure 1.7, which can be seen in table 1.1. Later on, when the lines in the NEEM ice core is found, these fix point will be used to transfer the GICC05 time scale on the NEEM ice core. Using fix points for the onsets and offsets, it is possible to interpolate the GICC05 time scale in the stadial and interstadial periods, and get as an out an expected λ value with respect to the depth. This interpolated data is from now on named NEEM/GICC05.

Greenland Ice Core Chronology 2005 was a dating project of the NorthGRIP ice core. A number of methods were combined is this project. Here the time scale for the Holoscene is based on records from DYE-3, GRIP and NorthGRIP, and the glacial period only on NorthGRIP. By this the time scale was extended by 18.000 years to 60.000 years. The data are based on a number continouous data series: Concentrations of Ca^{2+}, Na^{+}, SO_4^{2-} and NO_3^{-} [Bigler, 2004] and [Röthlisberger et al., 2000], ECM [Dahl-Jensen et al., 2002] and visual stratigraphy [Svensson et al., 2005].

Figure 1.8 shows how different sources for annual counting were combined in a section, where visual stratigraphy and ECM has an clearly annual variation, which are not the case for sodium or DEP (Conductivity). At the other hand, figure 1.9 is from within GI-14, where counting is based mostly on Na^{+} and conductivity.

Figure 2.1: Picture of the line scan set up, with the camera in the left side. The top of a threebag was placed to the left. NEEM Field Dairy July 23 2009.

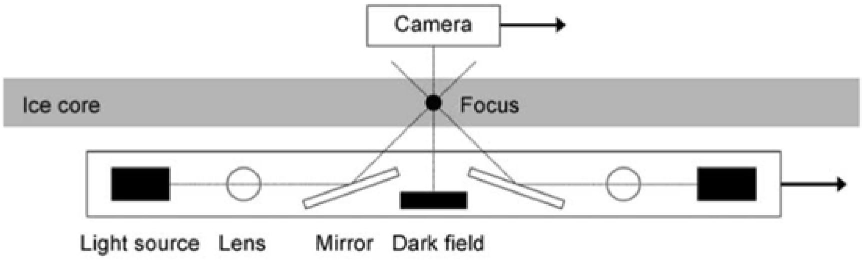


Figure 2.2: Principal layout of the line scan set up.

2 The NEEM line scan dataset

2.1 The line scanner

The main part of the line scan set up is a camera, which is moved above the selected part of the threebag. Below the same threebag, there are two light sources, lenses and mirror, with the purpose to guide the light beam from the sources through the threebag to a focus point directly under the camera in the middle of the threebag. The camera is orientated against this focus point and a dark field under this point, as shown on figure 2.2, [Nielsen, 2005] and [Ice and Climate Group, 2009].

2.2 Season 2009

In the 2009-season was used a camera with a resolution in width pa 1048 pixels. All images in this season was photographed in the same manner in threebags, in such a manner that the top rear, and thus with the lowest number that had a bagnumber that were divisible by three. Each threebag is photographed at least once and some several times due to an error in the camera, so that parts or the entire core was moved around on the image. However, for all threebags least one picture where there are no problems with shooting. This or any of these images are used for analysis. An example of a 2009 line scan picture is shown in figure 2.4(a).

2.2.1 Different layers

There is a clearly variation in the ice core through out its length. In figure 2.3 three typical examples from the core are shown. Figure 2.3(a) is from the firn, where the bubbles are clearly visible. Furthermore this section gives an examples of different kinds of breaks. In the top, there is two breaks close to each other, resulting in a small peace. All though the core is scanned with a gab here, there length was measured with the gabs closed. The third breaks from the top is an example for, that the breaks not all the time were close to horizontal.

Figure 2.3(b) is from close before the period, where visual stratigraphy is possible. At this depth, there is not visible lines originating from annual layers. There are some indistinct lines, which results from the processing before scanning, where the up- and downside should be as plane as possible. Besides this there are *no* usable information in the picture for visual stratigraphy.

The last threebag processed in 2009 is shown in figure 2.3(c)

2.2.2 Failures in 2009-pictures

The camera in season 2009 was not 100 percent perfect. There were to different problem, one with a missing bit in the camera, the other being an unwanted flip function.

2.2.2.1 Missing bit-problem Figure 2.4(b) shows an example of the problem with the missing bit. The bit associated with the highest value was 512. For each pictures of a threebag, there is created a picture of the saturation. If the pixel was saturated, the corresponding pixel is shown in white on the saturation pictures, in the opposite case results in a black pixel. Figure 2.4(b) shows an example of the saturation pictures, and this picture are, as all other saturation pictures, allmost black. The number of saturated pixels is so low, that this problem is ignored. A detailed description can be found in [Nielsen, 2005].

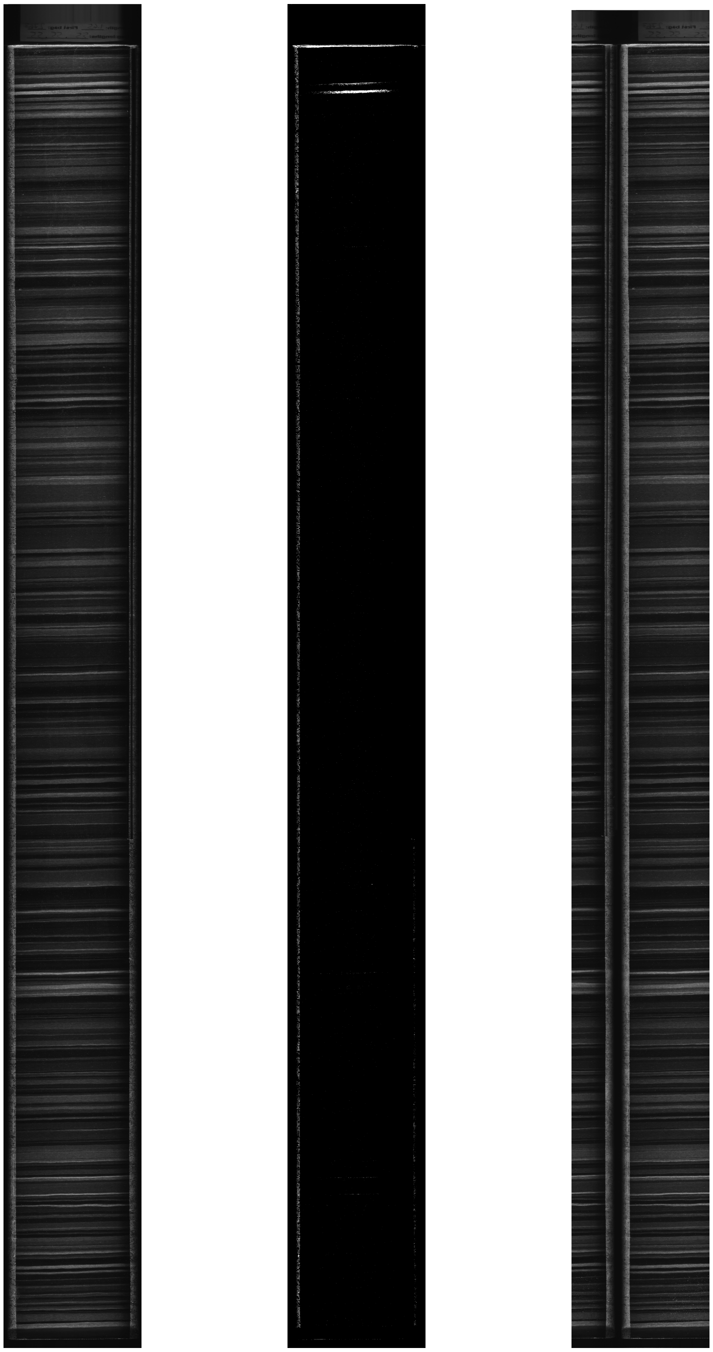
2.2.2.2 Unwanted flip function Figure 2.4(c) shows an example of the unwanted flip function. This function draw a vertical line through the all or parts of the picture. Then the two parts on either side of this line are swap spaces. This is not a problem for the project, because the line scan crew discovered this problem, and when it occurred they simply took a new picture until the problem was not present. This could take up to eight attempts! There were of course also saturation pictures of the pictures with the unwanted flip function. The reason for this failure is unknown.

(a) Threebag 1050 - firn bubbles and breaks.

(b) Threebag 2667 - no visible lines.

(c) Threebag 3192 - the last bag in 2009.

Figure 2.3: Pictures of different threebag from 2009.



(a) Threebag 2877 without problems.

(b) Threebag 2877 saturation image.

(c) Threebag 2877 with the unwanted flip function.

Figure 2.4: Different pictures of the threebag 2763.

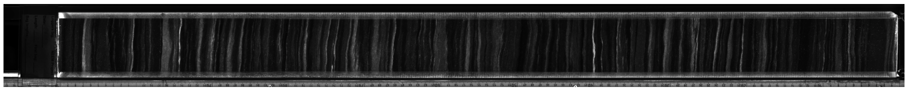


Figure 2.5: Twobag 3380, 1858.45-1859.55 m.

2.3 Season 2010

In the 2010-season there was introduced a new camera, which caused some changes in the line scan pictures. The was caused due to a higher resolution and colour depth. The resolution was doubled in both dimensions, which give four times more pixel per area, and the colour depth were also doubled compared to the old camera. Totally this gave eight times more data per area unit in 2010 compared to 2009.

Furthermore the pictures were changed in two other ways: The line scan scanned twobags and not threebags, and beside this, the pictures are up side down, meaning that the bottom of the twobags is in the top of the pictures.

Besides this, the scanning method where also introduced to two new variations in the scanning. In 2009, all pictures were scanned from the same depth and with the same opening time. These two parameters were variated in 2010.

2.4 Grey scale

Visual stratigraphy is bases on the information from the line scan. The output is pictures with a variating brightness, and it is assumed, that a brighter part of the core corresponds to a colder period. As described, there is also a connection between δ^{18}O and the temperature, which lead to the conclusion, that the grey scale and δ^{18}O may "follow" each other.

Figure 2.6 and 2.7 shows the grey scale of the analyzed part of NEEM ice core in 2009 and 2010 respectivily. The result is plotted together with the δ^{18}O data, where by it can be justified, that the visual variation, e.g. lines, can be used as a counting method.

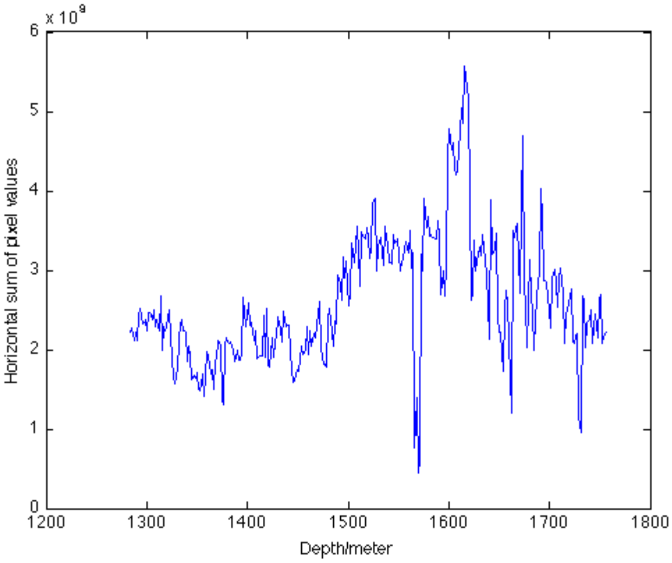


Figure 2.6: Grey scale of NEEM ice core. The grey scale value is a sum over the pixel value in a given depth. The power of 10 on the y-axis is 10^9.

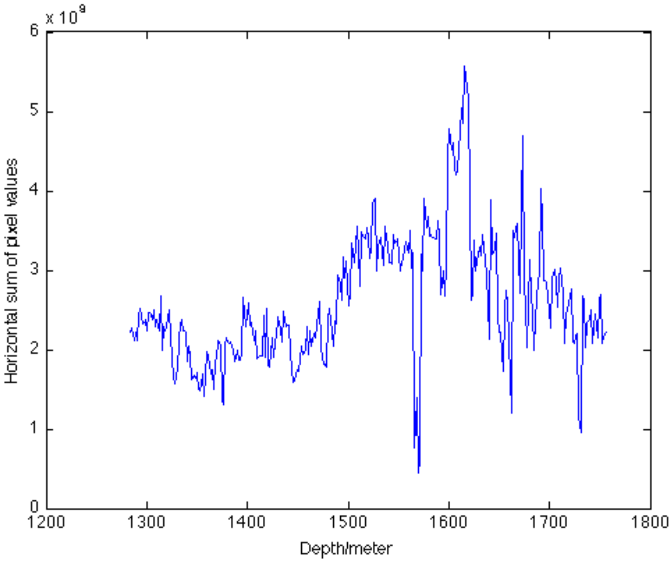


Figure 2.7: Grey scale of NEEM ice core. The grey scale value is a sum over the pixel value in a given depth. The power of 10 on the y-axis is 10^9.

3 Methods

3.1 Raw data

The image of the ice core is available in PNG format in black and white. Technically it is accomplished by all three colors, red, green and blue, is completely saturated and there is no transparency in the image (alpha value is zero).

The camera used in the 2009-season, there was an error at the most significant bits.

The first step in this process is to identify the individual lines. Since there is no garanti that there is just one identifiable line per year. due to this, on year could be counted more than one time, or not at all.

The raw data comes directly from the camera. As described previously, there is a difference in the datas for 2009 and 2010.

3.2 Imaging

When the pictures are recorded, the next step in the process is line identifying. Figure 3.0.A shows the picture of threebag 2946. A first view on this picture shows clear white lines, grey band and black band in the horizontal direction. Furthermore there are non-continious white lines in the vertical direction.

The challenge is now to figure out, based only on the pixel values in the pictures, where the lines are. There are a lot of information, so all unusable and or disturbing information need to be removed or ignored, if possible.

The easiest trick here is removing the vertical edges; the two vertical bars on each sides, storing subpictures from the drill knifes. The vertical edges, or top and bottom is not considered a problems, as the is compromised of black or very dark grey areas, which will not be detected as lines. The real ends of the theebags are from time to time visible as more or less clear white lines. These would eventually be counted as lines. All in all the cuts could be counted as zero, one or two lines, depending on the countability of the top and bottom. The uncertainty arising from this is

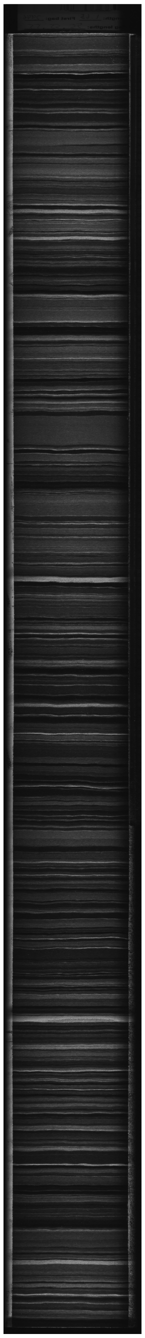


Figure 3.0.A: Threebag 2946, 1619.75-1621.50m.

neglected due to the small numbers of "bagcuts" compared to the number of lines, and the methods of finding all possible lines as described later on. In a similar way breaks could be counted as a varying but at maximum a handful of lines, and it is not analysed how the scripts handles the break in details, but the counted number of lines are, as expected small and therefor the uncertainty once more is small enough.

3.3 MatLab-codes

In this chapter I will describe the mathematical method in details, step by step. I will use an example from the top of bag 2.946, shown in figure 3.0.A, where the top is at 1.619,75 m depth, see figure 3.0.B. In this selected section, there are some clearly visible lines, and some more and less grey areas, a few doubles lines and some possible different λ-values. Furthermore there is some "salt and peber" noise, randomly distributed pixel in the grey scale. Each of the next section will describe the 10 steps by which the lines are identified.

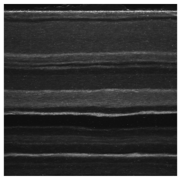


Figure 3.0.B: Top op bag 2946, unprocessed.

Before any interesting manipulations, the edges of each pictures are cut off. These areas of the pictures has a significant different grey scale distribution, which would affect Step 2, and they have a huge number of small lines from the drill head, which could generate more than one line per millimeter, 10-folds more than the expected λ-value.

3.3.1 Step 1

In Step 1 there is focus on the `filtering`-function, which reduce "salt and peber" noise. The result is shown i figure 3.1 and the corresponding `MatLab`-code is:

```
no_filtering = 3;
for i = 1:no_filtering
   I = medfilt2(I, [7 15]);
end
```

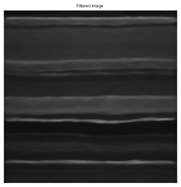


Figure 3.1: Top op bag 2946, the status after Step 1 with *filtering*-function, where "salt and peber" noise is removed.

This step is required before the `imadjust`-function in Step 2. Without this filter, the noise would affect the grey scale distribution in an unwanted way, and later on tricking the `horzedge`-function in Step 3.

3.3.2 Step 2

In Step 2 the focus is on the `imadjust`-function again. The result is shown i figure 3.2 and the corresponding `MatLab`-code is:

```
I = imadjust(I);
```

The main task here is to change the grey scale distribution. The risk by this is, that *very* weak lines are vanished out, and would there not be detected later on.

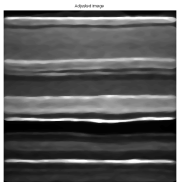


Figure 3.2: Top op bag 2946, the status after Step 2

3.3.3 Step 3

In Step 3 there is focus on the `image`-function. As the name indicate, the function has focus on the horizontal differences. The result is shown i figure 3.3 and the corresponding `MatLab`-code is:

```
N = 7;
horzedge = NaN(N,N);
horzedge(1:(N-1)/2,:)=-1;
horzedge((N+1)/2,:)=0;
horzedge((N+1)/2+1:N,:)=1;
strength = 5;
I = imfilter(I,strength/10*horzedge, 'conv');
```

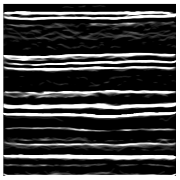


Figure 3.3: Top op bag 2946, the status after Step 3 with *horzedge*-function

3.3.4 Step 4

In Step 4 the focus is on the `morpho`- and `imclose`-functions. The result is shown i figure 3.4 and the corresponding `MatLab`-code is:

```
morpho_row = ones(1,20);
no_filtering = 1;
for i = 1:no_filtering
   I = imclose(I,morpho_row);
end
```

The process closes small holes in figure 3.3, i.e. where there is an black area in a white lines. This step do not lead to a big difference between figures 3.3 and 3.4.

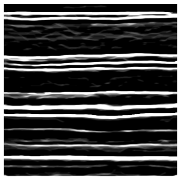


Figure 3.4: Top op bag 2946, the status after Step 4

3.3.5 Step 5

In Step 5 the focus is on the `im2bw`-function. The result is shown i figure 3.5 and the corresponding `MatLab`-code is:

```
threshold = 12.5;
I = im2bw(I,threshold/100);
```

All the bit have a value $I \in [0;255]$. By this function, the lever 12.5% of the interval I is set to 0: $threshold(I \in [0;255/8]) = 0$. All values above the threshold value are set to 1: $threshold(I \in [255/8;255]) = 0$. Status now is a picture with a source matrix containing *only* 0-bits and 1-bits. From now on the noise needs to be removed, and changing the thickness of the relatively thick lines to 1.

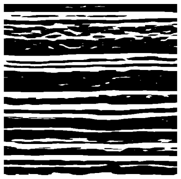


Figure 3.5: Top op bag 2946, the status after Step 5

3.3.6 Step 6

In Step 6 the focus is on the `bwareaopen`-function. The result is shown i figure 3.6 and the corresponding `MatLab`-code is:

```
I = bwareaopen(I, 100);
```

Step 6 removes small object with an area of less than 101 pixels, whereby small object are removed. By this all the small objects in figure 3.5, which could be described a "salt and peber"-noise with large corns are thrown away in figure 3.6.

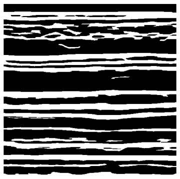


Figure 3.6: Top op bag 2946, the status after Step 6

3.3.7 Step 7

In Step 7 the focus is on the `imopen`- and `strel`-functions. The result is shown i figure 3.7 and the corresponding `MatLab`-code is:

```
se = strel('line',20,0);
I = imopen(I,se);
```

The `imopen`-function removes in this case horizontal arrays of ones, which are shorter than 21 pixel. The direction and length are specified by the `strel`-function.

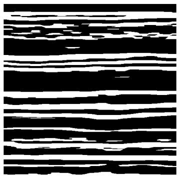


Figure 3.7: Top op bag 2946, the status after Step 7

3.3.8 Step 8

In Step 8 the focus is on the `bwmorph`-function. The result is shown i figure 3.8 and the corresponding `MatLab`-code is:

```
I = bwmorph(I,'thin',Inf);
```

Figure 3.7 countains a number of very thick lines. This step simply reduces these lines to lines with a thickness one 1. In the vertical direction, each line is described by a number of 1's. The lowest 1-bit is stored unchanged, all the 1-bits above in a unbroken row of 1-bits are changed to 0.

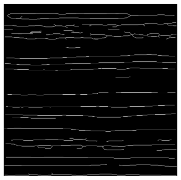


Figure 3.8: Top op bag 2946, the status after Step 8

3.3.9 Step 9

In Step 9 the focus is on the `bwmorph`-function again. The result is shown i figure 3.9 and the corresponding `MatLab`-code is:

```
I(:,1:100)=[];
I(:,end-100:end)=[];
I = bwmorph(I,'spur',Inf);
```

If we at figure 3.8 there are secondary lines ending in "nothing". This is a kind of noise from all the preceding step. Every bit in this step have a value of 0 or 1. If a 1-bit is surrounded by 7 0-bits and 1 1-bit, this bit is now changed to a 0-bit. This reamining 1-bits from the surrounding is now evaluated, and if this bit now has 7 surrounding 0-bits, including the latest changed bit, it is also changed to a 0-bit. This process is repeated until no bit fullfill the criteria. Figure 3.8 also contains lines which are drawn all the way from the left side to the right. But there are also a number of lines, which only reach one of the side or none of them. These small lines are removed too.

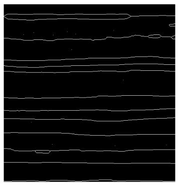


Figure 3.9: Top op bag 2946, the status after Step 9

3.3.10 Step 10

In Step 10 the focus is on the bwmorph-function again again. The result is shown in figure 3.10 and the corresponding MatLab-code is:

```
I = bwmorph(I,'clean');
```

If we at figure 3.9 there are secondary 1-bit surrounded by 8 0-bits. All these 1-bits are removed in this step. Statistically a few one of these dots would have been counted as full lines, if they are not removed.

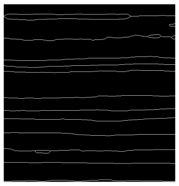


Figure 3.10: Top op bag 2946, the status after Step 10

3.3.11 The identified lines

Step 10 represent the identified lines. The final result is shown on figure 3.11, which is the same figure as 3.0.B, but with the identified lines. In the final pictures there are some lines, which has section with double lines. Some of these will later on be counted as one, others as two lines. But the corresponding λ-value would be significant smaller than the average λ-value, and therefore the lower one of the double lines would be removed. The lines on figure 3.11 are those from 3.10, all though in a thicker version just for the visability.

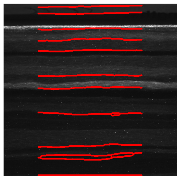


Figure 3.11: Top op bag 2946, same as figure 3.0.B with identified lines.

3.4 Tie points and interpolated data

Before the main part of the data analysis, I need to find a number of tie points between the NEEM and the GICC05 time scale. The most significant points are the onsets before the interglacial periods. These tie points are found by combination of the δ^{18}O data from NEEM and the GICC05.

With the tie points it is now possible to interpolate the GICC05 time scale on the NEEM ice core, and thereby getting a guideline for an expected variation of λ, as shown in figure 3.12.

The tie points are an important information, when the NEEM ice core has to be sectionated in cold and warm periods, a step which is important because visual stratigraphy works much better in cold than warm periods and λ has significant other values in cold and warm periods.

Event	NorthGRIP	NEEM
YD/PB transition	1492,45	1420
GI-1	1604,64	1489,5
GI-2	1793,2	1598
GS-2/3	1860	1637
GI-3	1869,12	1641
GI-4	1891,57	1655
GS-4/5	1940	1682
GI-5	1951,66	1690
GS-5/6	1964	1697
GI-6	1974,56	1703
GS-6/7	1990	1711
GI-7	2009,45	1723
GS-7/8	2027	1635

Table 3.1: Tie points between NorthGRIP and NEEM, both depth are measured in meters.

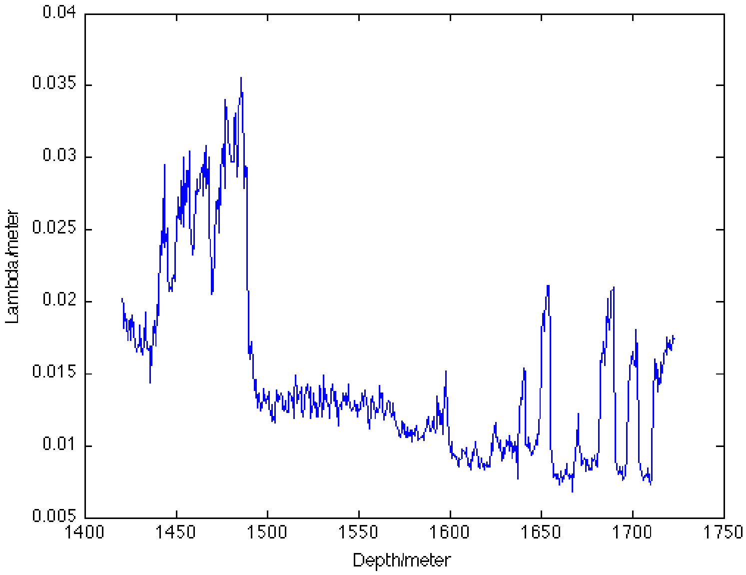


Figure 3.12: λ from GICC05 interpolated at NEEM depth.

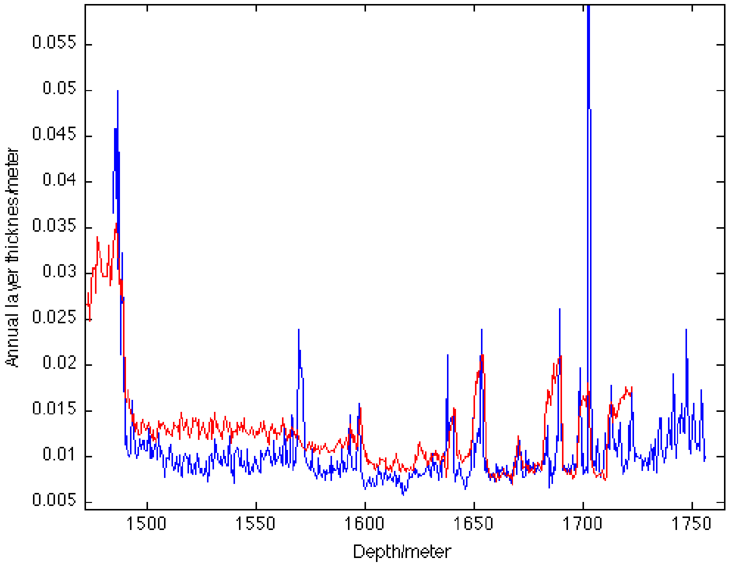


Figure 4.1: A first run on the NEEM ice core (blue) and interpolated GICC05 (red), where the onset are clearly identifiable. The peak at around 1.570 meters is will be discussed later.

4 Results

In this section I will represent the results from the line identifying method in the previously section. As mentioned before, the first part of the dating process is line identifying, where all possible lines are stored. After this, the next challenge is to figure out, which lines are really lines, and which are "false positives". Furthermore I expect, that some lines is missing. These lines are not visible, but if the layers were counted manually, we would have assumed, that there would be some invisible lines due to unexpected large interval, corresponding to large λ values.

4.1 First run with NEEM ice core

To get an overview, I made a first run with the NEEM ice core, where I identified the layers with the expectations, that especially the onset are visible. The result can be seen in figure 4.1. At first hand this result seems to be reasonable. The λ values are in the magnitude of 1 cm, and will soon be showed to be close enough to the interpolated NorthGRIP-data, which are created as a guideline. It is easy to match the onset in figure 1.7 and figure 4.1.

The NorthGRIP λ values has been shown in figure 1.7, and by combination

Depth/m	NEEM/GICC05	NEEM
1490-1591	8050	10441
1591-1598	600	679
1598-1637	4030	5039
1637-1641	410	293
1641-1649	730	1023
1649-1655	390	504
1655-1682	3140	3163
1682-1690	460	779
1690-1697	840	903
1697-1703	400	536
1703-1711	920	797

Table 4.1: Number of lines in GICC05 and NEEM in each of the five evaluated interval. Blue colour corresponds to glacial periods, red to interstadial. NEEM/GICC05 data found with combination of tie points and [Svensson et al., 2008]. The uncertainty for NEEM/GICC05 is not shown here, but known for a glacial period and the stadial period below it, and available in table 1.1.

of these data with those in table 3.1 it is possible to "create" a guideline for an answer for the NEEM data.

In the first run, the script would try to detect every line, even if it really should be there, or not. The next problem is to validate each line in such a way, that the "real" is counted, and false positives, i.e. double lines, are removed. Furthermore in a later step, I would try to find the "false negative", lines which probably should have been there, but where nothing is detected. The result of this can be seen, at noted above, in figure 4.1, the λ-distribution in figure 4.3 and the number of lines in each cold period are shown in table 4.2.

Table 4.2 and figure 4.2 show a decreasing tendency in the "overdetection"

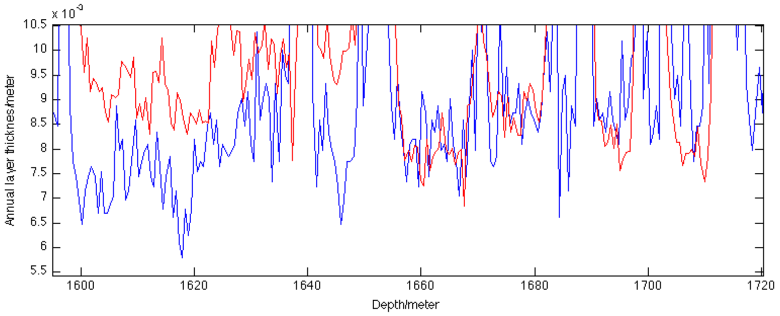
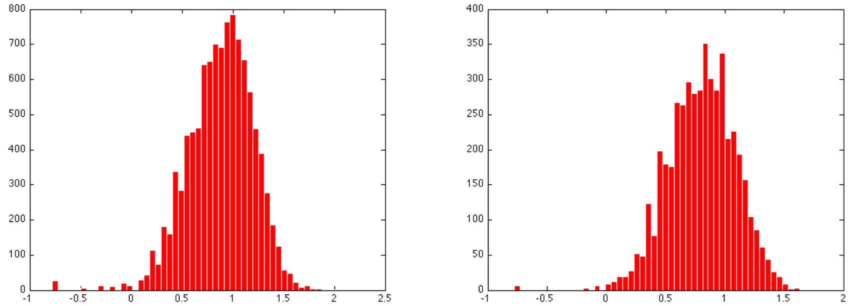
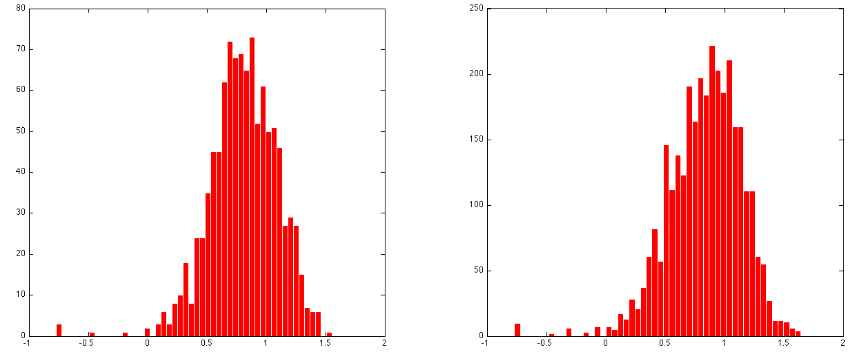


Figure 4.2: A close up of figure 4.1. NEEM ice core (blue) and interpolated GICC05 (red).



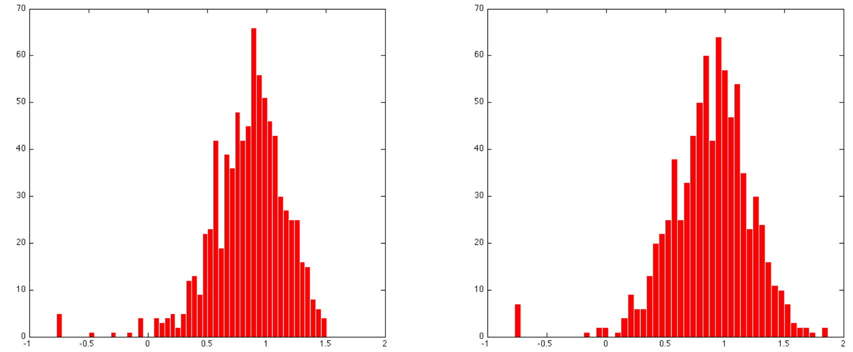
(a) Depth: 1490-1591 m

(b) Depth: 1598-1637 m



(c) Depth: 1641-1649 m

(d) Depth: 1655-1682 m



(e) Depth: 1690-1796 m

(f) Depth: 1700-1711 m

Figure 4.3: Histograms for the chosen intervals. Note that the x-axis is $\log_{10}(\lambda)$.

Depth/m	NEEM/GICC05	NEEM
1490-1591	8050	10441
1598-1637	4030	5039
1641-1649	730	1023
1655-1682	3140	3163
1690-1697	830	803
1703-1711	920	797

Table 4.2: Number of lines in NEEM/GICC05 and NEEM in each of the six evaluated interval

of lines. In the uppermost interval, there is 16.0 % too many lines, compares with the NorthGRIP ice core. This "overdetection" is decreased to an "underdetection" by 13.4 % in the lowermost interval! I hoped, that I would find more lines, that there are expected to be. At this state, I would note, that *all* parameters has been tuned in more or less every possible combination to increase the number of lines until now. If this was the case, the task from now would have been focusing on removing lines from the data, but now I also need to find the missing lines, if possible.

Let $\Delta\lambda$ be the vertical distance *from* the NEEM-data *to* the transferred GGIC05-data. There seems to be a tendency, so that $\Delta\lambda$ is decreasing with the depth, and around 1660-1680 m it is zero, and even deeper *negative*. The last one mean, that I have found a smaller number of lines than there should be! So here the main task is, with the same algorithm is to find more lines, and not only having focus on removing lines.

This tendency is visible on figure 4.2, where the λ_{NEEM} (blue line) "cross" $\lambda_{NEEM/GICC05}$ (red line).

The process in the next step has been developed in three step, each of trying to catch the problem noticed above.

4.2 Manually counting

If a normal person should count each layer manually, this person would made an evaluation of each line immidiatly. It is likely, that two lines close to each other would be counted as one, and the same person would try to detect "invisible" lines, where the distance between to lines are significant higher than normal. This mean, that an intelligent counter would not only count, but also validate or not the individual lines with respect to, how likely it is, that there would be a line, where he detects it.

The result of this "intelligent", but maybe also a little "subjective" counting is a relative small variation in the λ-distribution, likely much smaller than randomly distributed lines.

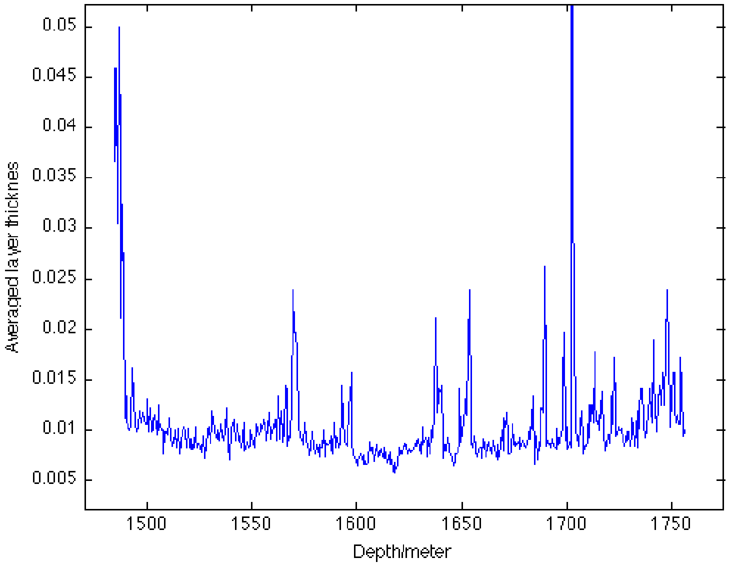


Figure 4.4: NEEM λ after statistical removing and adding of lines with a 3σ variation. (PLOT GICC05)

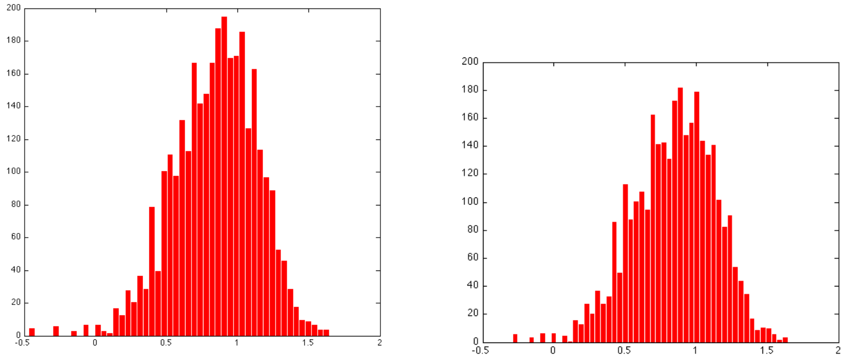
4.3 Step 1: Removing and adding lines by statistics

The first step in the cleaning process is purely statistical. It is known from the NGRIP-core, that 95 % of the layers has a λ-value within two standard variation of the average value, that is $\lambda = \mu \pm 2\sigma$. I will use this knowledge to handle the thinnest and thickest lines, those with the smallest and largest λ-value.

- Find the smallest λ-values
- Choose the uppermost of these values, remove this line
- Continue the process with finding the line connected with the smallest value, it could eventually be the second uppermost from the first step
- Stop the process when the smallest λ-value is greater than $\mu - n\sigma$. n is 5 in the first run.

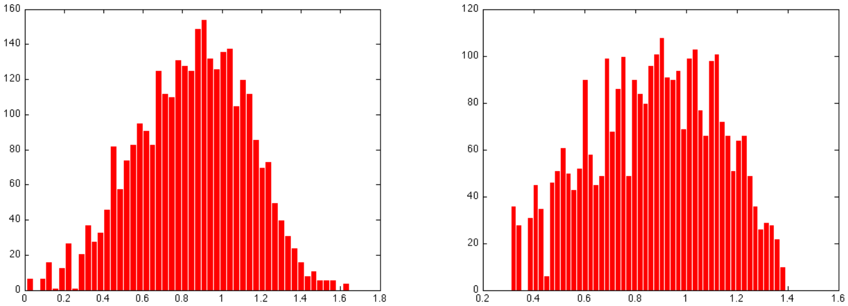
For the largest λ-values, the process is close to that for the smallest values:

- Find the largest λ-values
- Choose the uppermost lines with this λ-value
- Place a line between this line and the line above, with result that these to lines has a thickness of $\lambda/2$.



(a) $\sigma = 5$, a secondary top left to the main top.

(b) $\sigma = 4$



(c) $\sigma = 3$

(d) $\sigma = 2$, no tails on the distribuion!

Figure 4.5: Evolution of interval 3, starting with $\sigma = 5$. Note that the x-axis is $\log_{10}(\lambda)$.

Depth/m	NEEM/GICC05	NEEM	$\sigma = 5$	$\sigma = 4$	$\sigma = 3$	$\sigma = 2$
1490-1591	8050	10441	10420	10409	10373	10293
1598-1637	4030	5039	5034	5032	5022	5034
1641-1649	730	1023	1021	1019	1016	1007
1655-1682	3140	3163	3156	3152	3137	3094
1690-1697	840	803	800	798	791	782
1703-1711	920	797	797	791	789	788

Table 4.3: Number of lines in GICC05 and NEEM in each of the six evaluated intervals. Column 4-7 shows the number of lines for 2σ to 5σ.

Depth/m	NEEM/GICC05	NEEM	$\sigma = 5$	$\sigma = 4$	$\sigma = 3$	$\sigma = 2$
1490-1591	8050	10441	29%	29%	29%	28%
1598-1637	4030	5039	25%	25%	25%	25%
1641-1649	730	1023	40%	39%	39%	38%
1655-1682	3140	3163	1%	0%	0%	-1%
1690-1697	840	803	-5%	-5%	-6%	-7%
1703-1711	920	797	-13%	-14%	-14%	-14%

Table 4.4: Changing in number of lines in GICC05 and NEEM in each of the six evaluated intervals. Column 4-7 shows the percentage deviation for 2σ to 5σ.

Depth/m	NEEM/GICC05	NEEM	$\sigma = 5$	$\sigma = 4$	$\sigma = 3$	$\sigma = 2$
1490-1591	8050	10441	18%	18%	18%	17%
1598-1637	4030	5039	15%	15%	14%	15%
1641-1649	730	1023	39%	39%	-6%	39%
1655-1682	3140	3163	-2%	-6%	-4%	-7%
1690-1697	840	803	-2%	-2%	-12%	-3%
1703-1711	920	797	-13%	-12%	-12%	-12%

Table 4.5: Number of lines in GICC05 and NEEM in each of the six evaluated interval after Step 2.

- Continue the process with finding the line connected with the largest value, it could eventually be the second uppermost from the first step
- Stop the process when the largest λ-value is smaller than $\mu - n\sigma$. n is 5 in the first run.

It should be noted, that it is important, that the lines are treated in both end in step of 1σ, and not the lower end all the way from 5σ to 2σ and then the upper end of the histograms. At NorthGRIP the variation was found to be 2σ [Rasmussen et al., 2006]. Compared with figure 4.5, this seems not to be the case here. At figure 4.5(d), where $\sigma = 2$, the histogram is cut "in" the main part of the distribution. As it can be seen in appendix A, the same is case for all intervals. So it can not be justified, that the variation in λ is the same as the NorthGRIP-variation, based on this method. Figure 4.4 shows the λ values after this modification.

4.4 Step 2: Removing and adding according to local variation

The next step compares a given layer or two layers next to each others with their "local environment". Whether it can be justified is discutable, but the

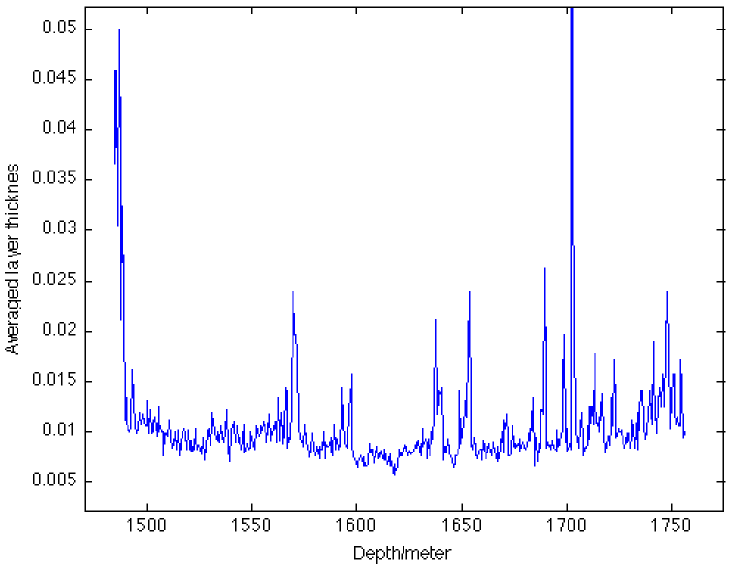
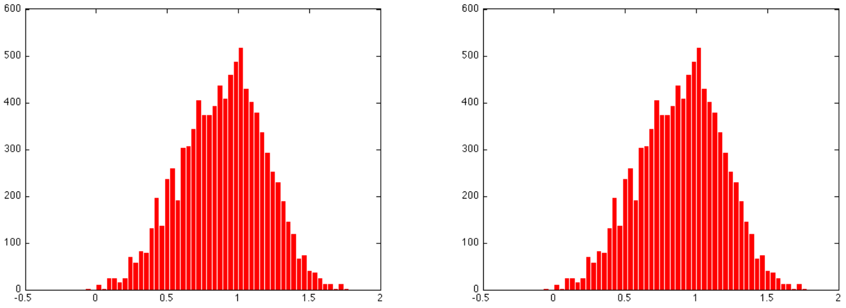
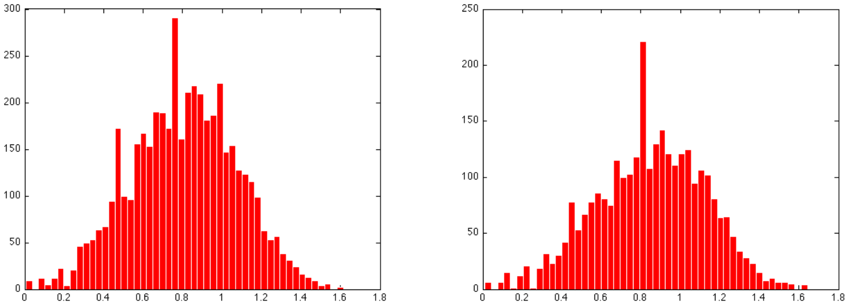


Figure 4.6: A first run on the NEEM ice core, where the onset are clearly identifiable. The peak at around 1.570 meters will be discussed later.



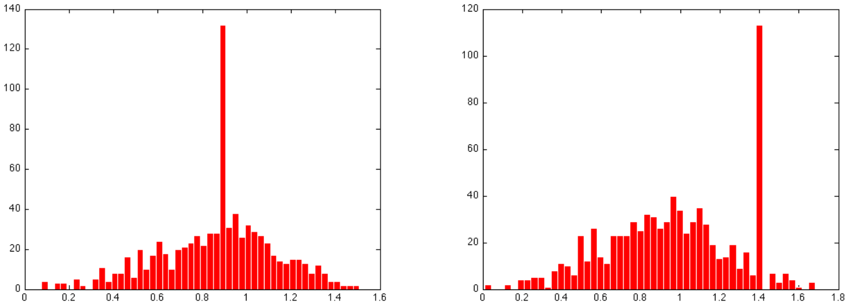
(a) $\sigma = 3$

(b) $\sigma = 3$



(c) $\sigma = 3$

(d) $\sigma = 3$



(e) $\sigma = 3$

(f) $\sigma = 3$

Figure 4.7: Histograms for the glacial periods after step 2 with $\sigma = 3$. Note that the x-axis is $\log_{10}(\lambda)$.

Depth/m	NEEM/GICC05	NEEM	$\sigma = 5$	$\sigma = 4$	$\sigma = 3$	$\sigma = 2$
1490-1591	8050	10441	18%	18%	18%	17%
1598-1637	4030	5039	15%	15%	14%	15%
1641-1649	730	1023	39%	39%	39%	38%
1655-1682	3140	3163	-6%	-6%	-6%	-7%
1690-1697	840	803	-2%	-2%	-4%	-4%
1703-1711	920	797	-8%	-7%	-5%	-4%

Table 4.6: Chaning in number of lines in GICC05 and NEEM in each of the five evaluated interval after Step 3.

defence argument is, that a large variation is unlikely, by the same way, that we do not expect λ values greater than $2\lambda_{average}$ or less than $\frac{1}{2}\lambda_{average}$.

- Begin from the top of a section
- Evaluate over a sequence over four line intervals
- If the two intervals in the middle of the four together has a length, that is less than one third of the four intervals combined, remove the line dividing these the to intervals in the middle

In a similar way, the unexpected large intervals are handled:

- Begin from the top of a section
- Evaluate over a sequence over three line intervals
- If the center intervals of these three has a length, that is more than half of the three intervals combined, then the center interval is split in two equal large intervals with an extra line.

The result of this can be seen in figures 4.6 and 4.7 and table 4.5. The general tendency in these histograms is, that they are more symmetric than in figure 4.3, but with an unlikely large bin in four of the histograms! This problem is handled in section 4.5, but not in a very nice way!

4.5 Step 3: Bin manipulation in histograms

The last step is more "fluffy", and the ideas justifiability can be discussed. In the previously, the histograms often has a significant bin, which are much higher than all the center of the distribution. This is not probable, therefor the part of this bin, which is "over" the expected according to the gaussian distribution, is manipulated.

The bin or bins, which are too high, is either to the left or right of the top. This bin is cut in two, and if the bin to be cutted has number n, then the cut is done at:

$$\Delta bin(n) = \text{int}\left(\frac{bin(n-2) + bin(n-1) + bin(n+1) + bin(n+2)}{4}\right)$$

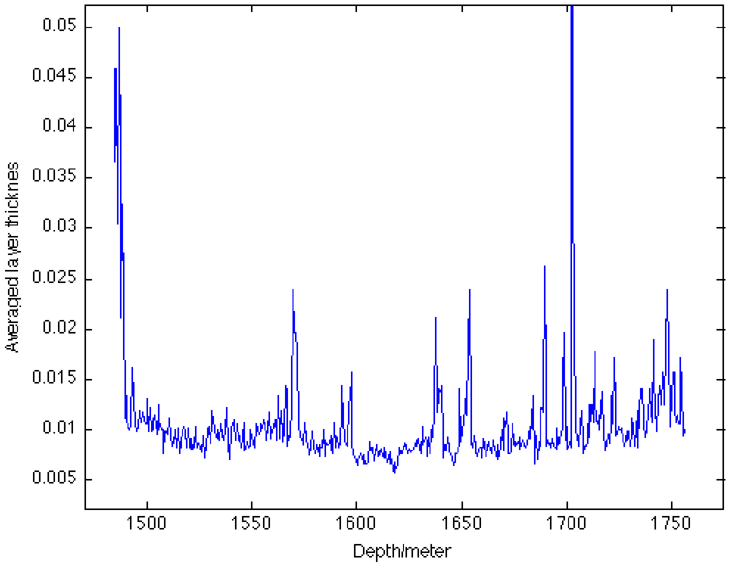


Figure 4.8: A first run on the NEEM ice core, where the onset are clearly identifiable. The peak at around 1.570 meters is a failure

Depth/m	NEEM/GICC05	NEEM	$\sigma = 5$	$\sigma = 4$	$\sigma = 3$	$\sigma = 2$
1591-1598	600	679	679	675	673	674
1637-1641	410	293	293	293	292	286
1649-1655	390	504	504	502	499	497
1682-1690	460	779	779	773	769	798
1697-1703	400	536	536	536	535	535
Sum of stadial:	2260	2791	2791	2779	2768	2750

Table 4.7: Chaning in number of lines in GICC05 and NEEM in each of the five evaluated interstadial periods.

Depth/m	NEEM/GICC05	NEEM	$\sigma = 5$	$\sigma = 4$	$\sigma = 3$	$\sigma = 2$
1591-1598	600	679	13%	13%	12%	12%
1637-1641	410	293	-29%	-29%	-29%	-30%
1649-1655	390	504	29%	29%	28%	27%
1682-1690	460	779	69%	68%	67%	65%
1697-1703	400	536	34%	34%	34%	34%

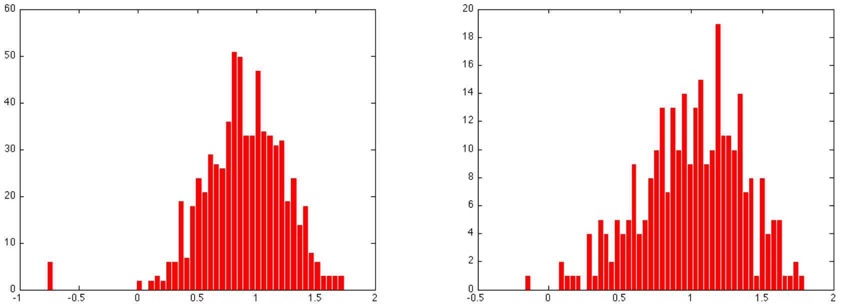
Table 4.8: Number of lines in GICC05 and NEEM in each of the five evaluated interstadial periods. Column 4-7 shows the percentage deviation for 2σ to 5σ.

where $\Delta bin(n)$ is the change in $bin(n)$, which again is the number of entries in bin number n, and int the integer function. This procedure will not could handle the two outermost bins in each side, which turned out not to be a problem. The part of the bin below this value is unchanged. The upper part contains a number of lines, representing a given length of the core. The histogram excluding the upper part over the cutted bin represent a part too, all though much longer, and a number of lines, which gives a $\lambda_{average}$ for this part. The number of lines in this part is now changed with the difference between the number of lines in the cutted part and the number of lines, there would have been, if λ for this part is set to $\lambda_{average}$.

4.6 Interstadial periods

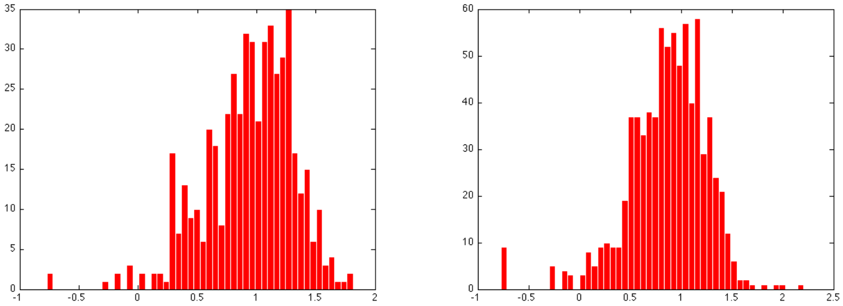
As already mentioned, visual stratigraphy is not expected to work very well in the warm periods. The methods has tried to find lines all the way from 350.90-601.70 and 1281.50-1756.70 meters, including both the warm and cold periods. It was expected, that it was unsuccessful to find any reasonable amount of lines in the warm periods, which seems to be confirmed with figure. The result of the applying is shown in figure 4.9 and table 4.8.

A close up of an interstadial period can be seen on figure 5.3. As it can be seen, the methods detects the insets and terminations, but the "central" part of the interstadial periods are not significant higher than the glacial periods. The peaks at onsets and termination are at the other hand more magnitudes higher,



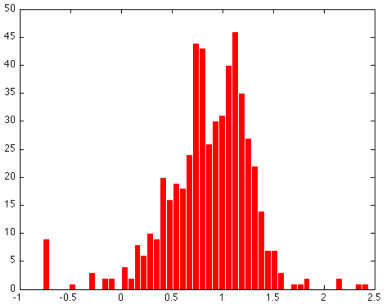
(a) Depth: 1591-1598 m

(b) Depth: 1637-1641 m



(c) Depth: 1649-1655 m

(d) Depth: 1682-1690 m



(e) Depth: 1697-1591 m

Figure 4.9: Unmanipulated histograms for the interstadial periods. Note that the x-axis is $\log_{10}(\lambda)$.

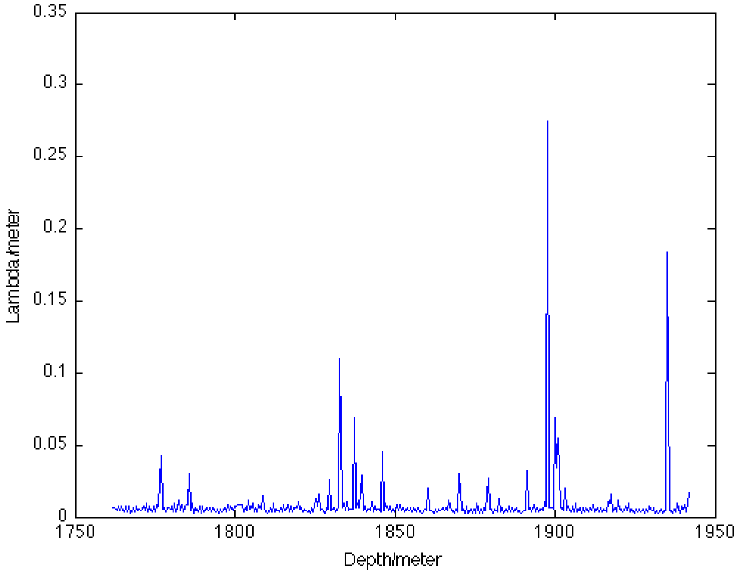


Figure 4.10: λ for a part of the 2010 season.

resulting in a double peak.

The histograms has the same tendency as in the glacial periods with a secondary top, all though less markedly. With respect to he variation, which in [Rasmussen et al., 2006] was found to be 2σ in both colder and warmer periods, we see the same tendency here, that the variations in the colder and warmer periods are close to each other at around 3σ.

This result should be interpreted with an element intact, due to the relative small number of lines and their correspond thickness in each bin. Furthermore, I will show in section 5.1.4, the detection in the interstadial periods are not credible. For comparison, their are around ten times more lines in the glacial periods than in interstadial.

4.7 First run with 2010 data

Figure 4.10 shows the λ for 2010, averaged over one bag, and figure 4.11 a close-up of a part of figure 4.10. There are detected variation in λ, but not with a "shape" that looks like GICC05, Furthermore the bag averaged λ seems to have a periodicity of one bag length. Due to these result, I quickly concluded, that an extension of this methods over the 2010-bags would require a recalibration of the parameters, which was not possible within the time limit of approximately one month. Another problem was, that the was several scanning series with different grey scales, an no one was covering all bags from 2010.

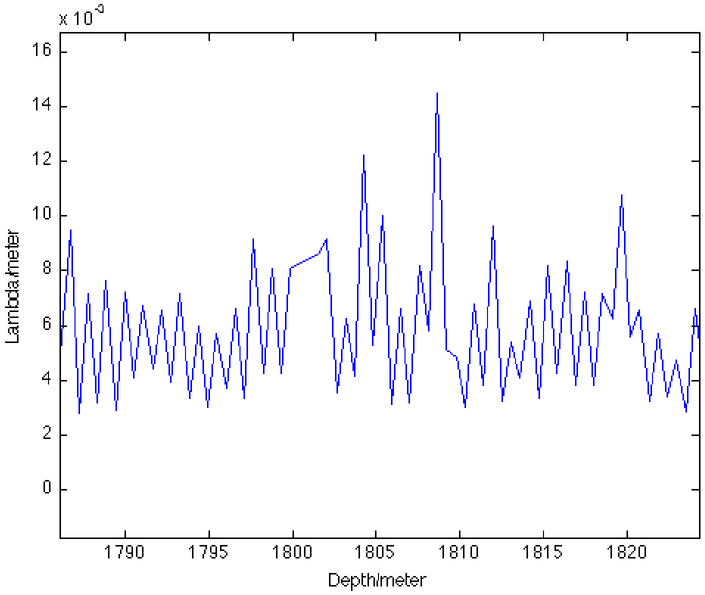


Figure 4.11: Close up of a part of figure 4.10. The power of 10 on the y-axis is 10^{-3}.

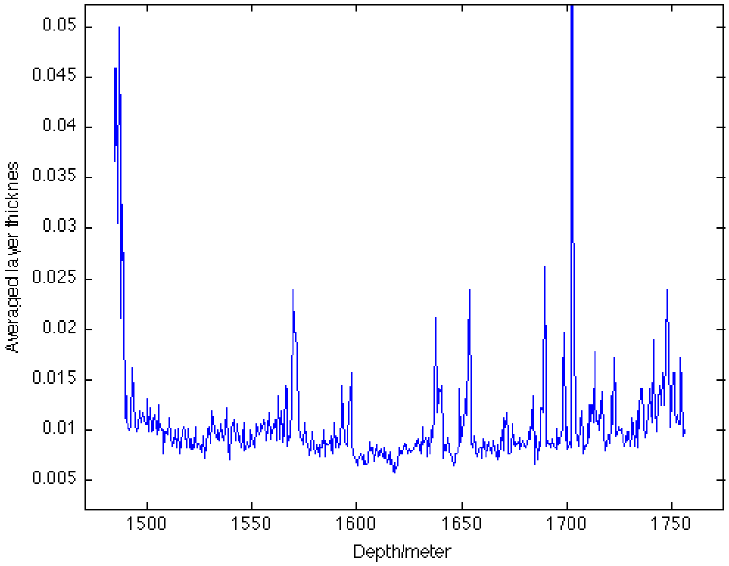


Figure 5.1: A first run on the NEEM ice core (blue) and interpolated NorthGRIP (red), where the onset are clearly identifiable. The peak at around 1.570 meters is a failure.

5 Discussion

The result as presented above can not be designated as "spot on" on the expected. There are problem with both identifying lines and validating them. Furthermore there differences in how the methods treats different part of the core, especially when compared with NEEM/GICC05. Besides from this, there are also some unexpected results.

5.1 Comparison to GICC05

As mentioned earlier, the characteristic "shape" from the NorthGRIP ice core are found in the NEEM ice core. The cold and warm periods are distinguishable, the onsets are distributed as expected. The main problems, which will be discussed, is in the warm periods, a tendency of increasing ratio in the λ_{NEEM} with respect to $\lambda_{NorthGRIP}$ and a surprising peak at 1570 m.

5.1.1 Glacial periods

From the beginning it was expected, that visual stratigraphy would work best in the cold periods, where the lines are much more visible, than in the warmer periods. Figure 4.2 shows a close up of ∼1590-1700 m.

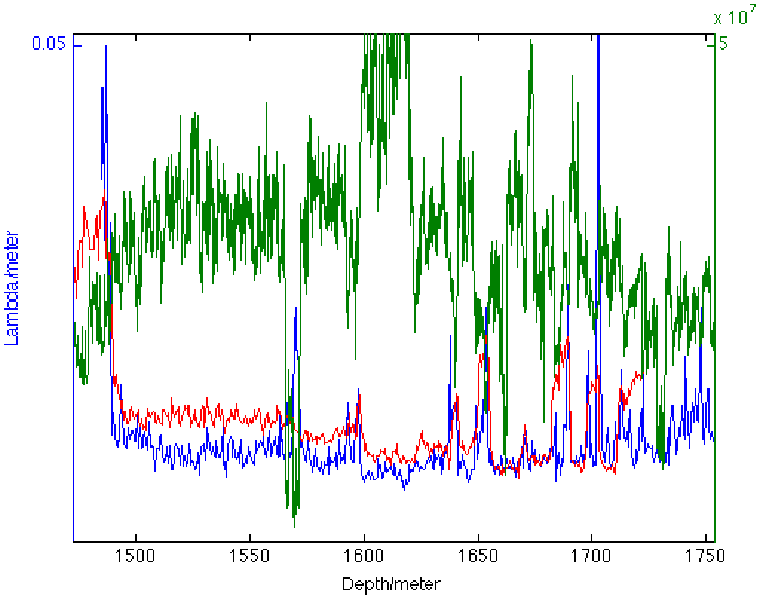


Figure 5.2: The blue line is λ_{NEEM}, red $\lambda_{NEEM/GICC05}$, both plotted on the left y-axis. The green line is grey scale on the right y-axis, which is measured i horizontal pixel sum.

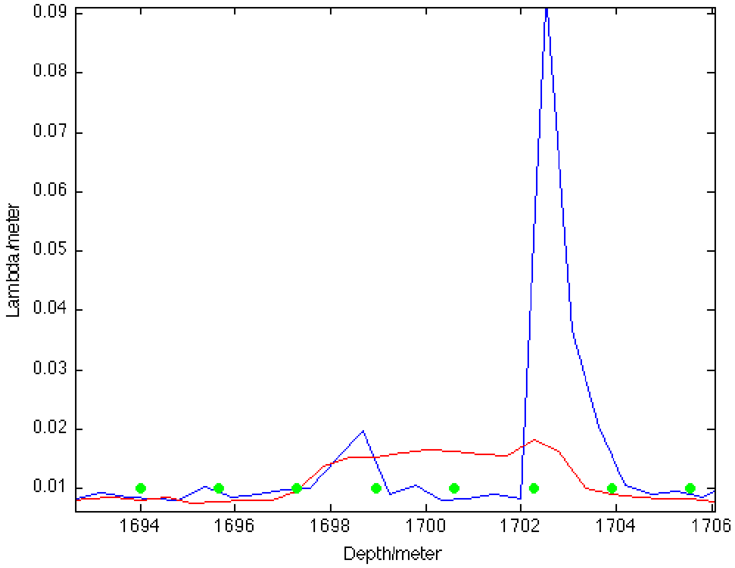


Figure 5.3: Average λ-values in a warm period (blue line), NEEM/GICC05 (red line) 1704 is the onset for GI-4. The interglacial period is from ~1697-1704 m. The green dots mark the threebag cuts.

A major problem is, that the ratio of detected lines and expected lines are *not* constant. Figure 5.2 compares the grey scale and the expected λ values from NEEM/GICC05. From this the ratio between the grey scale and expected number of lines does not seems to be constant, with a maximum around 1600-1625 m, and a large variation around 1675 m in the grey scale, but not in the expected λ.

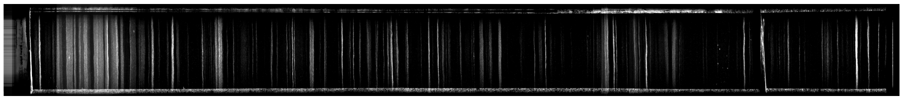
If λ_{NEEM} is compared to the grey scale, the expected effect of inverse proportionality between is seen.

5.1.2 Interstadial periods

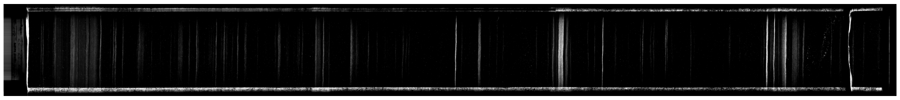
It was not from the beginning expected, that visual stratigraphy would be particular successful in the warm periods.

Figure 5.3 shows how the methods treats the warm periods, and the results of this from GI-4, and compared with the NEEM/GICC05. What we see is, that the onset and offset are visible and close to expected. But the period in between then onset and offset are completely different! The main reason for this is the `imadjust`-function as described in section 3.3.2. The threebags in the interstadial periods are significant darker than the glacial periods, which gives a output from the `imadjust`-function, that are not comparable to the

(a) Threebag 2844, 1563.65-1565.30 m.



(b) Threebag 2847, 1565.30-1566.95 m.



(c) Threebag 2853, 1568.60-1570.25 m.

(d) Threebag 2859, 1571.90-1573.55 m.

Figure 5.4: Threebags around 1570 m depth. The pictures are adjusted to highlight the change in grey scale.

glacial periods. The peaks at onsets and offset is due to these threebags are at transitions.

5.1.3 1490-1591 m

The part from ~1492-1591 m parts of the core and the corresponding time is considered as a cold period. At figure 5.1 the λ values a much closer to the other cold periods, all though a bit larger. This effect is seen in both NEEM and NorthGRIP, [Rasmussen et al., 2008].

Furthermore figure 5.2 shows and tendency in $\lambda_{NEEM/GICC05}$ to having a small and flat "hill", where λ_{NEEM} has a much large "valley" in the same area, a valley which are derived from the similar hill in the grey scale over the same part, excluding the part around 1570, which are discussed in section 5.1.4.

5.1.4 1570 m

At 1570 meter there is a peak, which has not been seen before in other cores. The peak indicate, that there should be less visible lines than expected from other cores. Figure 5.4 shows the core around this peak, where figure 5.4(a) is a little above the peak, 5.4(b) covers the foot of the peak, 5.4(c) is completely inside and 5.4(d) is just below the peak.

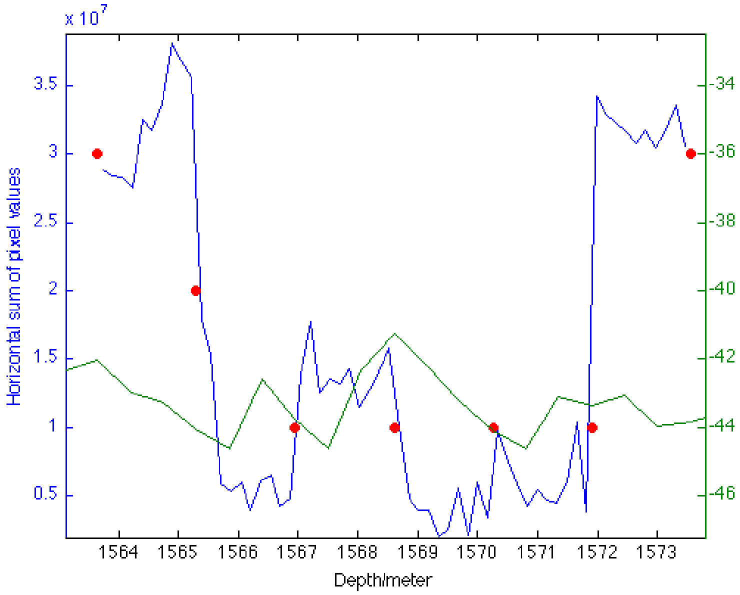


Figure 5.5: The grey scale around 1570 m. The blue line is the grey scale, the green line δ^{18}O and the red dots mark the threebag cuts.

Figures 5.4(a) and 5.4(d) has clearly visible lines, and the amount and grey scale are close to the average for that part of the core, nothing unusual here.

Figure 5.4(b) shows a kind of transition, where the top look similar to 5.4(a) and 5.4(d), but the main part is clearly darker and with significant fewer lines. Figure 5.4(c) is, as noted, inside the peak, and look much like 5.4(b), except for the top.

Figure 5.5 shows the greyscale around the peak, which also indicate a darker section of the core. Many of the bag cuts are close to significant changes in the grey scale, but the bag cut at 1565.30 m, threebags 2844/2847, has a small lighter part, as mentioned above.

Based on this observations, it is not strange, that this peak occurs. I do not have an explanation for this observation. But the coincidence between significant change in the grey scale and bag cuts suggest that something has been changed under the scanning. There is no information about a change in the scanning, and the transition in 5.4(b) tells, that something need to be explained. It *could* a be change in the brightness in the science trench at NEEM.

A look on the δ^{18}O in the same part does not suggest anything suspect, and does not have a similar tendency. Therefor the "tendency" in the visual stratigraphy is not confirmed by δ^{18}O.

At this time, only the δ^{18}O is available, and the cause for this peak could be confirmed or rejected with ECM data.

It should be noted, that there was problems with synchronization between NorthGRIP, GRIP and GISP2 in this period due to missing fix points, [Rasmussen et al., 2008].

5.2 Problems with validating lines

Besides from the observation in the cores, there is also a task with validating the lines. In the results I found a problem with a decreasing tendency to detect more lines than expected. This lead to two problems: Detecting enough lines and validating them.

In the ideal situation, all possible lines are detected, but if the methods is tuned to find more lines, it also generates more noise, with results in way too many lines, three or four times more than expected, until a point, where lines "merge" with each other, with a collapsing result with few lines. The algorithm try to treat crossing/merged lines as one line.

All in all, the task is to tune the filter in such a way, that real lines can be distinguished from noise and still have detected at least too many lines. This turned out not to be easy, a problem partly arising from a number of filter parameters, which was time consuming to tune, and the time invested in tuned did not gave the returns.

The next challenge is validating, with the knowledge from other cores, but based only on the NEEM data. As shown in the result, there is often a secondary top on the histograms to the left of the main top, meaning that there are too many "thin" layers. This could very well be a result from detected and unwanted lines, and by eliminating these, the secondary top will be shifted to the right, raising the average λ to the expected value.

From [Rasmussen et al., 2006] it is known, that NorthGRIP had an variation on logarithmic scale in λ of 2σ, and the first run on NEEM results in annual thickness less or greater than probable values. It is justifiable to eliminate these lines in the shifting procedure, as long as a probable λ distribution is maintained.

The histograms shows clearly some of these problems. First of all, the variation of 2σ from NorhGRIP could not be transfered to NEEM, since it seems to be closer to 3σ.

Depth/m	NEEM/GICC05	NEEM	$\sigma = 5$	$\sigma = 4$	$\sigma = 3$	$\sigma = 2$
1490-1591	8050	10441	10420	10409	10373	10293
1591-1598	600	679	679	675	673	674
1598-1637	4030	5039	5034	5032	5022	5034
1637-1641	410	293	293	293	292	286
1641-1649	730	1023	1021	1019	1016	1007
1649-1655	390	504	504	502	499	497
1655-1682	3140	3163	3156	3152	3137	3094
1682-1690	460	779	779	773	769	798
1690-1697	840	803	800	798	791	782
1697-1703	400	536	536	536	535	535
1703-1711	920	797	797	791	789	788

Table 6.1: Number of lines in GICC05 and NEEM in each of the six evaluated glacial and five evaluated stadial periods, both raw data analysis and adjusted with statistical variation

6 Conclusion

The expectations of this project were not fulfilled. There were a number of problems, but it was possible to find a connection between the line scan data and climatical variation, and that lines can be identified. The main problem was verifying, if the identified (not to be confused with the visible) lines was or was not connected with one year.

6.1 What did I found?

It is possible to find a yearly variation in the annual thickness, and to detect an expected tendency, to identify the glacial and stadial periods and a variation not far from that found in the NorthGRIP ice core. Furthermore it was possible to count lines, and the result of this is shown in table 6.1. The result was also much closer to the expected in the glacial periods compared with the stadial periods, which was caused by an expected variation in the line scan data and their grey scale.

I did not find an acceptable number of lines, and thereby could not come up with a relative time scale for the investigated part of the NEEM ice core. Maybe the result will be useful in combination with ECM or other datas, and thereby, like in GICC05, be a part of a composite time scale. By this I mean, that other data could be used as a validating function for the lines.

6.2 How well did it go?

It would have been nice, if the number of found lines in table 6.1 were within the uncertainty in table 1.1. This is not the case, and as described below, the main problem was to verify if an identified line could be counted as one annual line. Table 6.1 shows the results after Step 1, since the to other did not had a purely optimizing results.

6.3 Problems

A problem with this method was the verifying of the identified lines. In this step I tried only looking at the lines and their statistics, variation and probability to verify or delete a given line.

One fundamental idea was to find too many lines, and from this find the real lines. All ready here there was a problem: The number of found lines per expected lines was decreasing with the depth, and below 1660-1680 m the number of found lines was *lower* than the expected number.

This caused the verifying process to be more complicated than expected. If we look a the histograms, those with too many lines should be shifted to the right, e.i. removing lines where by the average λ would increase, and for those parts with too few lines the shift should be to the left.

The problem in this was to find the magnitude of these different shifts only based on the data from the NEEM ice core. Originally the idea was, that the secondary top to the left of the real top could be used as a guide, e.g. when this top was "shifted" relative to be at same position the primary top by statistical manipulation, the needed shift in the histogram was found.

This turned out not be the case. One problem was, that it was not enough to vanish this top out, but also the before mentioned problem with too few lines. This method would, since the secondary top always was to the left of the primary top, always remove lines, even if the opposite was needed in the lower intervals.

Secondly it had a surprising tendency to produce a unwanted and significant amount λ values with a specific value, whereby it "destroyed" the nicely distributed histograms.

6.4 Future improvements

If the works by this method should continue, a number of improvements would be necessary. As mentioned before, one problem was that there were not here any way to conclude only on the datas from NEEM, when a line correspond to an year or not.

As an alternative to the statistical approach, the lines could eventually have been verified with the Rayliegh method, a frequency analysis.

Other improvements could be combination with other data, i.e. ECM or δ^{18}O. Neither the GICC05 was done only based on visual stratigrahy in the glacial periods.

6.5 Final words

All in all, it was found possible to detect and count lines in the NEEM ice core in glacial periods as predicted, but the result need to be compared with other sources or be tuned even better. Alternatively a completely other approach could be used.

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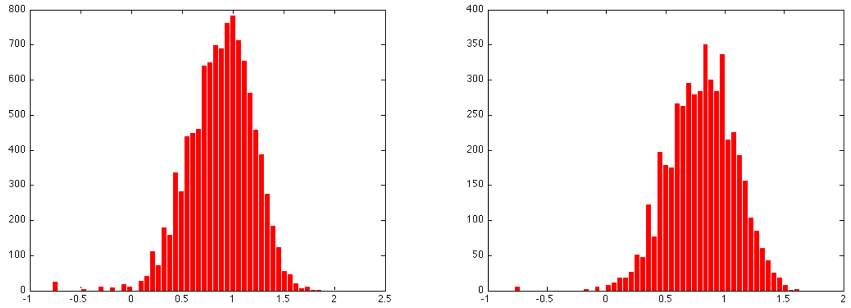
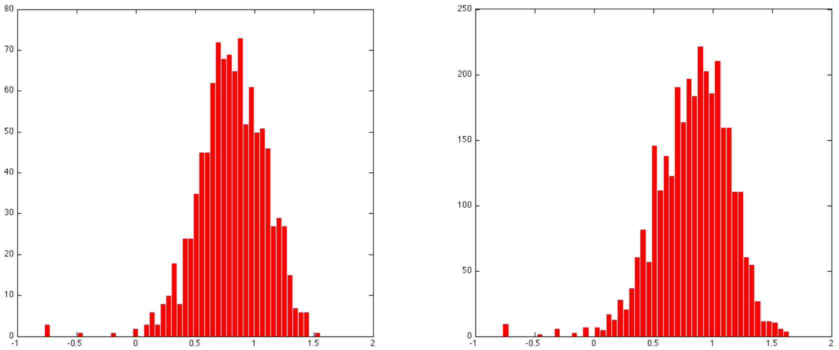
A Histograms

A.1 Unmanipulated histograms for glacial periods



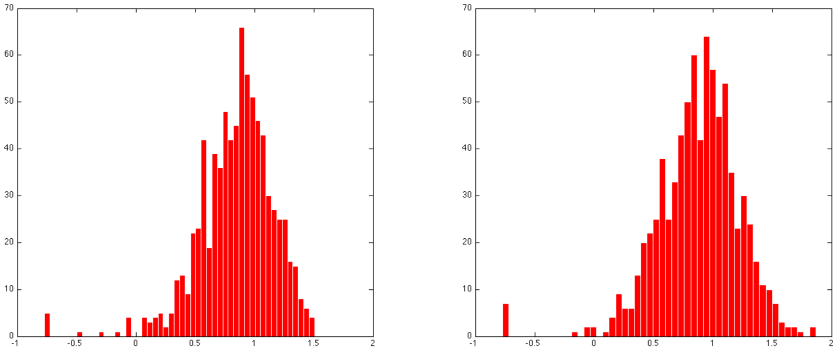
(a) Depth: 1490-1591 m

(b) Depth: 1598-1637 m



(c) Depth: 1641-1649 m

(d) Depth: 1655-1682 m

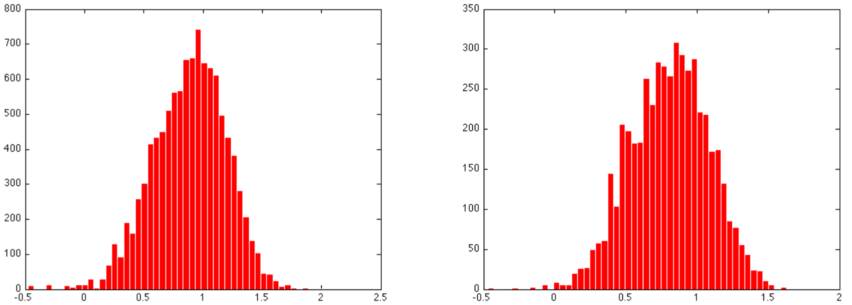


(e) Depth: 1690-1796 m

(f) Depth: 1700-1711 m

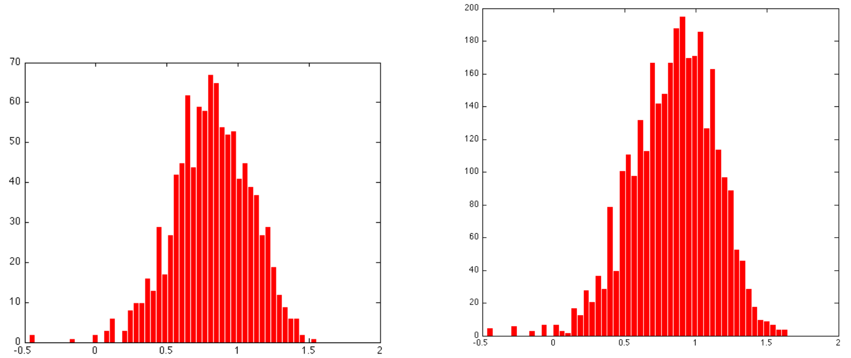
Figure A.1: Unmanipulated histograms for glacial periods, note x-axis is $\log_{10} \lambda$

A.2 Manipulated histograms for glacial periods, 5σ



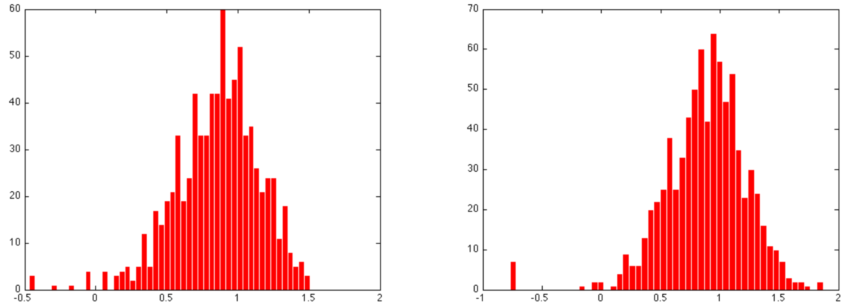
(a) Depth: 1490-1591 m

(b) Depth: 1598-1637 m



(c) Depth: 1641-1649 m

(d) Depth: 1655-1682 m

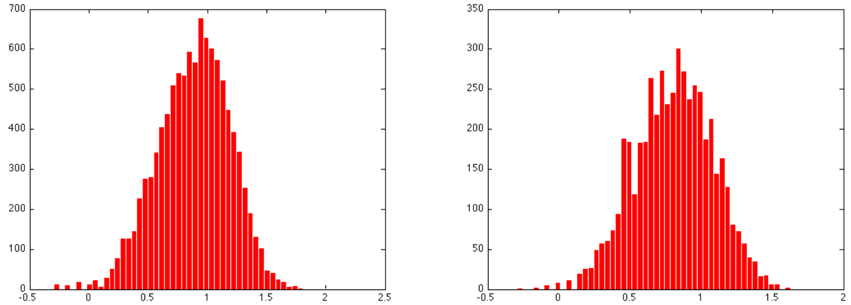


(e) Depth: 1690-1796 m

(f) Depth: 1700-1711 m

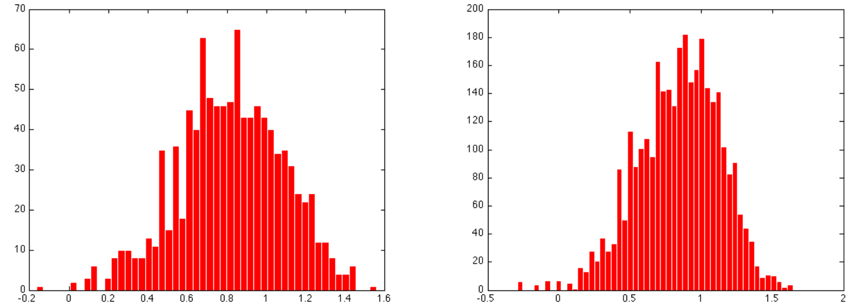
Figure A.2: Manipulated histograms for glacial periods, cut at 3σ. Note x-axis is $\log_{10}\lambda$

A.3 Manipulated histograms for glacial periods, 4σ



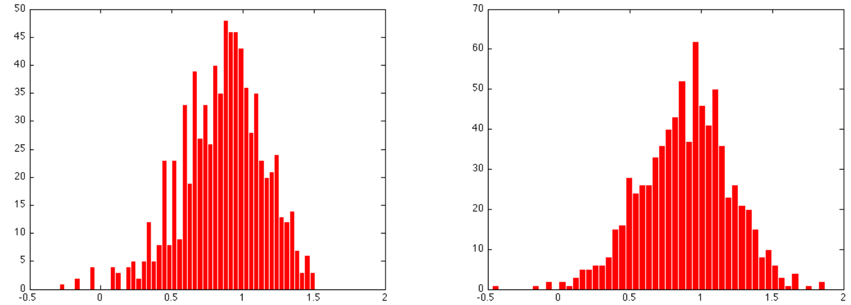
(a) Depth: 1490-1591 m

(b) Depth: 1598-1637 m



(c) Depth: 1641-1649 m

(d) Depth: 1655-1682 m

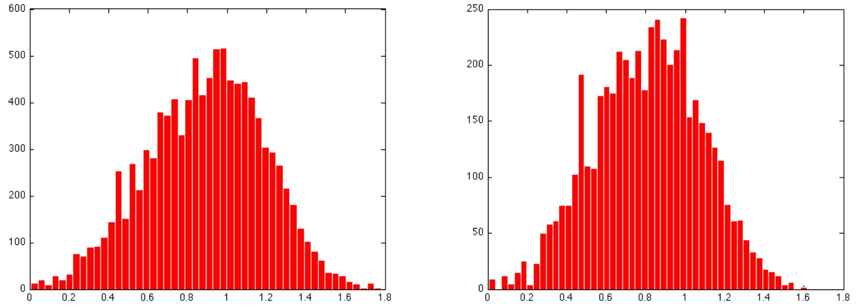


(e) Depth: 1690-1796 m

(f) Depth: 1700-1711 m

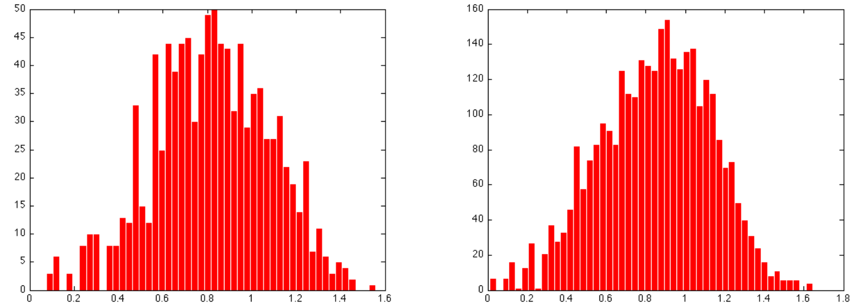
Figure A.3: Manipulated histograms for glacial periods, cut at 3σ. Note x-axis is $\log_{10} \lambda$

A.4 Manipulated histograms for glacial periods, 3σ



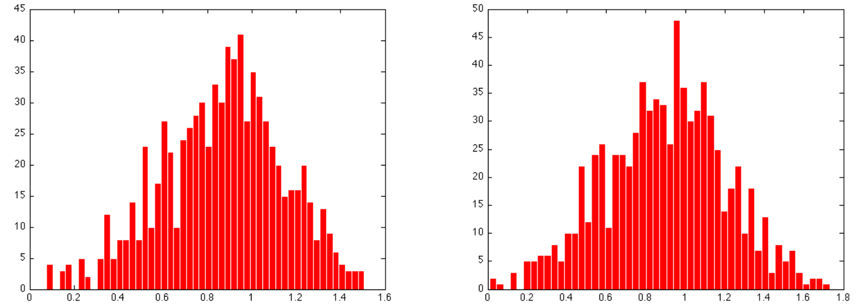
(a) Depth: 1490-1591 m

(b) Depth: 1598-1637 m



(c) Depth: 1641-1649 m

(d) Depth: 1655-1682 m

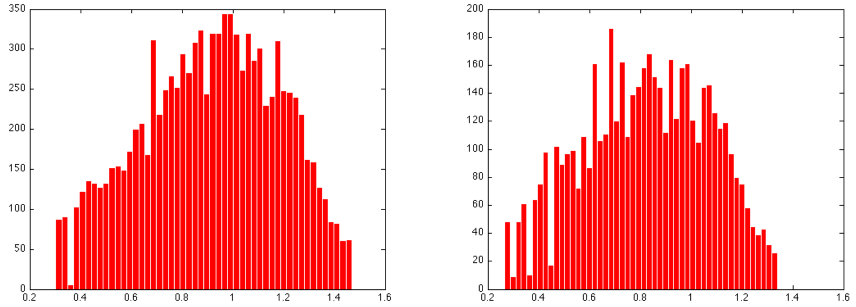


(e) Depth: 1690-1796 m

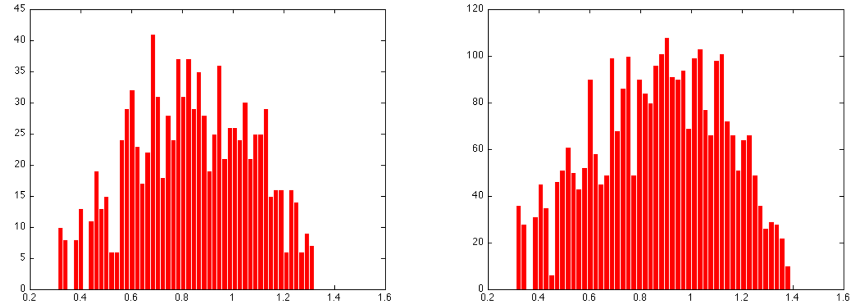
(f) Depth: 1700-1711 m

Figure A.4: Manipulated histograms for glacial periods, cut at 3σ. Note x-axis is $\log_{10} \lambda$

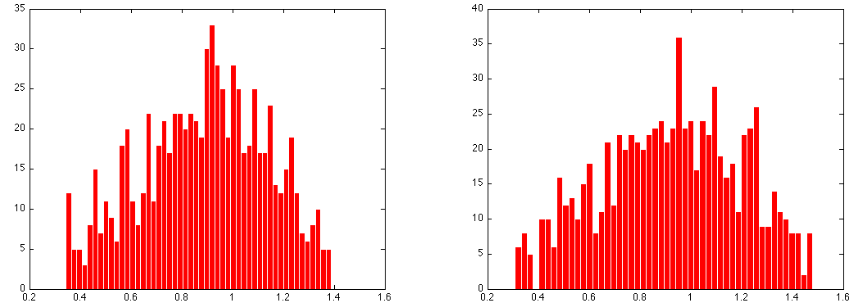
A.5 Manipulated histograms for glacial periods, 2σ



(a) Depth: 1490-1591 m (b) Depth: 1598-1637 m



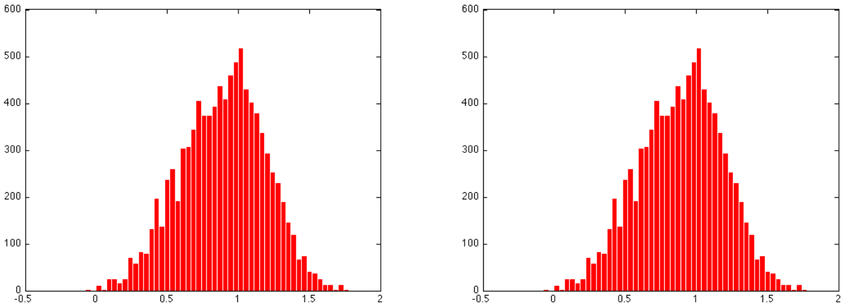
(c) Depth: 1641-1649 m (d) Depth: 1655-1682 m



(e) Depth: 1690-1796 m (f) Depth: 1700-1711 m

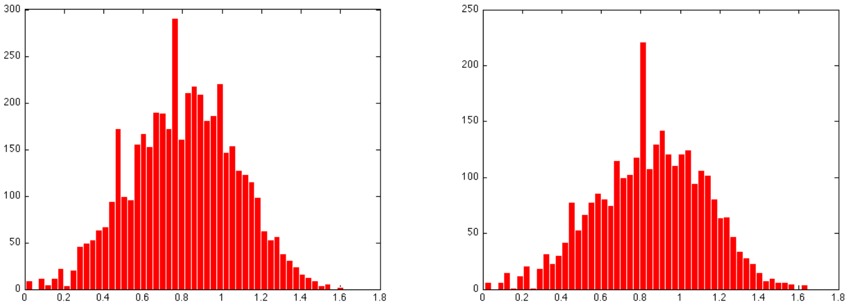
Figure A.5: Manipulated histograms for glacial periods, cut at 3σ. Note x-axis is $\log_{10}\lambda$

A.6 Manipulated histograms for glacial periods after Step 2: Manipulation according to local variation



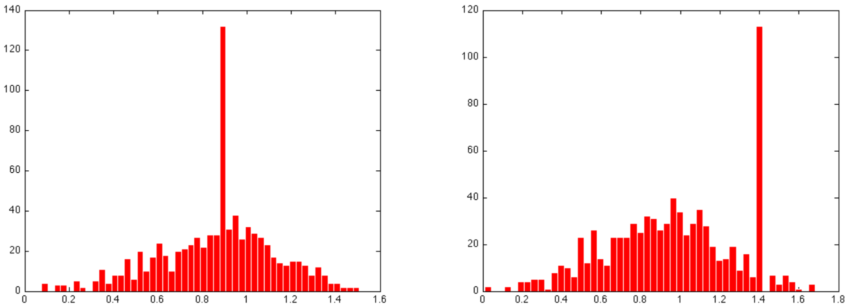
(a) Depth: 1490-1591 m

(b) Depth: 1598-1637 m



(c) Depth: 1641-1649 m

(d) Depth: 1655-1682 m

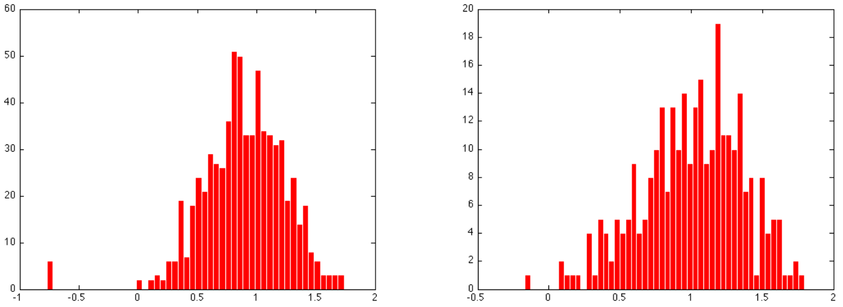


(e) Depth: 1690-1796 m

(f) Depth: 1700-1711 m

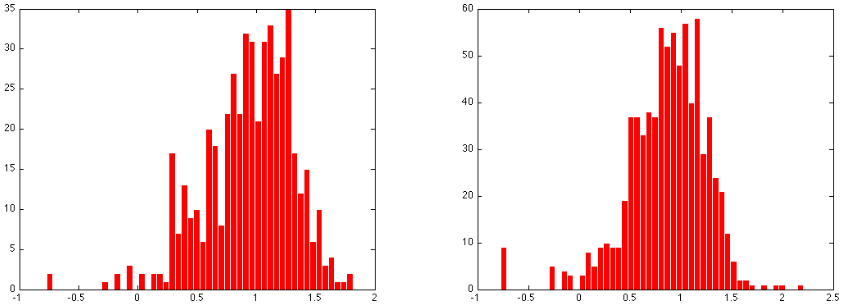
Figure A.6: Manipulated histograms for glacial periods, after Step 2, manipulation according to local variation with 3σ Note x-axis is $\log_{10} \lambda$

A.7 Unmanipulated histograms for stadial periods



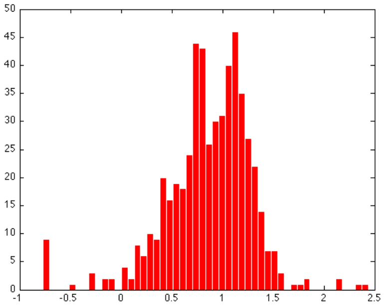
(a) Depth: 1591-1598 m

(b) Depth: 1637-1641 m



(c) Depth: 1649-1655 m

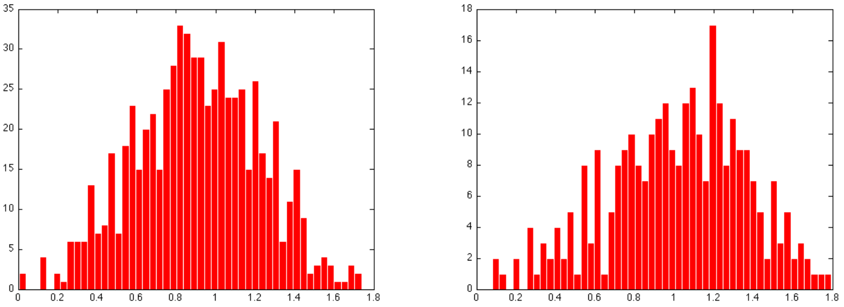
(d) Depth: 1682-1690 m



(e) Depth: 1697-1591 m

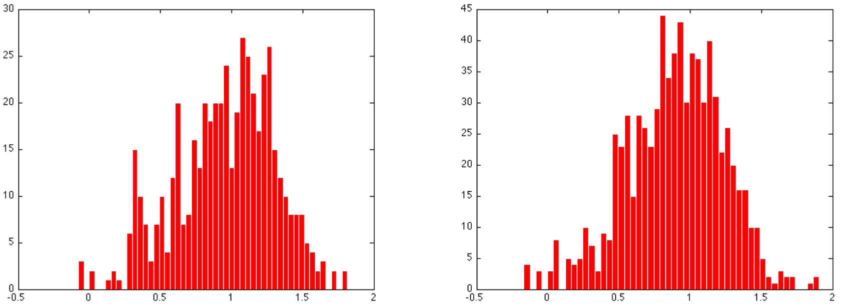
Figure A.7: Unmanipulated histograms for stadial periods, note x-axis is $\log_{10} \lambda$

A.8 Manipulated histograms for stadial periods, 3σ



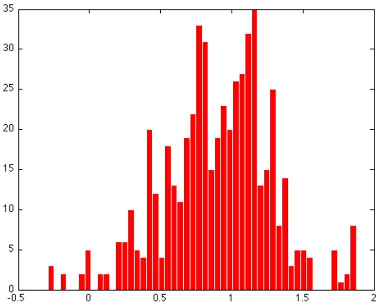
(a) Depth: 1591-1598 m

(b) Depth: 1637-1641 m



(c) Depth: 1649-1655 m

(d) Depth: 1682-1690 m



(e) Depth: 1697-1591 m

Figure A.8: Manipulated histograms for stadial periods, cut at 3σ. Note x-axis is $\log_{10} \lambda$

B Scripts

B.1 Gradient.m

```
clear I
%% Read image
I = imread(fn);
I = fliplr(flipud(I));
%I = imadjust(I);

%% Crop image
imagewidth = length(I(1,:));
% Determine new image width
newimagewidth = 501;
% Image is cropped equally much from left and right:
I(:,imagewidth-floor((imagewidth-newimagewidth)/2)+1:imagewidth)= [];
I(:,1:ceil((imagewidth-newimagewidth)/2)) = [];
% Considering just a small part:
%I(1:200,:)=[];
%I(9000:end,:)=[];

% Show image:
% figure(1)
% imshow(I)
% title('Original image')

%% Filtering image
% Using median filtering to reduce salt and pepper noise
% When using this approach, the median values for the points within [m n]/2
% of the edges will appear distorted.

no_filtering = 3;
for i = 1:no_filtering
   I = medfilt2(I, [7 15]);
end

%figure(2);
%imshow(I)
%title('Filtered image')

%% Deblurring?

%% Color scaling: Changing the intensity of image
I = imadjust(I);
%I = histeq(I,256);
%figure(3)
```

```
%imshow(I)
%title('Adjusted image')

%% Finding gradients:
N = 7;
horzedge = NaN(N,N);
horzedge(1:(N-1)/2,:)=-1;
horzedge((N+1)/2,:)=0;
horzedge((N+1)/2+1:N,:)=1;

strength = 5;
I = imfilter(I,strength/10*horzedge, 'conv');
figure(4)
imshow(I)

%% Closing image:
morpho_row = ones(1,20);
no_filtering = 1;
for i = 1:no_filtering
   I = imclose(I,morpho_row);
end
figure(5)
imshow(I)

%% Converting to binary image:
% Using a threshold of:
threshold = 12.5; % percent - 37.5
I = im2bw(I,threshold/100);
%figure(6)
%imshow(I)

I = bwareaopen(I, 100);
%figure(7)
%imshow(I)

%% Opening image:
se = strel('line',20,0);
I = imopen(I,se);
%figure(8)
%imshow(I)

%% Thinning image:
I = bwmorph(I,'thin',Inf);
%figure(9)
%imshow(I)
```

```
%% Pruning (= "spur" in Matlab):
% Removing edges: could be done differently
I(:,1:100)=[];
I(:,end-100:end)=[];

% Pruning:
I = bwmorph(I,'spur',Inf);
%figure(10)
%imshow(I)

% And finally cleaning:
I = bwmorph(I,'clean');
%figure(11)
%imshow(I)

%% Plotting onto the original image:
% figure(1)
% hold on
% for i = 1:length(I(:,1))
%   index = find(I(i,:)==1);
%   if ~isempty(index)
%       plot(index+100,i*ones(length(index)),'.r')
%   end
% end

% Saving image:
% print(gcf,'-dtiff','-r400','output')

% clear M
% M(:,:,1) = J(:,:);
% M(:,:,2) = J(:,:);
% M(:,:,3) = J(:,:);
% M(:,363:662,1) = J(:,363:662) + uint8(255*I);
% imwrite(M,'2892_00B.png','png');
```

B.2 Intensity.m

```
for n = bagstart:3:bagslut;
if n <= 1092 || n >= 2334;
disp(n);
d = d+1;
Specificfiles
I = imread(fn);
Inten = sum(I);
Bagintensity(d,1) = 0.55*(n+0.5);
Bagintensity(d,2) = sum(Inten);
Bagpart = floor(size(I,1)/10);
for e = 1:10;
    f = f+1;
    Inten2 = sum(I((e-1)*Bagpart+1:e*Bagpart,:));
    Bagintensity2(f,1) = 0.55*(n-1)+0.165*(e-0.5);
    Bagintensity2(f,2) = sum(Inten2);
end
end
end
```

B.3 Lines.m

```
index = 0;
clear F;
clear FF;
clear G;
clear H;
for f = 1:size(I,1);
    if I(f,1) == 1;
        index = index+1;
        F(index) = f;
    end
end
for g = 1:size(F,2)-2;
    G(g) = F(g+1)-F(1)+1;
end
FF = (F(size(F,2))-F(1))/1650;
H = G/FF+550*(n-1);
for l = 1:size(H,2);
    LINES2010(lines+l) = H(l);
end
lines = size(LINES2010,2);
```

B.4 Lineaverage.m

There is a similar version for the interstadial periods, where the intervals are changed.

```
averagelength = 1; % Number of bags (1 = 0.55 m, 2 = 1.10 m etc.)
for line = 1:size(LINES,2)-1;
    LAMBDA(line,1) = LINES(line)/1000;
    LAMBDA(line,2) = (LINES(line+1)-LINES(line));
end
b = floor(LAMBDA(1,1)/0.55)+1;
d = 1;
acount = 0;
for a = 1:line-1;
    c = floor(LAMBDA(a,1)/0.55)+1;
    if b+averagelength-1 < c;
        acount = acount+1;
        e = d;
        d = a;
        LAMBDAAVERAGE(acount,1) = (b+0.5*averagelength-1)*0.55;
        LAMBDAAVERAGE(acount,2) = 0.55*averagelength/(d-e);
        b = c;
    end
end
clear a b c d e acount line
```

B.5 Modifiedlambda.m

There is a similar version for the interstadial periods, where the intervals are changed.

```
%% Interval for line removing
clc
clear DATA1 DATA2 DATAmu DATAsigma DATAr DATAs DATAt
DATA1 = [0;4030;730;3140;840;920];
bin = 50;
for run = 2:5;
for interval = 1:6;
    clear LOGLAMBDA INTLAMBDA LAMBDAINTERVAL NEWLAMBDAINTERVAL
    clear LOGLAMBDAINTERVAL NEWLOGLAMBDAINTERVAL MU SIGMA
    if interval == 1
        lowerbound = 1490;  % Lower boundery for histogram interval (meter)
        upperbound = 1591;  % Upper boundery for histogram interval (meter)
    elseif interval == 2;
        lowerbound = 1598;  % Lower boundery for histogram interval (meter)
        upperbound = 1637;  % Upper boundery for histogram interval (meter)
    elseif interval == 3;
        lowerbound = 1641;  % Lower boundery for histogram interval (meter)
        upperbound = 1649;  % Upper boundery for histogram interval (meter)
    elseif interval == 4;
        lowerbound = 1655;  % Lower boundery for histogram interval (meter)
        upperbound = 1682;  % Upper boundery for histogram interval (meter)
    elseif interval == 5;
        lowerbound = 1690;  % Lower boundery for histogram interval (meter)
        upperbound = 1697;  % Upper boundery for histogram interval (meter)
    elseif interval == 6;
        lowerbound = 1703;  % Lower boundery for histogram interval (meter)
        upperbound = 1711;  % Upper boundery for histogram interval (meter)
    end
if lowerbound < LAMBDA(1,1);
    lowerbound = LAMBDA(1,1);
end
if upperbound > LAMBDA(size(LAMBDA,1),1);
    upperbound = LAMBDA(size(LAMBDA,1),1);
end
lowerbound = find(LINES>1000*lowerbound,1);
clear find
upperbound = find(LINES>1000*upperbound-1,1);
clear find
for a = 1:upperbound-lowerbound+1;
    LAMBDAINTERVAL(a) = LAMBDA(a+lowerbound-1,2);
    LOGLAMBDAINTERVAL(a,1) = log10(LAMBDAINTERVAL(a));
end
```

```
DATA1(interval,2) = size(LOGLAMBDAINTERVAL,1);
for a = lowerbound:upperbound
    LOGLAMBDA(a-lowerbound+1) = log10(LAMBDA(a,2));
    INTLAMBDA(a-lowerbound+1) = (LAMBDA(a,2));
end

%% Lambda statistics
[mu,sigma] = normfit(LOGLAMBDAINTERVAL);
mua = 10^(mu+0.5*sigma^2);
sigmaa = 10^(mu+0.5*sigma^2)*sqrt(10^(sigma^2)-1);
acount = 0;
if run == 2
    figure(interval)
    hist(LOGLAMBDAINTERVAL,bin);
end
h2 = findobj(gca,'Type','patch');
set(h2,'FaceColor','r','EdgeColor','w')
for d = 2:run;
    e = 7-d;

%% Removing lines 1
for a = 1:10000;
    b = find(LAMBDAINTERVAL(:)==min(LAMBDAINTERVAL(:)));
    if log10(LAMBDAINTERVAL(b(1))) > mu-e*sigma
        [mu,sigma] = normfit(LOGLAMBDAINTERVAL);
        mua = 10^(mu+0.5*sigma^2);
        sigmaa = 10^(mu+0.5*sigma^2)*sqrt(10^(sigma^2)-1);
        break
    else
        if b(1) == 1;
            NEWLAMBDAINTERVAL(2:size(LAMBDAINTERVAL,2)-1) =
            LAMBDAINTERVAL(3:size(LAMBDAINTERVAL,2));
            NEWLAMBDAINTERVAL(1) = LAMBDAINTERVAL(1)+LAMBDAINTERVAL(2);
        elseif b(1) == size(LAMBDAINTERVAL,2);
            NEWLAMBDAINTERVAL(1:b(1)-2) = LAMBDAINTERVAL(1:b(1)-2);
            NEWLAMBDAINTERVAL(b(1)-1) = LAMBDAINTERVAL(b(1)-1)+LAMBDAINTERVAL(b(1));
        else
            NEWLAMBDAINTERVAL(1:b(1)-1) = LAMBDAINTERVAL(1:b(1)-1);
            NEWLAMBDAINTERVAL(b(1):size(LAMBDAINTERVAL,2)-1) =
            LAMBDAINTERVAL(b(1)+1:size(LAMBDAINTERVAL,2));
            NEWLAMBDAINTERVAL(b(1)) = LAMBDAINTERVAL(b(1))+LAMBDAINTERVAL(b(1)+1);
        end
        for b = 1:size(NEWLAMBDAINTERVAL,2);
            LOGLAMBDAINTERVAL(b) = log10(NEWLAMBDAINTERVAL(b));
        end
        clear LAMBDAINTERVAL
```

```
        clear LOGLAMBDAINTERVAL
        LAMBDAINTERVAL = NEWLAMBDAINTERVAL;
        for a = 1:size(LAMBDAINTERVAL,2);
            LOGLAMBDAINTERVAL(a) = log10(LAMBDAINTERVAL(a));
        end
        clear NEWLAMBDAINTERVAL
        clear b
    end
end

%% Adding lines 1
for a = 1:10000;
    b = find(LAMBDAINTERVAL(:)==max(LAMBDAINTERVAL(:)));
    if log10(LAMBDAINTERVAL(b(1))) < mu+e*sigma
        [mu,sigma] = normfit(LOGLAMBDAINTERVAL);
        mua = 10^(mu+0.5*sigma^2);
        sigmaa = 10^(mu+0.5*sigma^2)*sqrt(10^(sigma^2)-1);
        break
    else
        if LOGLAMBDAINTERVAL(b(1))/mu > 3
            if b(1) == 1;
                NEWLAMBDAINTERVAL(3:size(LAMBDAINTERVAL,2)+2) =
                LAMBDAINTERVAL(1:size(LAMBDAINTERVAL,2));
                NEWLAMBDAINTERVAL(1) = LAMBDAINTERVAL(1)/3;
                NEWLAMBDAINTERVAL(2) = LAMBDAINTERVAL(1)/3;
            else
                NEWLAMBDAINTERVAL(1:b(1)-1) = LAMBDAINTERVAL(1:b(1)-1);
                NEWLAMBDAINTERVAL(b(1)+2:size(LAMBDAINTERVAL,2)+2) =
                LAMBDAINTERVAL(b(1):size(LAMBDAINTERVAL,2));
                NEWLAMBDAINTERVAL(b(1)) = LAMBDAINTERVAL(b(1))/3;
                NEWLAMBDAINTERVAL(b(1)+1) = LAMBDAINTERVAL(b(1))/3;
                NEWLAMBDAINTERVAL(b(1)+2) = LAMBDAINTERVAL(b(1))/3;
            end
        else
            if b(1) == 1;
                NEWLAMBDAINTERVAL(b(1)+1:size(LAMBDAINTERVAL,2)+1) =
                LAMBDAINTERVAL(b(1):size(LAMBDAINTERVAL,2));
                NEWLAMBDAINTERVAL(1) = LAMBDAINTERVAL(1)/2;
                NEWLAMBDAINTERVAL(2) = LAMBDAINTERVAL(1)/2;
            else
                NEWLAMBDAINTERVAL(1:b(1)-1) = LAMBDAINTERVAL(1:b(1)-1);
                NEWLAMBDAINTERVAL(b(1)+1:size(LAMBDAINTERVAL,2)+1) =
                LAMBDAINTERVAL(b(1):size(LAMBDAINTERVAL,2));
                NEWLAMBDAINTERVAL(b(1)) = LAMBDAINTERVAL(b(1))/2;
                NEWLAMBDAINTERVAL(b(1)+1) = LAMBDAINTERVAL(b(1))/2;
            end
```

```
        end
        clear LAMBDAINTERVAL
        clear LOGLAMBDAINTERVAL
        LAMBDAINTERVAL = NEWLAMBDAINTERVAL;
        for a = 1:size(LAMBDAINTERVAL,2);
            LOGLAMBDAINTERVAL(a) = log10(LAMBDAINTERVAL(a));
        end
        clear NEWLAMBDAINTERVAL
        clear b
    end
end
end

%% Removing lines 2
for a = 3:size(LAMBDAINTERVAL,2)-2;
    if a < size(LAMBDAINTERVAL,2)-2;
        b = LAMBDAINTERVAL(a+1)-LAMBDAINTERVAL(a-1);
        c = LAMBDAINTERVAL(a+2)-LAMBDAINTERVAL(a-2);
        if c/b > 3;
            NEWLAMBDAINTERVAL(1:a-1) = LAMBDAINTERVAL(1:a-1);
            NEWLAMBDAINTERVAL(a:size(LAMBDAINTERVAL,2)-1) =
            LAMBDAINTERVAL(a+1:size(LAMBDAINTERVAL,2));
            clear LAMBDAINTERVAL
            LAMBDAINTERVAL = NEWLAMBDAINTERVAL;
            clear NEWLAMBDAINTERVAL
        end
    end
end

%% Adding lines 2
for a = 3:100;
    if a < size(LAMBDAINTERVAL,2)-2;
        b = LAMBDAINTERVAL(a+1)-LAMBDAINTERVAL(a-1);
        c = LAMBDAINTERVAL(a+2)-LAMBDAINTERVAL(a-2);
        if c/b < 1.5;
            NEWLAMBDAINTERVAL(1:a-1) = LAMBDAINTERVAL(1:a-1);
            NEWLAMBDAINTERVAL(a+1:size(LAMBDAINTERVAL,2)+1) =
            LAMBDAINTERVAL(a:size(LAMBDAINTERVAL,2));
            NEWLAMBDAINTERVAL(a) = LAMBDAINTERVAL(a+1)/2;
            NEWLAMBDAINTERVAL(a+1) = LAMBDAINTERVAL(a+1)/2;
            clear LAMBDAINTERVAL
            LAMBDAINTERVAL = NEWLAMBDAINTERVAL;
            clear NEWLAMBDAINTERVAL
        end
    end
end
```

```
%% Ending removing/adding
clear LOGLAMBDAINTERVAL
for a = 1:size(LAMBDAINTERVAL,2)
    LOGLAMBDAINTERVAL(a) = log10(LAMBDAINTERVAL(a));
end
if interval == 1|2|3|4|5|6
    figure(6*(run-1)+interval)
    hist(LOGLAMBDAINTERVAL,bin);
end
h2 = findobj(gca,'Type','patch');
set(h2,'FaceColor','r','EdgeColor','w')
[mu,sigma] = normfit(LOGLAMBDAINTERVAL);
MU(interval,run+1) = 10^(mu);
SIGMA(interval,run+1) = 10^(sigma);
DATA1(interval,run+1) = size(LOGLAMBDAINTERVAL,2);
DATA2(interval,run+1) = 100*(DATA1(interval,run+1)-DATA1(interval,1))/DATA1(interval,1);
DATAmu(interval,run+1) = mu;
DATAsigma(interval,run+1) = sigma;

%% Changing histogram
 [p,q] = hist(LOGLAMBDAINTERVAL,bin);
 for o = 1:1;
     [r,s] = max(p);
     if s < 3
         s = 3;
     elseif s > bin-2
         s = bin-2;
     end
     p(s) = round((p(s-2)+p(s-1)+p(s+1)+p(s+2))/4);
     [mub,sigmab] = normfit(q);
     if abs(q(s)-mub) > 0.5*sigmab
         if r > 1.1*((p(s-2)+p(s-1)+p(s+1)+p(s+2))/4)
             t = sign(q(s)-mub)*round((r-(p(s-2)+p(s-1)+p(s+1)+p(s+2))/4)/(q(s)/mub));
             DATA1(interval,run+1) = size(LOGLAMBDAINTERVAL,2)+t;
             DATA2(interval,run+1) =
             100*(DATA1(interval,run+1)-DATA1(interval,1))/DATA1(interval,1);
             DATAr(interval,run+1) = r;
             DATAs(interval,run+1) = s;
             DATAt(interval,run+1) = t;
         end
     end
 end
end
end
for a = 1:run+1;
```

```
    DATA1(7,a) = sum(DATA1(1:6,a));
    DATA2(7,a) = 100*(DATA1(6,a)-DATA1(6,1))/DATA1(6,1);
end
```