Storglaciären's ablation period 2017

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Abstract

The purpose of this study was to examine the mass balance of Storglaciären during its ablation period, in the summer of 2017. The hypothesis is that due to changes in the Gulf stream, mainly the cooling of the Gulf stream, would lead to a mass increase on Storglaciären. In order put this hypothesis to the test, a group of 5 students and 1 instructor traveled from Stockholm to Tarfala research station to measure both snow density and mass balance. The density was calculated in order to determine the mass balance. Density measurements were conducted in the following manner. A 2 meter deep snow pit was dug on a snow hill next to Storglaciären. A hollow cylinder was knocked into the wall of snow with a hammer with an interval of about 10 cm per each depth measurement, which was measured with a meter stick. When the hollow cylinder was knocked in the wall, the snow surrounding it was scraped off, extracted to a bag and the weight was measured.

In order to determine the mass balance, the Scandinavian mass balance method (measuring stakes height above the surface) was used. For this method a snow density formula was constructed and the difference in snow (in meters) that has accumulated, or melted (ablated) during the summer/winter was measured. Therefore the stakes height above the surface was measured in order to determine the amount of ablation or accumulation at the stakes position. This was done by placing an ice axe on the surface next to a stake and measure the height above the surface in order to establish the seasonal change in snow, for the net mass balance calculations.

Furthermore, hydrology measurements from 2005 were used to calculate the water discharge of the Tarfala jokk. The results of this study indicate on a net mass gain and a total run off of $1{,}057 \cdot 10^9$ m^3 during the ablation period.

However, the net mass balance indicated on a gain in mass on Storglaciären from 2017-03-25 to 2017-07-20. The findings of this study can not provide evidence of external influences on Storglaciären's net mass balance, only implications of it. Due to there being annual fluctuations in mass on Storglaciären, it needs to be taken into account that a one year analysis of Storglaciären does not provide a general and insightful overview of Storglaciären's state. Several sources of error such as measurement tools, execution of the methods applied to the study and hydrology measurements and also sublimation effects on the findings of this study, needs to be taken into account when analysing the results of these findings. Therefore it would be in its order to have more recent hydrology measurements for this study to be effective.

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1. Introduction and background

1.1 Purpose
The purpose of this study is to examine Storglaciären's mass balance during 2017 in order to make a statistical analysis of the net mass balance and ablation of Storglaciären.

1.2 Examination questions
What is the net mass balance?
What is the current state of Storglaciären, regarding mass losses during the ablation season?
Is there any external influence that has affected the results, for example climate change or sources of error?

1.3 Hypothesis
The Gulf stream is generally believed to heat up northern Europe and is one of the main sources of heat in Sweden. There has been a rapid increase in melting ice on Greenland and the Arctic sea(11) and the amount of ice melting is so significant that it's reasonable to assume that global climate change is a contributing factor in the increased melting of the glaciers of Greenland. Due to the melting of ice on Greenland and in the Arctic Sea, the temperatures of the Gulf stream are lowered and in turn slows down the velocity of the Gulf stream (16) which will decrease northern Europe's annual temperatures.
Current trends of global warming would therefore indicate on an overall accumulation on Storglaciären because the temperatures of the Gulf stream has been lowered due to the melting of ice on Greenland and the Arctic sea (See appendix 4 for description for illustrative picture) (16).
The hypothesis is that changes of the Gulf stream's temperatures would lead to a mass gain on Storglaciären due to lowered temperatures, created by the decreasing velocity in the Gulf stream (16).

1.4 Storglaciären
Storglaciären is a glacier located at 67°53'10''N 18°34'00'E (1) which is the glacier studied in this paper. Most of the data about Storglaciären come from the research station in Tarfala which is located nearby the glacier. There is also research published about Storglaciären which has not come directly from Tarfala research station. However, the researchers have usually kept residence there. Storglaciären is important to study because of three reasons:
1. It is a glacier and glaciers tend to be sensitive to climate change, especially heating.
2. There is a lot of research on the glacier, mass balance calculations dates back to 1947(14), and constant updating of data makes the development of Storglaciären traceable.
3. Since the mass balance of Storglaciären is so well documented, it can be used to make assumption about other similar glaciers (15).

1.5 Glaciological year

A glaciological year consists of two periods; the ablation- and the accumulation period.

Ablation period can also be called a glaciological summer. The ablation period is the period when a glacier is losing mass, due to raised temperatures. On Storglaciären temperatures rise during the summer period (late May - mid September) and Storglaciären generally accumulate mass during the glaciological winter (late September - late March/ early April)(8) . This paper will study the development of Storglaciärens mass balance from 2017-03-25 to 2017-07-20 using stake- (see appendix 1 and 2 for photographic description of a stake) and density measurements from Tarfala research station (for detailed description of the method used, see 2.1 Method). This study measures the accumulative period and also some of the ablation period. However, due to the ablation period ending in mid September, this study does not measure the entirety of the ablation period, only the time frame from 2017-03-25 to 2017-07-20.

During the accumulation period, mass is accumulated on the glacier. The accumulative periods stake heights are important for the mass balance equation (see 1.6.1 Mass balance equation and 1.6.4 Function of density).

1.6 Mass balance

1.6.1 Mass balance equation

Mass balance is the total mass loss or gain during a glaciological year(8). This is calculated in this study in order to determine Storglaciärens state of mass. The net mass of Storglaciären is defined as the net mass balance (b_n). The net mass balance can be related to the accumulation (see 1.6.2 Accumulation),defined as (b_w), and the ablation (see 1.6.3 Ablation), defined as (b_s). The formula used to calculate the mass balance was;

$b_n = b_w + b_s$.

If the net mass balance is equal to zero,the glacier sustains a “steady state”. Steady state is when the total amount of mass accumulated is also ablated, mathematically(8), meaning, that the glacier could seem to sustain a steady state but morphologically, it might undergo large ablation in one area whilst compensating with large accumulation in another, leading to changes in its morphology. A steady state does therefore not mean that there are no morphological changes to the glacier. It is therefore possible for the glacier to overall lose mass in one area, and accumulate the same amount in other areas of the glacier. Therefore there is some uncertainty regarding the mass balance measurements, especially when one consideres the measurements tools used. However the formula is a simplification of the complex nature of glaciers mass accumulation/ ablation. If the net balance is negative during a long period of time this would indicate on that the glacier is losing mass and shrinking, and vice versa if the net balance is positive(8).

In order to measure the mass balance of Storglaciären, the Scandinavian mass balance method (3) (see 2.1.1 Field Trip and stake measurements for detailed description of method). The Scandinavian mass balance method use stakes, which are located on the glacier, where the height above the glacier’s surface is taken. The height measurements are taken in order to determine the stakes depth in the glacier. The winter depth is an essential part for the summer depth calculations. The formula used

to measure the summer snow depth is $d_s = d_w + (h_w - h_s)$, where “d” means depth, “h” means height, “w” and “s” means winter and summer. As the formula states, the difference in height above the surface, with the previous seasons stake depth as a reference point, provides the new stake depth. Therefore stakes height above the surface were measured in order to determine the depth, since the winter depth and height had been calculated during the accumulation period. However, in order to determine bn and bw in each individual point, the seasonal stake depth was multiplied by the snow density for that season (see 1.6.4 Function of density for snow densities used). Therefore bn in the individual point of measurement has the following formula, $b_n = d_s * \rho_{snow.}$ (Where ρ_{snow} means the seasonal, in this case summer snow density, and d_s means summer stake depth). bw has the same formula but with different measurements, $b_w = d_s * \rho_{snow}$, were the winter snow density and stake depth are used to determine the mass balance. the unit for all mass balance is firstly, kg/m^2
The density of snow for the summer was constructed in an IF formula with an integrated function (for description see 1.6.4 Function of density.)
Furthermore, after each individual stake mass balance had been calculated, the average mass balance of the net mass balance and ablation mass balance for all the stakes combined was calculated in m.w.e using Google Sheets “average” function. This was done in order to provide a general number of mass balance on Storglaciären.

1.6.2 Accumulation

Accumulation is a gain in mass on a glacier (8).
The accumulation period time span for this study is from the first recorded stake measurement of the accumulation period to the last recorded stake measurement.
For this study, the stake measurement data was recorded between 2017-03-25 to 2017-05-16. Therein lies a source of error since there could have been more snow that could have fallen on some stakes since not every individual stake was measured at the same dates. The entire accumulation period was from mid september in 2016 to 2017-05-16.

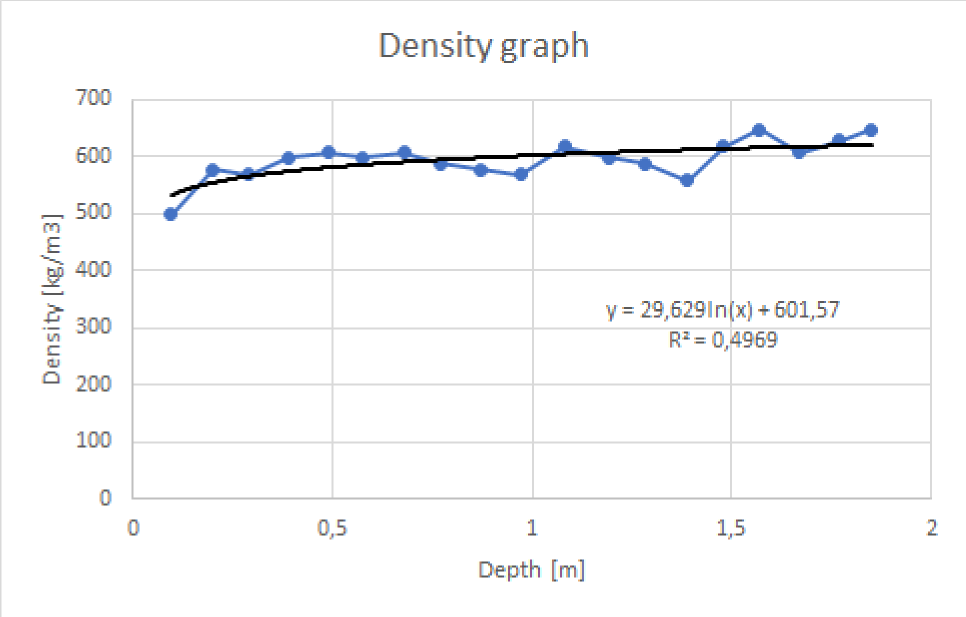
1.6.3 Ablation

Ablation is a loss in mass on a glacier due to snow changing its state of mass due to rising temperatures, sublimation, minor avalanches, subglacial water streams, and any form of changes in energy, because it leads to differences in temperatures which triggers sublimation, melting of snow to ice and water etc.(8).
The main contributor of energy on a glacier during the glaciological summer is rainfall. Rainfall contributes with kinetic energy which raises the temperatures of glaciers and due to rain’s state of matter ($H_2O_{(l)}$), which has a higher temperature than snow ($H_2O_{(s)}$). The heat from the rain transfers to the snow of the glacier which is explained by the second law of thermodynamics. In a closed system, when there is a difference in temperature, where one part of the system has a higher temperature than the other, the heat from the part with higher temperature of the system will transfer its heat to the cooler part of the system, which in turn increases entropy(13). The inside of the glacier could be considered a closed system, at least the transferring of heat from rain to snow crystals. The raised temperatures of Storglaciären’s caused by rainfall is a contributor to increased ablation, and since rainfall varies, the ablation will also vary depending on the amount of rainfall.

The ablation period's time span for this study is defined from the last recorded stake measurement of the accumulation period to the last recorded stake measurement of the ablation period . These dates for this study are 2017-05-16 to 2017-07-20.

1.6.4 Function of density

The density of snow near the glacier was measured at different depths (see 2.1.2 Density measurements). The data was put into Windows Excel and the density was calculated. A graph was fitted to the data with density [kg/m^3] on the y-axis and snow depth [m] on the x-axis (see 4.1 Summer density function).



(Graph nr 1:
Density on the Y-axis and depth on the X-axis, with function of density ;
Source: Author's private excel document.(6))

A function of density was then applied so that the ablation of each stake could be determined. The kind of function that was applied was a logarithmic one. This function was chosen based on the principle that the deeper the snow depth, the higher the density will be due to compaction from overlying snow. The logarithmic functions resembles this phenomena because the function of snow density should be asymptotic to the density of ice (9). This is because the more snow laying on top (i.e. depth) the more pressure is applied. When pressure increases, the temperature needed for snow to change its state of mass will be less than the temperature needed in normal atmospheric pressure(9 and 11). Therefore, with increased depth of snow, the density will increase and therefore approach the density of ice, which is 917 kg/m^3 (10). Functions do not provide as reliable measurements for mass balance as taking each individual stakes snow density and multiply them by the snow depth. However, in order to get a more easily calculable mass balance and to save time by not digging a hole by each stake in the glacier, which could affect the glacier and contribute to changes in the glacier, a function is to be prefered.
The function of density was integrated in order to calculate the meter water equivalent (see 1.6.5 Water equivalent m.w.e) and then put into an IF function in the spreadsheet (For reasoning of integration of density function, see 1.6.5 Meter water equivalent (m.w.e.). Because the state of matter surrounding a stake can vary from snow to ice,

the densities of the material surrounding the stake will also vary. Stakes surfaces in areas with higher temperatures are more often surrounded by ice. Therefore applying a function of snow density to a stake with an ice surface provides invalid data, due to the ice density being different than that of snow. Then, if the stake measurement depth (d_s) is negative during the ablation period (b_s) it will be multiplied with the density of ice (10) which would calculate the mass balance. The formula and IF expression was structured as follows:
$d_s = d_w + (h_w - h_s)$
(see 1.6.1 Mass balance equation for the variables definition).

f(x)=29,629ln(x)+601,57

$$\int_0^{ds} f(x)dx = F(ds) - F(0) = F(ds) - 0$$

b_n= IF; d_s>0; then F(d_s); if else d_s*917 kg/m3.

The same process of integration was used for the winter density used. The winter density measurements was handed to the students by Dr. Helanow (12) and like the summer density, a function of the density was constructed using Windows Excel. However, the function of density was not put as an IF expression since the IF expression was formulated due to negative depths. Since there were no negative stake depths during the winter, there were no IF expression. Furthermore the function chosen for the winter density has lower density values (observe the y-axis) higher to the surface. This is because during winter time, there are more intact snow crystals above the surface than during the summer since there is the snow doesn't change it state of matter to ice or water during this period due to temperatures being under 0 ℃ for the majority of the winter season. However there is a large increase in density the at larger depths is due to compaction (see 1.8.3 Compaction for explanation of the increase in density). Furthermore, it’s important to note that the density depth interval is 20 cm per each measurement, not 10 which it was for the summer density measurements. Therefore, the graph does not start at 0, but at 0,2 m on the x-axis.

After summer, winter and net mass balance was calculated, the calculations were handed in to the supervisor Dr. Helanow, to make a schematic map of Storglaciären, regarding ablation and accumulation on Storglaciären.. These maps can be found in 4.3 Net mass balance and 4.4 Summer mass balance.

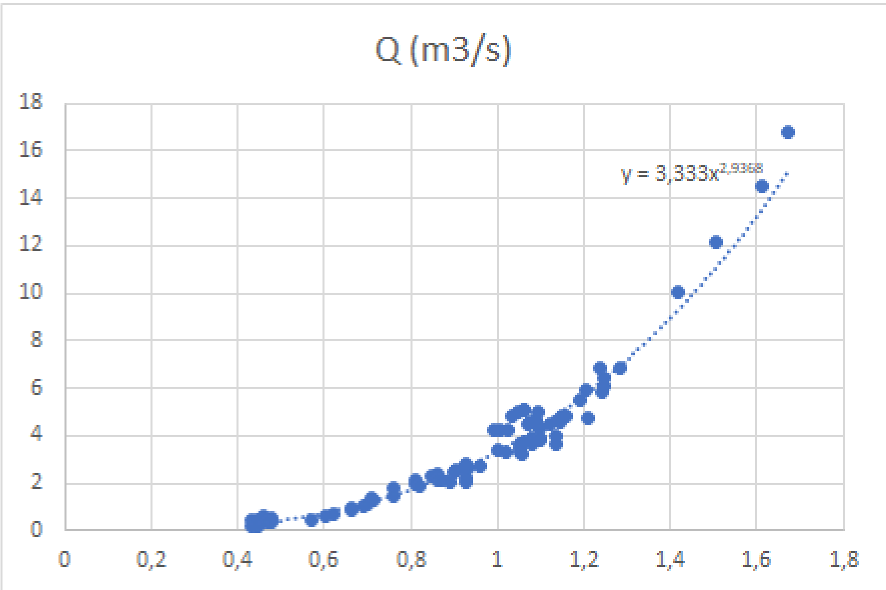
1.6.5 Meter water equivalent (m.w.e)

The integration of the function is done in order to calculate the mass balance relative to last year. Meter water equivalent is an measurements which is the amount of snow equivalent in meters of water [m.w.e]. This is used because water’s density is constant. It does not change. As snow’s density is not constant but varies with different conditions (such as pressure, temperatures, snow metamorphosis etc.) it does not have a definitive measurements unit representative to its nature. Therefore meter water equivalent is used in order to have a unified measure across the glacier. In order to calculate this, the mass balance calculated via the IF expression (see 1.6.4 Function of density) was divided with the density of water, which is 1000 kg/m^3 (kg

meaning kilograms and m^3 meaning cubic meter) When integrating the density of snow, which measurement unit is defined as kg/m^3 , the resulting measurement unit after integrating will be kg/m^2. If this measurement unit is divided with the measurement unit of water's density the measurement units will be meters. Illustration of measurements unit in the calculation;
$b_n/\rho_{H2O} = (kg/m^2)/(kg/m^3) = (kg/m^2)*(m^3/kg) = m$.
(Density of water being ρ_{H2O} , m meaning meters and kg meaning kilogram)

1.7 Hydrology function

Hydrology was used in order to account for the mass loss which could not be measured with the conventional Scandinavian mass balance method (3), i.e. the stake measurements. Therefore, hydrology measurements were taken (see 2.1.3 Hydrology measurements for description of the hydrology measurements). A function of the water discharge (Q) value was gathered, however, the data is from 2005 (for affects the outdated data might have, see 3.1 Sources of error). Water discharge is the amount of water in cubic meters (m^3) per second (s). The data was provided by Dr. Helanow and the formula was extracted from Windows Excel own formula provider.



(Graph nr 2:
The function of hydrology measurements. Water discharge on the Y-axis and meters of height on the X-axis.
Source: Tarfala research station, provided by; Dr. Helanow, Constructed by; Viktor Skog (Author) 2017-09-15)

The following power function was used.
$Q = f(x) = 3{,}333x^{2{,}9368}$
h=height
$f(h) = 3{,}333h^{2{,}9368}$
The function of the water discharge (Q) is used in order to formulate a relation

between Q and the height (h) of the water level in the Jokk. This function is appropriate because when h≈0, f(h)≈0. When h≈0 there is a small amount of water running through the Jokk. During the accumulation period h≈0, however, during the summer when h≈0, it means that there are either ice, snow or almost no water running through the Jokk. The power function is also used because when looking at graph nr 2**,** the water discharge (Y-axis) grows exponentially as the height increases but also the height's acceleration (X-axis) decreases. This means that the Jokk probably will only reach a certain water height level and therefore not reach a humongous water discharge level as well. It's therefore reasonable to assume that this is the case since the Jokks are relatively small and the amount of water running through the Jokks is therefore relatively small. Since there is no significant mass loss, the Jokks size will also remain the same, however in the case of a huge mass loss, due to external influences (i.e. global warming), the function to be used would need to be reconsidered.

1.8 Basic glaciology

1.8.1 Sublimation

Sublimation is when snow and ice changes its state of matter to gas. This is considered a contributing factor in snow metamorphosis and ablation. Sublimation on glaciers is caused by a difference in humidity. If cold snow falls on a glacier, and the snow on the glacier has a higher temperature, there will be a temperature gradient. Differences in temperatures also creates a humidity gradient. The differences in humidity and temperatures enhances the energy movement which makes snow and ice change its state of matter to gas (8).

1.8.2 Snow metamorphosis

Snow metamorphosis is when snow crystals change their shape and density due to wind, changes in temperature and pressure. A snow crystal has a complex shape in the sense that it has a large area with unequal distribution of mass. The snow crystals changes its shape to a sphere when affected by winds and differences in temperatures and pressure. Sphere-like shapes have a more equal the distribution of energy than a crystal shape, due to it having an equal distribution of mass. If the shape of a snow crystal is persevered when it has fallen on the glacier and then another material of significant mass is upon it, i.e. more snow, the crystals shape undergoes compaction, which compresses the crystal and forms a sphere-like form as well. Effects that snow metamorphosis and compaction can have on this study is in the measurements of density (8) (for description of snow metamorphosis impact on density measurements, see 3.1 Sources of error).

1.8.3 Compaction

Compaction is when snow crystals are compressed and forms a sphere-like form from its original complex form. This occurs when snow crystals form are affected by an increased amount of pressure by an overlaying mass, most often newly fallen snow.

1.8.4 Glacial water systems

During the ablation period, glaciers form glacial water systems which are created by melting of snow and ice which turns into water, or created by rainfall (supraglacial water system). When snow and ice melts and forms into water, it can either travel on the surface of the glacier (supraglacial water system) or under the surface of the glacier (subglacial water systems)(8). When water system are formed it contributes with energy due to the flow of water. The flow is created by gravity, due to it "pulling down" the water, and by the angle of the surface, which the water is transported upon (if it is a steep enough angle, the water's, velocity, traveling in, on or under the glacier, increases and therefore contributes with more energy since potential energy is converted into kinetic energy). Increased energy levels inside the glacier and on the surface leads to increases in temperatures which can spread over the entirety of the glacier and contribute to a larger ablation.

2. Method

2.1 Trip to Tarfala research station

2.1.1 Field Trip and stake measurements

The group of Forskarskolan performed a field trip to Tarfala research station which lasted 6 days (12 of July- 18 July, 2017). The group kept residence at the Tarfala research station which is located nearby Storglaciären. On the 15th July the group and the supervisor from Stockholm University (Dr. Helanow) walked on the glacier to measure the stakes. The stakes were measured in the following manner:
1. An ice axe was placed on the surface next to the yardstick (measured in cm).
2. The yardstick was measured to the nearest 2m mark, which was a strap of tape on the stake, which determined the stake's height above the surface.
3. If the surface around the stake was surrounded with snow, the snow depth was measured with a snow depth stick which penetrated the snow surface and was continually pushed until it was stopped by a solid mass. When the stake reached the solid mass, measurements were taken and this was measured to be the snow depth. However, this measurement was more supplementary, since the snow depth measurements from the snow field (see 2.1.2 Density measurements) was used instead for depth calculations. 4. The measurements was collected into a small not epad and was later put into the computer station on the glacier in order to download all the valuable data. Stake measurements were not taken for all the points by the Forskarskolan group.
5. The remainder of the stake measurements were measured by the research team at the Tarfala research station and was provided to the author by the supervisor, Dr. Helanow.
(For photographic illustrations, see 8. Appendix, 1 and 2.)
(For detailed description of mass balance equation see 1.6.4 Function of density and 1.6.5 Water equivalent)

2.1.2 Density measurements

On the 16th of July the group climbed up on a snow field next to Storglaciären in

order to measure the snow density there. A 2 meter deep snow pit was dug. Samples of snow were extracted from the side of the snow pit which had not been affected by external influence, i.e. touched or changed during the digging, in order to minimize the source of error of compaction. A meter stick was placed along the pits wall and glued onto the wall using snow. The snow density was measured at different depths with a hollow cylinder, which was knocked into the snow with the help of a wooden hammer. When the cylinder had been knocked into the wall, the snow surrounding the cylinder was scraped off (see 8.Appendix 3, for photographic illustration). This was done in order to get a clear sample of snow, unaffected by compaction. The snow in the cylinder was extracted into a bag and the weight was measured with a dynamometer. Density for each depth was determined because the following measurements:
- Volume of the cylinder
- Mass of the snow
- Mass / Volume= Density

The graph (see 4.1 Summer density function) was created using Windows Excel.

2.1.3 Hydrology measurements

The hydrology measurements were provided by Dr. Helanow and were measured in 2005.
Water discharge measurement unit is m^3/s and was measured everyday from the 119th day to the 366th day of the year in 2005. The ablation period is defined as the last measured accumulation period date of the stakes to the last measured ablation period date of the stakes. The ablation period in 2017 started on the 136th (2017-05-16) day and ended the 201st day (2017-07-20) of the year. This period is of interest for the calculation of the water discharge (See 1.7 Hydrology function for description of water discharge).
The calculations were performed in the following manner:
- m^3/s was converted into m^3/day by multiplying Q*(3600s*24hours).
- The sum of the water discharge during the ablation period was calculated which was then multiplied by the amount of days (65 days)

2.2 Research, lessons and help from supervisor

Research was done via Google and with the help of Stockholm University. The supervisor of this study, Dr. Helanow, provided useful information and supervising, as well as seminars in basic glaciology regarding hydrology and mass balance calculations before, during and after the stay at the Tarfala research station.
After the stake measurements had been calculated via Google Sheet, the values were handed to Dr. Helanow. After summer, winter and net mass balance was calculated, the individual stakes coordinate and mass balance was matched in Google Sheets. This was done in order to make a broader statistical analysis of glacier with the help of a map.

3. Sources of error

Sources of error are important to address in order to identify potential flaws in the study’s method and different variables that may affect the findings of this study. The purpose of this section of the text is to point out flaws in the measurements of this study in order to analyse how different glaciological phenomenas affect the results of this study. This section will also include source criticism to provide a section where the the entire study will be criticized.

3.1 Sources of error

Hydrology measurements were used in order to measure the total run off of the Tarfala Jokk, however, the validity of the hydrology measurements are not ideal since the hydrological measurement instrument last recorded data is from 2005. During the time span from 2005 until 2017 various changes in the climate may have affected the ablation (for example the carbon dioxide amount released in the atmosphere during this period (7), warmer temperatures around the Tarfala valley and lowered temperatures around the Gulf stream(16)). This creates a source of error due to the time outdated data being a part of this study.

Furthermore, because the amount of rainfall varies, the height measurement of the Jokk (see 2.1.3 Hydrology measurements for description of height) will vary from each year which makes potential calculation, using hydrology measurements from 2005, a source of error. However, since this study is based on more averages (making conclusions on more wider basis) the hydrology measurements time scale is not a great concern. However, it's important to note that it has an impact on the measurements.

Also, there are several glaciers that contribute to the forming of the Jokks in the Tarfala valley which makes it difficult to determine the specific amount of water that Storglaciären contributes with.

Furthermore, sublimation can also increase the ablation but is non-measureable. Effects on the measurements due to the possibility of unaccounted mass loss can distort the data and create uncertainty in the ablation measurements of the glacier. Therefore the sublimation could create measurements which indicates on a smaller ablation due to no measurement tool for the sublimation of the glacier, which is an source of error. However, when looking at the glacier on a wider scale, the sublimation becomes neglectable since it can not be measured and because it does not account for a significant amount of mass loss. It is still a source of error, but not a major one.

This study of the glacier was performed during the ablation period which means that stake measurements does not contain substantial enough information for an overview of the ablation state of the glacier. Therefore hydrological examinations of the nearby Jokk's is required in order to establish a conclusion Storglaciären's state of mass during the ablation period of 2017. To establish Storglaciären's state of mass, regarding the run off by subglacial water systems, a complementary study with recent hydrology measurements would be a good supplement to the analysation of Storglaciären.

Furthermore, due to the fluctuations of rainfall, temperatures and global warming (changes in the Gulf stream), from year to year, this analysis of Storglaciären does not provide a general and insightful overview of Storglaciären. This study is rather an analysis of Storglaciären during it's ablation period from 2017-05-16t to 2017-07-20. This period is not the entire ablation period of Storglaciären since the ablation period usually continues through the month of August and ends in september.

3.2 Source criticism

Several different sources have been used for this entire study. However, some of these sources were utilized differently due to the source information's relevancy. Some sources only contain numbers and values, for example, the density of ice (10). These are not main sources since they do not contain more than trivial information. Only the three sources, were the majority of information from the sources were utilized in the text, will be criticized in this section of the study. The definition of a main source in this paper is:

- The source provides more than trivial information than just a number, value, coordinate etc.
- The source provides legitimate scientific information.
- The source provides relevant information to this study.
- The source has been cited in the text .

Main source 1:

(8) "Glaciologi", By P.Holmlund and P.Janssons, Published by Stockholms University & Swedish research council in 2003, Collected 2017-08-03;
This source has been used to explain basic glaciological nomenclatures, phenomenas and facts. The authors of this book are glaciological researchers and are also working for a legitimate institute of science. The book generally explains theories, mathematical equations and formulas but provide rather limited explanations, compared to research papers and studies, as to the principles and practices of glaciological examinations. However, this book provide good information from two authors who both are well on the subject and do have PhD's in glaciology, and P. Holmlund is a professor in glaciology at Stockholms University. This makes the author's' information valuable and has therefore been used as a main source to explain the majority of the theories and nomenclatures in this paper.

Main source 2:

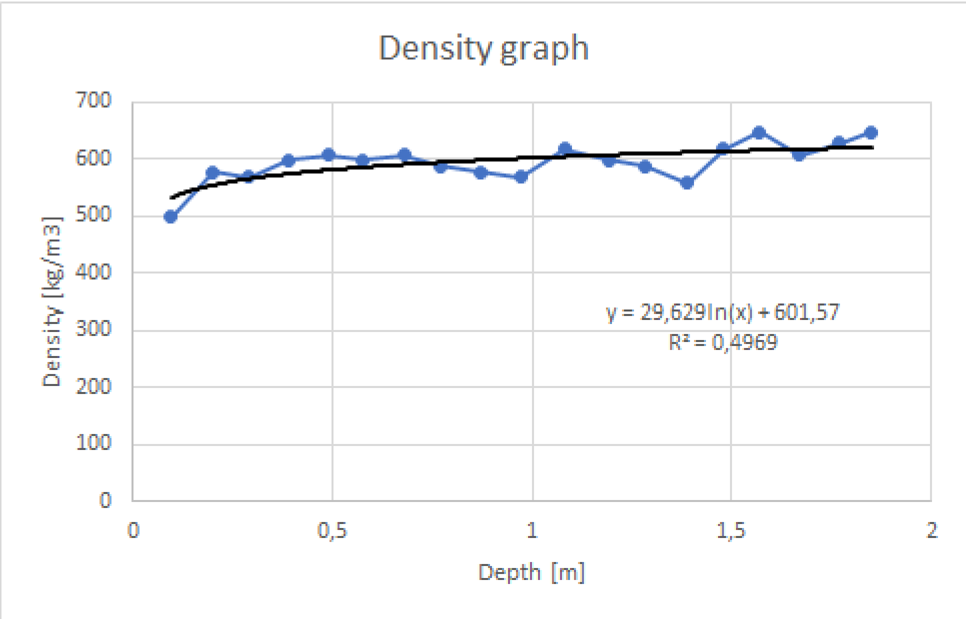
Paper (5) and blog post(4) about climate change and the Gulf stream by R. Seager of Columbia university (4,5):
This source was used in the discussion part (see 5. Discussion) in order to criticize the hypothesis (see 1.3 Hypothesis) of this paper. The cited studies (4) and blog post (5) claims that the gulf stream's effect on the European climate is false and other meteorological factors such as convergent atmospheric streams plays are the reason for the heating of northern Europe instead. R. Seager claims that the reason for northern Europe's heat is not caused by the gulf stream, but rather, atmospheric convergence. This main source was used because:

- R. Seager is a professor at a serious institute of scientific research.
- The scientific paper provides legitimate scientific reasoning in order to falsify what is described as "the gulf stream myth".
- The source provides a nuanced perception of the climatic influences of Storglaciären.

Main source 3:

Website articles by NASA’s climate analysis, (7) and (11):
2 sources from NASA were used in this study in order to attain deeper insight in two topics;
1. (11) The melting of glaciers in greenland and the Arctic sea, this being related to the hypothesis (see 1.3 Hypothesis)
2. (7) The increase of carbon dioxide in the atmosphere which could be a leading cause to climate change.
Theses sources were used because these sources;
- They were published by a legitimate institute of scientific research
- Provided information for the argument in the hypothesis.
- Provided a nuanced discussion of the climatic influences on Storglaciären state of mass.

4. Result
4.1 Summer density function



(Graph nr 1:
Density [kg/m^3] on the Y-axis and depth [m] on the X-axis with function of density, ;
Source: Author’s private excel document.(6))

Function of summer density:
y=f(x)
f(x)=29,629ln(x)+601,57
Integral of the function:
f(x)= 29,629ln(x)
g’(x)= 601,57

$\int ln(x)\,dx = x * ln(x) - x$

$\int f(x)\,dx = 29,629x * ln(x) - 29,629x$

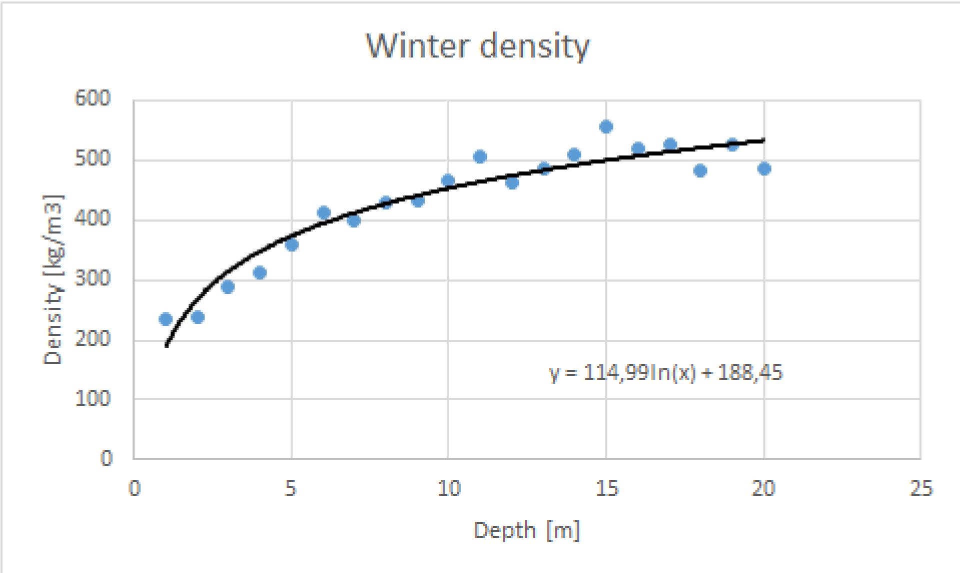
$\int g'(x)dx = 601,57x$

$F(x) = \int f(x) + \int g'(x) = (29,629x * ln(x) - 29,629x) + 601,57x = 29,629x * ln(x) + 571,941$

F(x)= 29,629x*ln(x)+571,941x+C
C=0

IF formula:
IF logical statement; value; if false, this value
b_n= IF; ds>0; then F(ds); if else ds*917 kg/m3(9).

4.2 Winter density function



(Graph nr 3: Winter density of 2017. Graph made by author.
Source: Tarfala research station, provided by; Dr. Helanow, Constructed by; Viktor Skog (Author) 2017-10-20 (12))
Winter density function:
y=114,99ln(x)+188,45

Integral of function:
y=f(x)
f(x)=114,99ln(x)+188,45
f(x)= 114,99ln(x)
g'(x)= 188,45

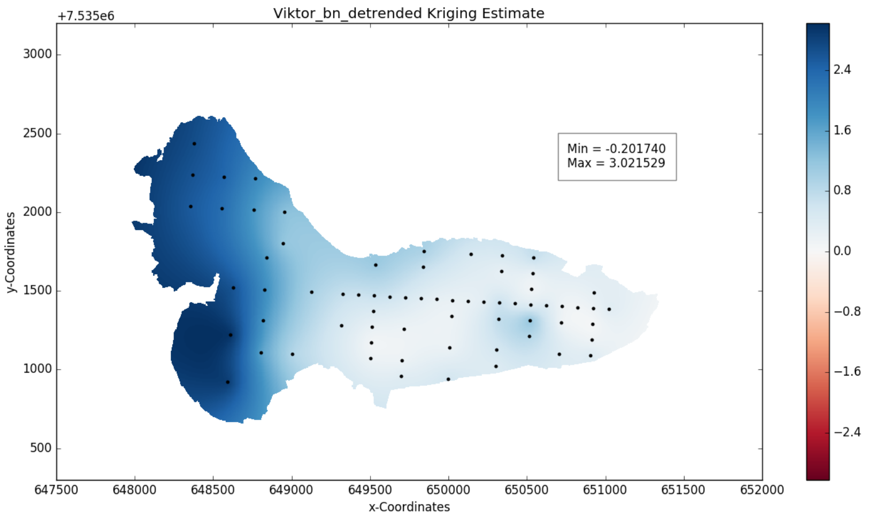
$\int ln(x)\,dx = x * ln(x) - x$

$\int f(x)\,dx = 114,99x * ln(x) - 114,99x$

$\int g'(x)dx = 188,45x$

$F(x) = \int f(x) + \int g'(x) = (114,99x * ln(x) - 114,99x) + 188,45x = 114,99x * ln(x) + 73,46x$

F(x)= 114,99x*ln(x)+73,46x+C
C=0

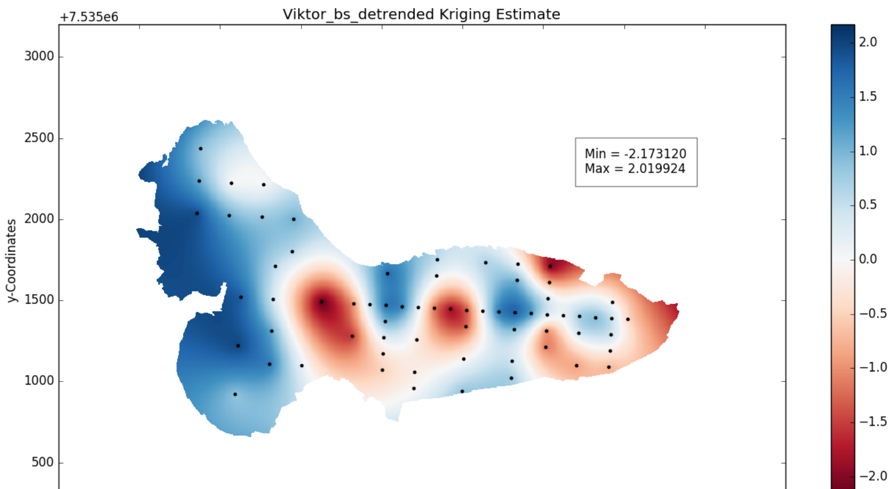


$b_w = F(d_w)$.

4.3 Net mass balance

(Map nr 1:
Map of Storglaciären's net mass balance [bn], the color blue represent accumulation, the color red represents ablation and the color white represents approximately 0. Source: Mapping of net mass balance by Dr. Helanow, collected 2017-10-25)

Average net mass balance for Storglaciären in the year 2017 was $+ 0,854905913$ m.w.e which is equal to $+ 854,905913$ kg/m^2 of snow. This is apparent in the schematic map above as the majority of the glacier is blue.



4.4 Summer mass balance

(Map nr 2:
Map of Storglaciären’s mass ablation [bs], the color blue represents accumulation and the color red represents ablation and the color white represents approximately 0.
Source: Mapping of net mass balance by Dr. Helanow; collected 2017-10-25)

The average mass loss during the ablation period of 2017 was $-\ 0,03536531909$ m.w.e which is the equivalent of -35,36531909 kg/m^2. This is apparent in the red colors in the schematic map above and the large accumulation to the western parts of the glacier.

4.5 Hydrology measurements

During the ablation period, there was approximately 1,057*10^9 m^3 of water flowing through the Jokk during the ablation period.
(see 1.7 Hydrology measurements, Graph nr 2 for the function of hydrology measurements and 2.1.3 Hydrology measurements for calculation method.)

5. Discussion

The results of this study indicates an accumulation of Storglaciären. This would align with the hypothesis claim (see 1.3 Hypothesis) that there would be a net mass gain. Analysing the results of this study (see 4.3 Net mass balance and 4.4 Ablation mass balance) the average net mass balance (b_n) indicates on a net mass gain 2017-03-25 and 2017-07-20. The ablation period indicates on ablation on the eastern and central parts of the glacier. The ablation in the central part of the glacier could be due to glacial water systems transporting water from the western parts, which have a higher altitude, to the center part of the glacier. It could also be due to one of the sources of error which is the certainty of the stake measurement tools used.
If the average net mass balance of the glacier indicates on a mass gain, which is the case in this study, the hypothesis is correct and indicates on a changing trend of mass on Storglaciären. When the lowered speed and temperatures of the Gulf stream is taken into consideration (16), it is clear that there is a) a change in the gulf stream b) when there was a mass gain on Storglaciären, there was lowered temperatures in the Gulf stream, south of Greenland.
However, the melting glaciers of Greenland and the Arctic sea, near the Gulf stream, can not be concluded to be the only influence on Storglaciären’s state of mass. There could be other factors weighing in, however, there are indications of the Gulf stream contributing to the accumulation observed. When the sources of error are take into account regarding the duration of this study, the study was performed during a short period of time and the glacier do not necessarily respond to external influences such as climate change during such a short period. Therefore the accumulation observed in the data could be that this study did not measure the entirety of the ablation period, there is approximately one to two more months of the ablation period left to analyze. Furthermore, the claim about the Gulf stream's effect on the northern European climate is questionable.

The hypothesis (see 1.3 Hypothesis) description of the Gulf stream's effect on the northern European climate does not align with the paper (5) and scientific article (6) published by Columbia University professor Richard Seager. According to Seager et al, the main reason for the northern European climate is the "convergent atmospheric streams of heat", and also " water's function of releasing energy, ie warm air, in cold areas and absorbing heat in warm areas are contributing factors in the heating of northern Europe". Therefore the hypothesis was incorrect, according to Seager et al, as so far the Gulf stream's effect on the northern Europes climate.
Also when looking at previous analyses of Storglaciären's mass balance during the 20th century, indications that the hypothesis is wrong occurs. According to a research paper published in the Swedish society for anthropology and geography, by; P. Holmlund(2), "Since 1910 the mass loss [of Storglaiären] has been $1.1 \cdot 10^{11}$ kg, or 26% of its mass in 1910." The study was published in 1987 and climate change and gas house effects has increased (7) since the publication of the study cited above. Also during the time period of the study cited (2) there were years where the net mass balance was positive. This study could be one of the years with a positive net mass balance. Therefore this year's net mass balance might not follow the trend of the long term ablation (2) , but not be the change in the trend of ablation.
Furthermore, some of the sources of error needs to be taken into account when analysing the results of this study.
Firstly, the formula for winter density was provided using Windows Excel with an r^2 value of about 0,5 which means there is almost a 50% uncertainty when applying the function to the data.
Secondly during the ablation periods, large part of the melting runs off the glacier in subglacial water systems which also is the reason for Jokks to form. The Jokks are snow which has changed it's state of matter into water due to the rising temperatures. Therefore the stake measurements are not representative for the entire mass loss during the ablation period because there could be a larger ablation of Storglaciären that have been unaccounted for due to water systems transporting water (formerly mass belonging to Storglaciären) to the Jokks, which the stake measurements do not account for. Therefore, hydrology was included in this study in order to minimize this source of error.
The hydrology measurements for the ablation period would indicate on a significant amount of water running through the Jokk. It is however, difficult determining the validity of the hydrology measurements considering the difference in time. During the twelve years (the time period from 2005 to 2017) which the hydrology measurements do not account for carbon dioxide levels in the atmosphere have increased(7) and the impact it might have on Storglaciären can not be determined without more recent data. This creates uncertainty regarding the validity in the hydrology measurements especially since the increased greenhouse effect could lead to raised temperatures of Storglaciären causing more ablation than observed in the hydrology measurements. However the results of the hydrology measurements could also indicate on less of a mass loss during the ablation period if the hypothesis (see 1.3 Hypothesis) is correct, as so far the Gulf stream's lowered temperatures providing a cooler climate, there could be an overall accumulation on Storglaciären.
In order to determine the specific mass loss of Storglaciären, with regards to hydrology and stake measurements, one improvement is to gather more recent hydrology measurements.

In summary, more recent hydrology data needs to be attained in order to enhance the validity of the measurements of these kinds of studies.
Fluctuations in mass on Storglaciären varies and therefore it needs to be taken into account that this analysis of Storglaciären does not provide data for the entire glaciological year of 2017 and also have some sources of error, such as the validity of hydrology measurements, which affects the data.
The results of this study indicates on a net mass gain from 2017-03-25 to 2017-07-20 which to some extent aligns with the hypothesis. Global climate change may be a contributor, however, a direct correlations between climate change and accumulation has yet to be established.

6. Conclusion

The results indicates on an average net mass gain of $+\ 854,905913$ kg/m^2 of snow between 2017-03-25 and 2017-07-20. The mass gain could be due to climate change, however, this study could not provide, with observational evidence, a direct correlation between the mass gain and climate change, only indications thereof. It's therefore in its order to perform follow up studies on Storglaciärens mass balance with more recent hydrology measurements. In order to provide more certainty regarding the hydrology measurements of Storglaciären, more recent data regarding the hydrology measurements should be put in place. Furthermore, it needs to be taken into account that this study was performed over a short period of time and could not provide data for the entire ablation period, only the ablation period from 2017-05-16 to 2017-07-20. Therefore, considering that the ablation period usually continues until mid September, this study do not provide an overall analysis of the entire glaciological year of 2017.

7. Sources

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8. Appendix

1.

(An example of stake measurements being taken on a stake were the surface is covered in snow.Source: Private collection, Picture captured with; Olympus Stylus TG-TRACKER,Collected; 2017-07-15)

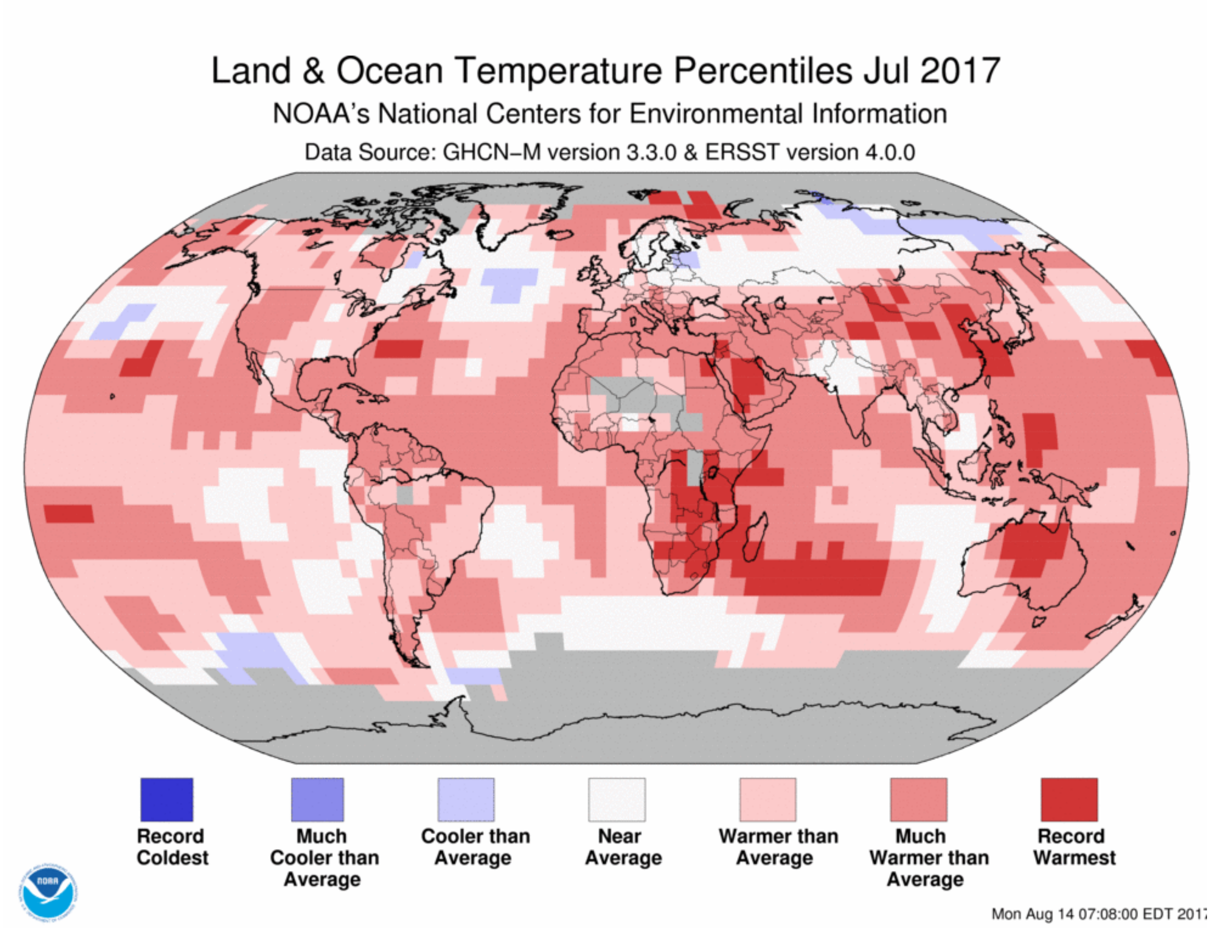
2.

(Another example of stake measurements but this time with an ice covered surface. The ice axe can be observed and the yardstick as well.Source: Private collection, Picture captured with; Olympus STYLUS TG-TRACKER ,Collected; 2017-07-15)

3.

(Photo of the density measurements with the scraping process and the yardstick.
Source: Kajsa Norin, a member of the research group; collected 2017-07-30)

4.



(A picture of the world's ocean and land temperatures during July 2017, the ablation period. This Picture illustrates a important things. That south of the Greenland the temperatures were cooler than average. This area is where the Gulf stream turns and release heat to northern Europe. This indicates on a cooling of the Gulf stream and could therefore affect the results of this study.
Source: NOAA Global climate report, (16))

9. Acknowledgements

First of all I’d like to thank all the wonderful people at Tarfala research station which welcomed us with open arms. The research station is responsible for some magnificent work and has held many notorious and important scientist resident there. Except from being the home for very important scientific research, the entire valley is really a most dazzling place which makes one reconsider the prosperity of nature and how we can protect it. Furthermore I’d like to thank all the wonderful people at Stockholm’s University and Christian Helanow at the Department of Physical Geography for giving us the chance to be apart of this wonderful journey. When I first were presented with the chance to be apart of Forskarskolan I could’ve choose any of following subjects; biology, chemistry, physics or glaciology. I obviously made the right choice in going to Tarfala and choosing glaciology. The trip made me into a new, more harmonic and stable person. I got the chance to see how field studies were performed and I also got to meet some of the most amazing and inspiring people in my entire life. However, all of this would not have been possible without the help of Tibble Gymnasium as well. The teachers at Tibble Gymnasium, in particular Henrick Mickos, Thomas Whilén, Peter Whitley and Ramona Holmlund, have helped me develop, not only as a student, but also as a person. If it wasn’t for there blunt, straightforward and helpful teachings I wouldn’t have been able to even get the chance to stay in Tibble. I single-handedly owe the success of my studies to the teachers, family members and pupils that have, through the entirety of my life, helped me in my studies and personal life. Especially a big thank you is handed out to Henrick Mickos who gave me, and 4 other pupils at Tibble, the chance to apply and get into Forskarskolan. Also a huge thanks to the other group members of the Tarfala trip who kept a positive and cheerful attitude towards others outside and in the group. They were all truly tremendous people to hang out with. Last thanks goes out to Alex Johansson for giving laughs that could last a lifetime.

CARPE DIEM!
~Viktor Skog