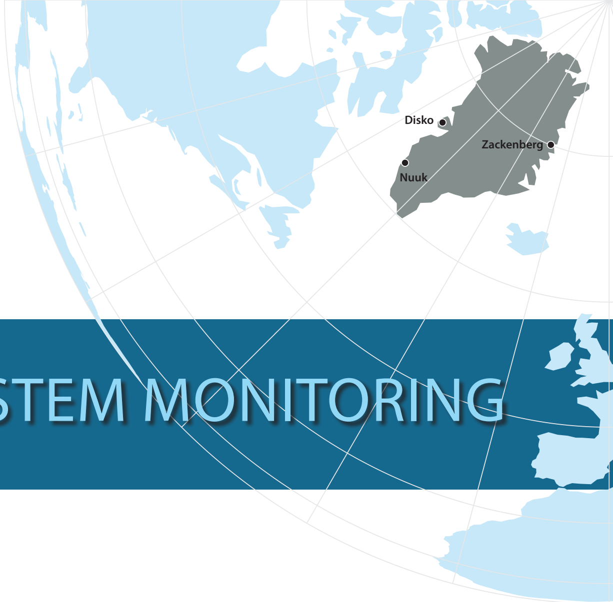
GEM



GREENLAND ECOSYSTEM MONITORING

25 *years anniversary*

of collecting data from the Greenlandic nature


PHOTO: KATRINE RAUNDRUP


PHOTO: KIRSTINE SKOV


PHOTO: KATRINE RAUNDRUP

This year, the GEM programme (Greenland Ecosystem Monitoring) celebrates its 25th anniversary of collecting data from Greenland.

The programme examines the effects of climate change from the High Arctic in northeast Greenland to the Low Arctic at Disko and Nuuk.

The long data time series constitutes the most comprehensive monitoring programme in the Arctic.

The GEM programme consists of five sub-programmes:

- ClimateBasis, focusing on climate and hydrology
- GeoBasis, focusing on measuring physical and chemical conditions on land
- GlacioBasis, focusing on glaciers and meltdown
- BioBasis, focusing on plant and animal life on land and in freshwater
- MarineBasis, focusing on biological, physical and chemical conditions in the sea along the coast

The programme is interdisciplinary with experts from different Greenlandic and Danish institutions, including ASIAQ, the Greenland Institute of Natural Resources, the University of Copenhagen, Aarhus University, the Technical University of Denmark and GEUS (the Geological Survey of Denmark and Greenland).

Sermitsiaq will be publishing six articles about GEM to celebrate the anniversary.

This first article describes the GEM programme in general. Subsequent articles will dwell into research results from the various sub-programmes.

PHOTO: MALIN AHLBÄCK

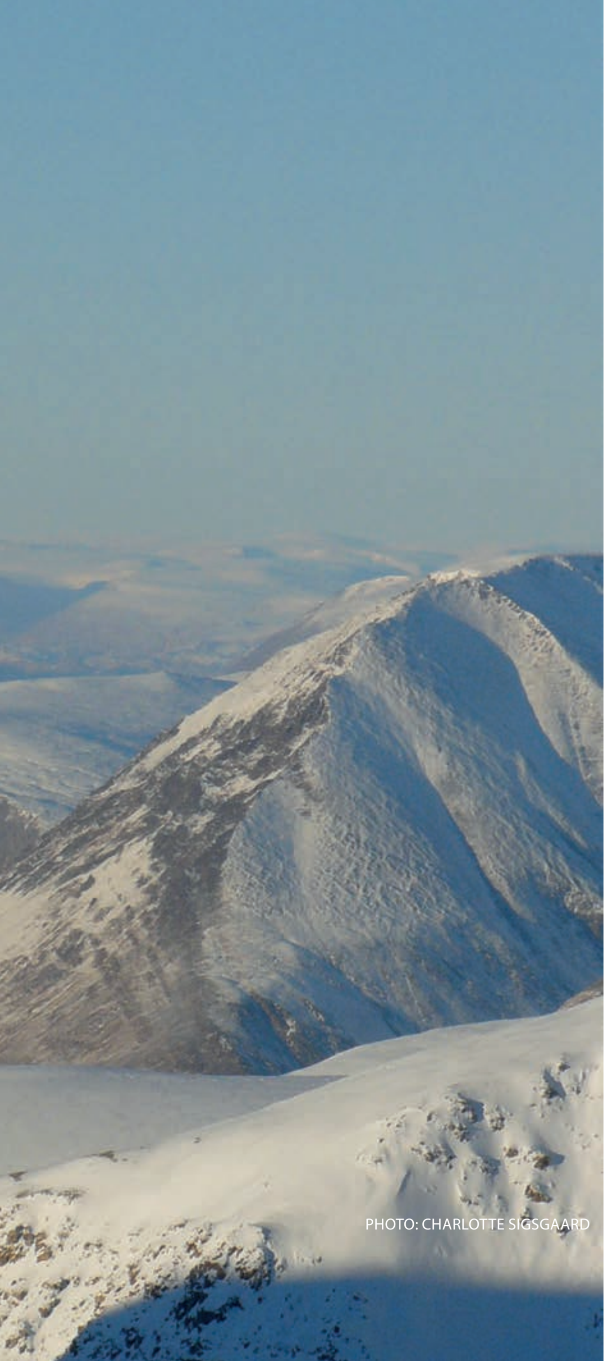
Greenland Ecosystem Monitoring Programme

Published: August 2021

Publisher: GEM

Printing: Rosendahls

Layout: Tinna Christensen



CONTENT

25 YEARS OF DATA DOCUMENTS CHANGES IN THE ARCTIC

The temperature in the Arctic is increasing much faster than we thought just 5-10 years ago. This is affecting nature in the Arctic. The message from researchers was clear at the spring meeting of the Arctic Council attended by ministers from all the Arctic nations. With measurements covering trends in Greenland's nature over the past 25 years, researchers have built a solid insight into the state of the Arctic region.

By: Signe Høgslund and Peter Bondo Christensen

Ice, snow and the cold govern nature in the Arctic. This is clear to anyone who has crossed the polar circle. However, new winds are blowing through Arctic nature – both on land and at sea.

The activities at Zackenberg began in earnest in 1995, when the first team of researchers and logistics experts lived under primitive conditions in tents. This was the beginning of the GEM programme, which has been supplying data on nature and climate in Greenland for the past 25 years. PHOTO: HENNING THING

"When we started our measurements 25 years ago, no one could have predicted that this year we would be telling the Arctic Council that the temperature in the Arctic is now rising three times faster than in the rest of the world," says Torben Røjle Christensen, a professor at the Arctic Research Centre and the Department of Ecoscience, Aarhus University, and head of GEM – Greenland Ecosystem Monitoring.

Unfortunately, this is the reality. With 25 years of uninterrupted data from the GEM programme, researchers have gained in-depth knowledge about climate developments in Greenland, and about how nature is reacting to the changes on land, and in lakes, fjords and the sea.

Unaffected by people

In 1986, a group of researchers from the Zoological Museum at the University of Copenhagen hatched the idea to establish a long-term, interdisciplinary research project in northeast Greenland with the aim to collect long time-series data on the physical and biological environment.

Without the researchers knowing it, this became the basis for documenting the effect of a concept that was barely known at the time: climate change.

The idea received so much support that, five years later, in 1991, a handful of researchers travelled north and designated the area at Zackenberg as particularly suitable for systematic studies of nature in the High Arctic.

Here, 450 km north of the closest settlement on the east coast of Greenland – Ittoqqortoormiit – the researchers could investigate the basic state of a typical Arctic ecosystem that was largely unaffected by humans.

In 1995, the Zackenberg Mountain caste its shadow over the researchers' tents for the first time. Here, on the tundra at the foot of the mountain, among small, angle-high willow bushes, a few millimetres of tent canvas shielded the researchers' sleeping area and laboratory from the wind and weather. This is where the first data points were drawn on the graphs we look at today when trying to understand the changes in the Arctic.

The programme has grown since then, and now it stretches across ecosystems along a climate gradient from the inhabited part of the Low Arctic in West Greenland to the uninhabited High Arctic in northeast Greenland. In addition to Zackenberg, there are now research hubs at Nuuk and on Disko Island.

Long time-series data reveals changes

The small willow bushes at Zackenberg Research Station are more than 90 years old. They were there long before the researchers arrived, and over their lifetime, they have experienced how the rhythm of Arctic nature has changed.

The willow bushes seem to adapt, but what about the rest of Arctic nature? Wading birds, for example. These birds winter as far away as South Africa. Do they know that spring is coming earlier in northeast Greenland, and how do they time their journey back north?

These are some of the questions that the researchers behind the GEM programme are seeking to answer by systematically monitoring nature year after year.

"Following nature changes in the Arctic can sometimes feel like watching the minute hand on a clock. We measure for several years, and all we see is that things are moving very slightly, but with patience and after some time, a picture of the changes in systems begins to emerge," says Torben Røjle Christensen.

These changes may be difficult to observe from one year to the next, but they become very clear in the long time series. And this is essential input to the climate models that predict the climate of the future and the effects of climate change.

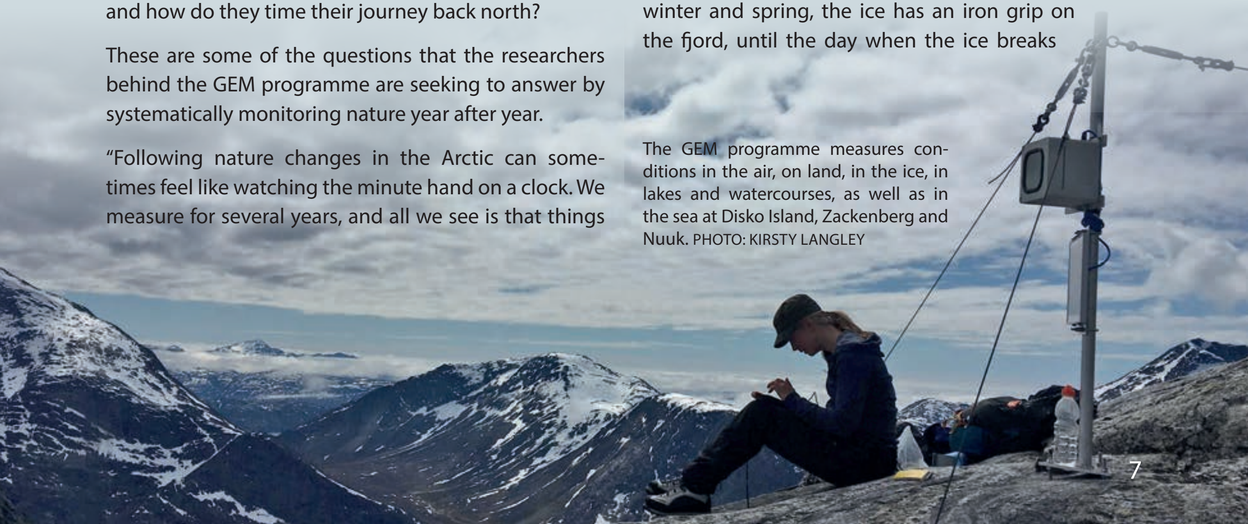
Less permafrost and longer ice-free periods are a wake-up call to politicians

The permafrost is important for nature in the Arctic. And it is moving. In the middle of the summer, year by year you have to dig deeper and deeper to reach the permanently frozen soil in northeast Greenland.

In the mid-1990s, the frozen layer was at a depth of approx. half a metre. Now, you have to dig deeper to find the hard frozen tundra; to almost one metre.

Among other things, the changed freeze-thaw dynamics direct a new rhythm in emissions of the aggressive greenhouse gas, methane, from the tundra. More methane in the atmosphere makes the global temperature rise further, and this affects the entire planet.

The annual cycle is also changing in fjords. Every winter and spring, the ice has an iron grip on the fjord, until the day when the ice breaks



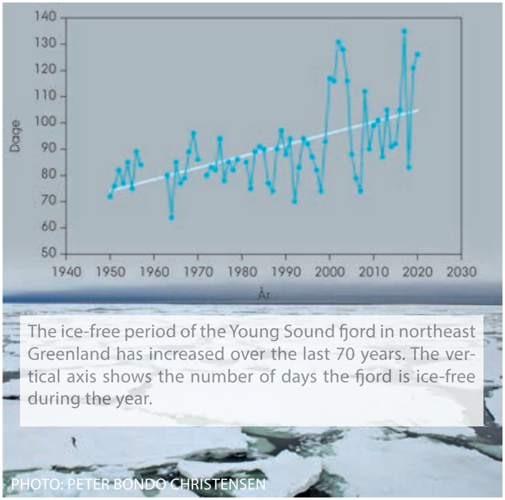
The GEM programme measures conditions in the air, on land, in the ice, in lakes and watercourses, as well as in the sea at Disko Island, Zackenberg and Nuuk. PHOTO: KIRSTY LANGLEY up and the white cover of the fjord disappears. This is the start of the brief, hectic summer in the fjord, when light drives the entire food chain before the ice closes in once again.

But the ice-free period is becoming longer and longer. In the past 70 years alone, during which the coming and going of the ice has been registered in Young Sound near Daneborg, developments are striking.

There are also signs that more freshwater is flowing into the Greenland fjords, and researchers are now monitoring whether the biology of the fjord will change to a new cycle with other species and changed quantities of algae and animals.

The data collected by GEM is crucial to fulfilling the Danish Realm's obligations in relation to Arctic Council monitoring of the environment and climate (Arctic Monitoring and Assessment Programme, AMAP) and biodiversity (Conservation of Arctic Flora and Fauna, CAFF). Therefore, there is a direct line from the measurements performed by the GEM programme to the reports in the Arctic Council's offices.

Danish Minister for Foreign Affairs, Jeppe Kofod, who participated in the Arctic Council meeting, stresses that the Council has grasped the gravity of the researchers' extensive data.

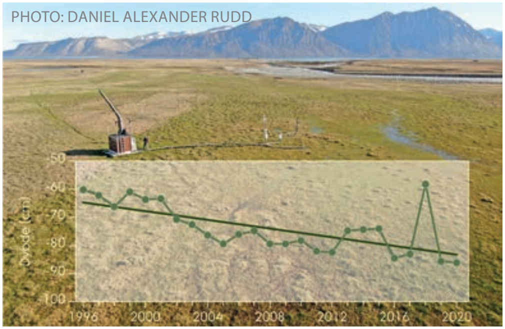


The ice-free period of the Young Sound fjord in northeast Greenland has increased over the last 70 years. The vertical axis shows the number of days the fjord is ice-free during the year.

"The data shows how serious and challenging climate change really is. This has huge consequences for nature and the environment, for biodiversity and wildlife, and for people's ability to live in the Arctic region," says Jeppe Kofod.

Jeppe Kofod points out that the results are a crystal clear call to the rest of the world to fight climate change and ensure that we meet the goals of the Paris Agreement, so that each country delivers its climate gas reductions.

"This is definitely a warning to all of us in the Arctic Council, and to the rest of the world. What we're seeing in the Arctic is a climate crisis that also affects the rest of the world," says Jeppe Kofod.



Gaps in knowledge about climate change

The Arctic Council publishes the so-called AMAP reports. And the AMAP report from the Council meeting in May was not optimistic reading.

The permafrost layer is dropping deeper and deeper into the tundra in northeast Greenland. The vertical axis shows the depth of the permafrost in the summer in centimetres.

Automated measurement stations secure data year-round, also through periods when it is difficult for researchers to get to the stations. PHOTO: ANDREAS AHLSTROM

Ten years ago, the best climate models predicted that the temperature in the Arctic would increase twice as fast as in the rest of the world. But this has turned out to be falsely optimistic.

Over the past 50 years, the temperature has increased by 3.1 degrees in the Arctic, while in the rest of the world it has increased by around 1 degree. In other words, the increase has been three times as fast in the Arctic.

"The new AMAP report made public at the Arctic Council meeting clearly shows that there are gaps in our knowledge about climate change. Our climate models need to be adjusted to simulate the temperature increase actually taking place," emphasises Torben Røjle Christensen.

The GEM monitoring of Arctic nature is now moving into a new phase, with strong focus on automating monitoring and covering larger areas. New technology is the key to producing more detailed input to climate models.

From space to the engine room of climate models

Every day, the Terra satellite passes over Disko Bay at a height of 705 km, and sends satellite images to the GEM researchers' computers. On one of the computers, Andreas Westergaard-Nielsen, assistant professor at the University of Copenhagen, processes the images. Based on the image material and a height model, he can estimate the moisture of the soil in the area every day. This is important information because the humidity of the soil is crucial for emissions of greenhouse gases, for example.

In the coastal waters at Nuuk and Disko Island, among other things researchers measure how much large algae grow, and they can compare this with the length of the ice-free period in the year in question.
PHOTO: PETER BONDO CHRISTENSEN

"We have good point measurements around the area in our time series, and we will now supplement these with measurements from satellites. This will enable us to measure larger areas, which is why satellites are a unique tool," says Andreas Westergaard-Nielsen.

Remote sensing using satellites is an important new addition to the GEM programme. There is a major task ahead in scaling up the measurements performed every year at the three main locations of the GEM programme in Zackenberg in northeast Greenland, at Nuuk and on Disko Island.

"The time series will continue, so that we can monitor the trends, but at the same time, we'll be able to get more information out of our point data by linking it with satellite data and automated measurement stations, which are now located in several places in Greenland," says Torben Røjle Christensen.

Can Arctic nature adapt?

The GEM programme has described new tones in Arctic nature. Like notes on a musical stave, each data point helps capture new rhythms in nature and puts them into a system.

Thanks to a considerable grant from Aage. V. Jensens Fonde, modern research stations have now been established in Zackenberg and Daneborg as well as in Nuuk/Kobbefjord. The stations are used extensively by researchers from all over the world. PHOTO: MIKKEL TAMSTORF

Røjle Christensen has spent 30 years studying nature and climate change in the Arctic.
PHOTO: PALLE SMEDEGAARD NIELSEN

PHOTO: OLE GEERTZ-HANSEN

And behind each data point is a wading bird, a musk ox, an hour of sunshine, an alga or some other element of Arctic nature monitored in the GEM programme.

The 25 years of data has provided insight into developments that no one had anticipated, and now the monitoring is being developed further, so that researchers can fine-tune models and answer in more detail how the climate and nature will change in the future.

Will the old willow bushes be buried in snow far into August or will they grow bigger during a longer summer? Will they bloom earlier and will there be insects to pollinate them? Will Arctic nature that over millennia has adapted to extreme conditions be able to adapt to a new climate?

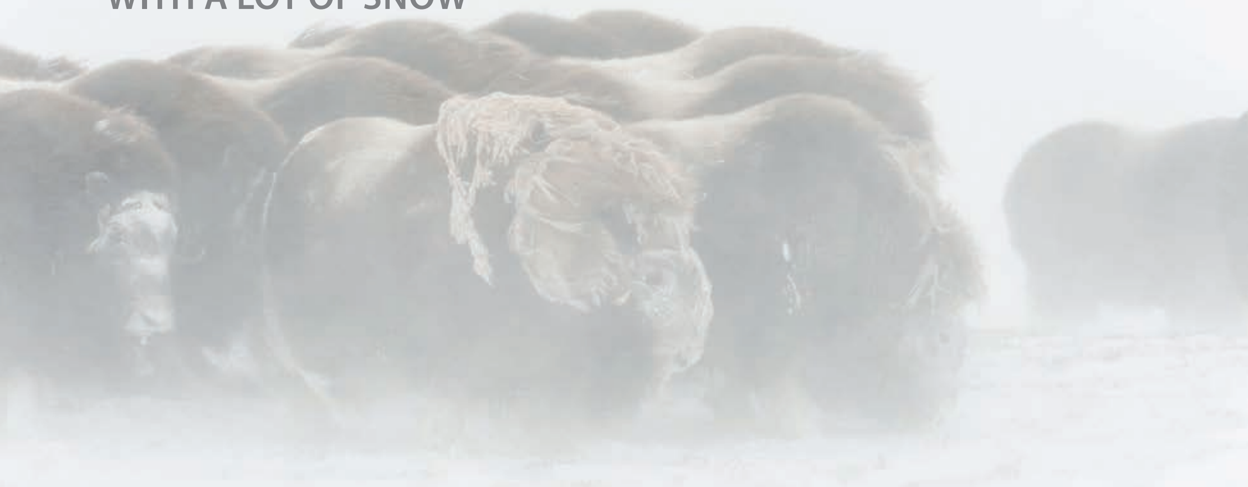
Further information:

Professor Torben Røjle Christensen
Arctic Research Centre and Department of Ecoscience – Arctic Ecosystem Ecology, Aarhus University
Phone.: +45 9350 9049; Mail: g-e-m@au.dk

Read more about the programme here:

https://g-e-m.dk/

THE MOST SERIOUS ENEMY FOR MUSKOXEN IS WINTERS WITH A LOT OF SNOW



The muskox's thick coat enables it to withstand the harsh conditions in the Arctic. PHOTO: LARS HOLST HANSEN

The number of calves that survive their first year of life is crucial for the population of muskoxen. And the success of the calves depends on their mothers' access to food. Both in summer but primarily in winter. Winters with a lot of snow are a threat to this Arctic 'blanket' with its rock-hard forehead. And perhaps a lot of snow is just what the future will bring.

By Peter Bondo Christensen and Signe Høgslund

The muskox is a key species on the Arctic tundra and it has survived in the harsh climate for thousands of years.

For 25 years, researchers have closely monitored and studied the population of muskoxen in the High Arctic region at Zackenberg in northeast Greenland. This has provided new insight into the behaviour and life of the species.

Researchers have now gathered this new knowledge into a model to explain what may happen to muskoxen when exposed to novel environmental conditions, including climate change, and thus help understand how best to manage the species in hunting areas.

Tracking collars

The muskox is closely related to sheep and goats and in fact it is not an ox at all. Ovibos is its scientific generic name, which actually means 'sheep ox'. With its thick coat of wool and long guard hairs, it has adapted to the cold Arctic climate with winters down to minus 40 degrees Celsius.

In Northeast Greenland, researchers have studied muskoxen since 1996. Each year, they have carefully registered the number of individuals in the population, the number of bulls, cows and calves, as well as the age for the individual animals.

When a muskox calf is born at the end of the winter, it is completely dependent on its mother's milk, but as the snow melts, it will begin to eat plants. PHOTO: LARS HOLST HANSEN

In order to understand where the animals go, where they forage, and how they cope with the harsh winter, the researchers equipped a number of cows with an electronic GPS collar, which registered the position of the animals, and sent data back via satellite every hour, all year round. Furthermore, the collars also collected data on their body temperature, and on how the animals moved their necks and heads – the latter can be used to infer their behaviour.

"If we're to understand what regulates the total population of muskoxen, it's crucial for us to gain insight into how individuals act and react under different conditions," says Professor Niels Martin Schmidt from the Department of Ecoscience – Arctic Ecosystem Ecology at Aarhus University, who has headed the studies.

Getting calves on their feet requires energy

In a tundra area of 47 km^2 around Zackenberg Research Station, the researchers counted more than 400 animals one autumn. And with a weight of 200 kg to 300 kg, it takes a lot of food to keep this prehistoric animal going.

"Our extensive data shows that during summer, the muskoxen basically don't do anything other than eat, when food is plentiful. During this period, they build up an energy deposit by storing body fat. This is absolutely crucial for the muskoxen to be able to survive, and not least reproduce, during the winter," explains Niels Martin Schmidt.

The muskox is a ruminant and the vegetation on the tundra is often of poor quality and takes a lot of time to digest.

In the winter, the animals rest more. And while pregnant cows maintain a constant body temperature during the winter, cows that are not pregnant will lower their body temperature by almost one degree Celsius.

Even with a body temperature of less than a single degree lower, they significantly reduce the amount the essential fat they burn. In fact, the reduced body temperature means that the animals weigh approx. 20 kg more at the end of the winter than pregnant cows that do not reduce their body temperature.

Cows with calves have to use as much energy as possible on the foetus and later on producing milk for the calves born in late winter (March-May). Then it becomes critical if large amounts of snow shut off access to the emerging plant forage.

“When there is a lot of snow, we can see that the animals start to move longer distances to find food. This requires energy and is critical for pregnant cows,” says Lars Holst Hansen from the Department of Ecoscience – Arctic Ecosystem Ecology at Aarhus University, who is involved in the studies.

If the females do not fully replenish their fat deposits during the summer, and if the winter is harsh, with very little access to food, many of them will miscarry their foetus to survive, and many of the calves that are born will die soon after birth because they do not get enough milk.

Model predicts the future

The researchers have used the vast amount of data to build a model to explain how the population of musk oxen will react to future changes in the climate.

“It’s quite clear that the amount of snow during winter is the most important factor for the size of the population. The model shows that years with even moderately increased snowfall will result in a smaller production of calves, which in turn translates into smaller population size. Moreover, the model shows that even after a few extremely snowy winters, it will take decades for the population to return to its pre-disturbance numbers,” explains Niels Martin Schmidt.

With the ongoing climate change, the researchers predict that there will be more precipitation in the Arctic. Therefore, it is crucial for the musk ox whether precipitation comes as snow in the winter or as rain during the summer months.

Climate change also means longer periods of fluctuating freezing and thawing temperatures. This results in an armour of ice on the ground, making it even more difficult for the animals to get to the sparse vegetation.

The muskox often lives in small groups – here is a group consisting of an adult bull, two cows and a calf.
PHOTO: LARS HOLST HANSEN

Finally, climate change means that we will have more years of extreme weather events – including years of extreme snowfall. This happened in northeast Greenland in 2018, when so much snow fell that large parts of the tundra were still covered by snow into August. If such events become more frequent, it will be fatal for the musk ox.

In 1962 and 1965, musk oxen were moved from northeast Greenland to Kangerlussuaq (Søndre Strømfjord) on the west coast of Greenland, where the climate is warmer and the vegetation more vigorous. Here, the animals do not encounter the same extreme conditions during a long winter, and they have developed into a large population that has spread to large areas, much to the joy of hunting enthusiasts.

"Our model could also be expanded to predict the amount of hunting pressure the western population of muskoxen could cope with during climate change. The model could therefore help support management of the species to ensure a good and sustainable population in West Greenland," says Niels Martin Schmidt.

Further information:

Professor Niels Martin Schmidt
Department of Ecoscience – Arctic Ecosystem Ecology, Aarhus University
Mail: nms@bios.au.dk; Phone: +45 4191 5664.

Lars Holst Hansen, member of academic staff
Department of Ecoscience – Arctic Ecosystem Ecology, Aarhus University
Mail: lahh@bios.au.dk; Telephone: +45 8715 8682.

Researchers have sedated a muskox so that they can fit it with a GPS collar, enabling the researchers to follow the migration of the muskox. PHOTO: LARS HOLST HANSEN

MORE SNOW SLOWS THE MELTDOWN OF GLACIERS

Iconic images of Greenland's glaciers go around the world when climate change is debated. The shrinking glaciers have become a symbol of the forces we are up against in a warmer world. Monitoring of two Greenlandic glaciers now shows that winter snow masses affect how the ice melts.

By Signe Høgslund and Peter Bondo Christensen

New research from the GEM programme has established that the more it snows in the winter, the less glacial ice melts away in the summer.

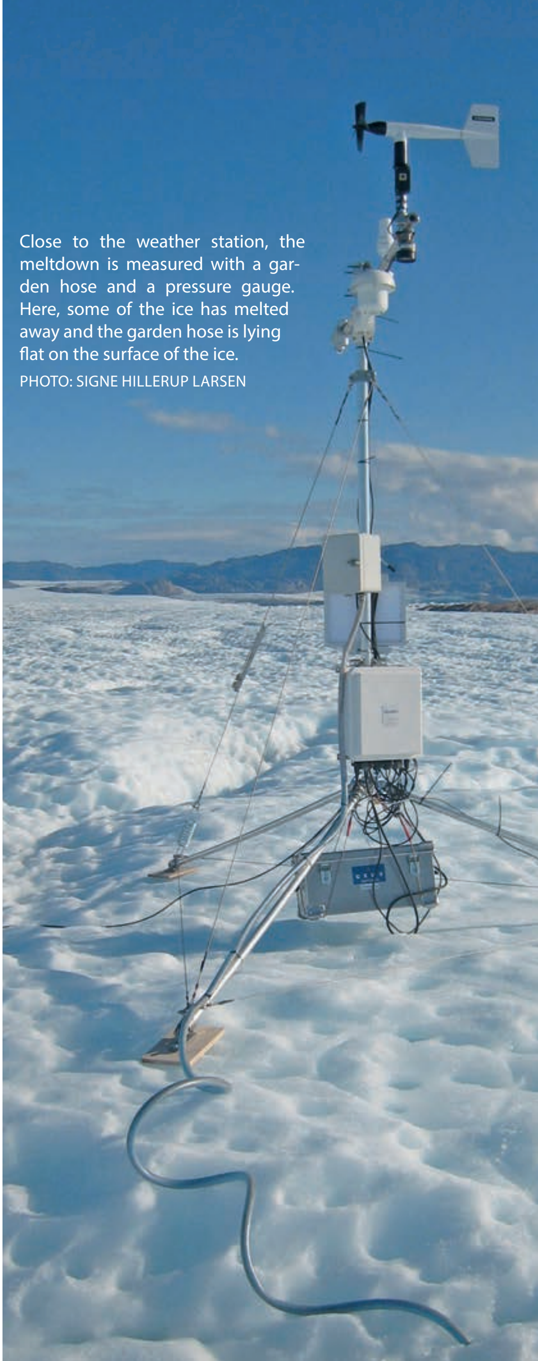
And the picture is the same both in the High Arctic northeast Greenland and in the Low Arctic areas around Nuuk. This is of significance to both the fjords of Greenland and rises in global sea levels.

Measurements of snow and meltdown have been carried out on two glaciers without contact with the ice sheet: The Qasigiannguit glacier near Kobbefjord, close to Nuuk and the A.P. Olsen glacier near Zackenberg in northeast Greenland.

"This type of glacier covers a much smaller area than glaciers in contact with the ice sheet. However, the local glaciers account for up to 20% of the total contribution to sea level rise from Greenland," says Signe Hillerup Larsen, a researcher at GEUS – the Geological Survey of Denmark and Greenland.

Garden hoses and acoustic sonar

The giant glacier tongues that shape the Greenlandic landscape have their own life and rhythm throughout the year. And this life is very much shaped by the snow. Snow that lands at the top of the glacier gradually becomes ice, and snow that lands in the melting zone further down controls how the glacier melts.



Close to the weather station, the meltdown is measured with a garden hose and a pressure gauge. Here, some of the ice has melted away and the garden hose is lying flat on the surface of the ice.
PHOTO: SIGNE HILLERUP LARSEN

The weather station on the glacier tongue of the A. P. Olsen ice sheet measures temperature, snow depth, solar radiation, wind speed and much more. PHOTO: MICHELE CITTERIO

There is very little data on the glaciers in Greenland not linked to the ice sheet, but the data that does exist shows a close correlation between snow depths and meltdown.

"We knew that the snow depths on the glaciers vary enormously from year to year. This is clear when we move from the research station in Zackenberg to the A.P. Olsen ice cap. In some years we have to zigzag between large rocks, because there is not much snow, while in other years we can drive directly across the landscape on our snowmobiles," says Signe Hillerup Larsen.

But it is one thing just to sense snow depths: getting accurate data about the snow is something else. And measuring snow depth and meltdown at the top of a glacier all year round is very difficult.

To solve this challenge, the researchers placed automated weather stations on the glaciers. The weather stations also had small sonars, which measured the distance down to the surface of the glacier every ten minutes. This provided a measurement for the depth of the snow.

But what about the meltdown? Here, the researchers turned to their garden shed to develop a unique method using a regular garden hose. One end of the hose was dug fifteen metres vertically into the ice with the other end at the surface of the ice. Then it was filled with anti-freeze, and a pressure gauge was fitted at the bottom which recorded the amount of liquid in the hose. When the ice melts, the hose lays on top of the ice and the pressure at the bottom of the hose drops, making it possible to calculate the meltdown.

"Even though 'the garden hose solution' is very simple, it works surprisingly well, and we're collecting incredibly important data. In this way, we can compare snow depth and meltdown quite accurately," explains Signe Hillerup Larsen.

More snow, less meltdown

Snow and ice are closely related, and data from the last ten years shows that large snow masses in the melt zone prevent meltdown which would otherwise reduce the thickness of the ice by up to one metre.

A fascinating workplace. Signe Hillerup is preparing to anchor the measuring equipment on the A. P. Olsen glacier.
PHOTO: MICHELE CITTERIO

Some climate models predict that in the future there will be more precipitation in northeast Greenland, where the A.P. Olsen glacier is located. If this happens, the glacier will be fed with more snow at the top, and more ice will form. At the same time, the snow could slow down the melt at the edge of the glacier.

"This effect is one of the reasons why we don't expect to see the same changes in the spread of glaciers in northeast Greenland as in other parts of Greenland. When global temperatures increase further in the coming decades, precipitation is likely to increase in northeast Greenland as well," explains Signe Hillerup Larsen.

Signe Hillerup Larsen stresses that many factors come into play when researchers predict how water inflow to the world's oceans will develop in the coming years.

The opposing dynamics between changed snowfall, rising temperatures and meltdown are a good example of some of the complex interactions that researchers are unravelling.

Ten years of data is a good start

Monitoring the glaciers over the past ten years has given researchers a glimpse of the glacial dynamics, and of how the climate affects them. But it will take a very long measuring period before researchers can say anything in detail about snow masses and meltdown in the future climate.

"Now it's a question of continuing our work, a 30-year measuring period, or longer, will be necessary for the data to be used in climate models, for example," says Signe Hillerup Larsen.

Researchers have shown that snow is very important for everything that occurs on and around glaciers. But they still do not know how much snow there actually is in a cubic metre. The next step will therefore be to monitor how compact the snow is – its density – so that the researchers can more accurately calculate how the snow affects the meltdown from the glacier.

The researchers are also trying to expand the monitoring to cover larger areas. The future understanding of the meltdown of glaciers will be driven by the automated weather stations as well as through remote sensing in the form of drones and satellites. So the simple garden hoses on the ice will be joined by fancy technology in the years to come.

Further information:

Signe Hillerup Larsen, researcher at GEUS
Mail: shl@geus.dk; Phone: +45 9133 3840.

The researcher is measuring the density of the snow at a snow-covered weather station.
PHOTO: MICHELE CITTERIO

DESPITE FROST AND SNOW, THE ARCTIC TUNDRA RELEASES METHANE ALL YEAR ROUND

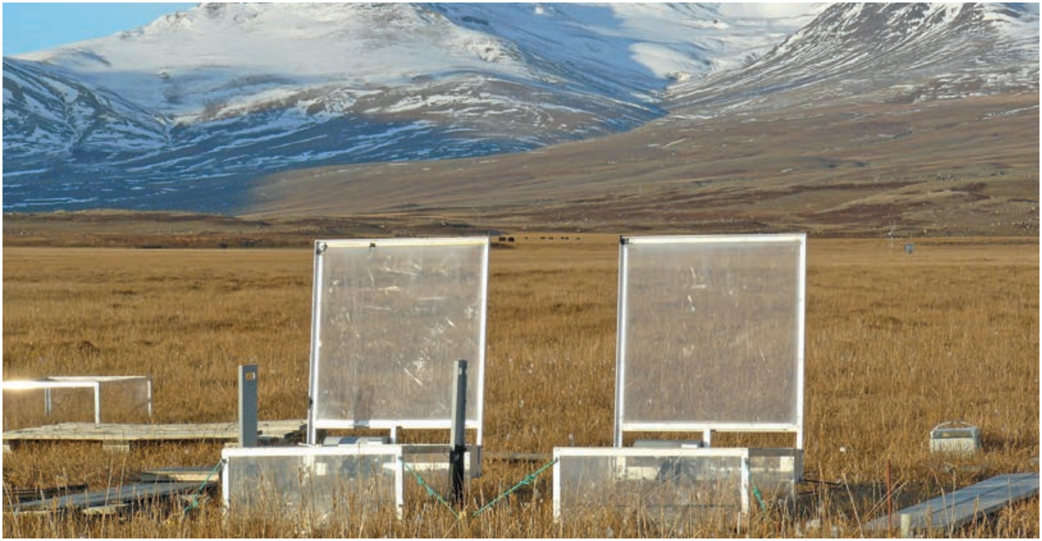
Fifteen years of continuous measurements on the frozen tundra show that methane is released from the soil during both summer and winter. Emissions of the very potent greenhouse gas come in waves, and are mainly governed by when the snow melts in the summer and the ground freezes in the autumn.

By: Peter Bondo Christensen and Signe Høgslund

The greenhouse gas methane is 22 times more potent than carbon dioxide, and there is therefore great interest in understanding where it comes from and how much is released into the atmosphere.

On the Arctic tundra between barren mountains, researchers have carefully been placing small plexiglass boxes above the low and sparse vegetation for fifteen years. Here, they regularly measure how much methane is released from the soil into the atmosphere.

The researchers have been to places where one would think that the cold and harsh climate would bring biology to a standstill. However, methane is continuously seeping from the deep-frozen Arctic tundra into the atmosphere, where it affects the global environment.



The researchers designed plexiglass boxes that automatically open or close several times a day. When the boxes are closed, the researchers can measure the amount of methane released by the Arctic tundra at Kobbefjord and at Zackenberg.

PHOTO: CHARLOTTE SIGSGAARD

Automated measuring stations monitor the release of methane

Methane is produced by bacteria in the spongy soils of the tundra. Using an ingenious system, researchers have managed to reveal new knowledge about the amount of methane being released from the Arctic tundra.

The researchers have constructed small, transparent plexiglass chambers covering 0.2 m^2 of the tundra. The chambers open and close automatically. While the lids are closed, a laser instrument measures the amount of methane that accumulates in the air above the tundra.

The entire system is controlled by a small computer powered by solar cells and wind turbines, so the researchers do not need to be physically present to perform their measurements. The system measures the release of methane once every hour 24/7 from the end of June to the beginning of November. And the researchers have been measuring the same small squares for 15 years.

"The GEM programme has now given us fifteen years of uninterrupted measurements of methane emissions from the tundra at Zackenberg Research Station in northeast Greenland," says Torben Røjle Christensen, who is professor at the Arctic Research Centre and at the Department of Ecoscience, Aarhus University, and who has been in charge of collecting the extensive data.

The measurements of the methane release are the longest time series from anywhere in the Arctic, and the detailed data set has provided the researchers with new and surprising insight into what controls the release of methane from the Arctic tundra.

Surprising autumn emissions

"We've long known that the tundra releases methane during the summer. When heat hits the tundra, the bacteria that produce methane accelerate their production. And some of this methane is released into the at-

Solar cells and wind turbines generate the power required to operate the researchers' test setups in the deserted areas.
PHOTO: MARCIN JACKOVICZ-KORCZYNSKI

mosphere. But the many years of measurements now show us that the amount of methane released, and the time at which it is released, vary significantly from year to year," explains Torben Røjle Christensen.

The date on which the snow starts to melt is primarily what controls the release of methane. Approximately 30 days after the snow has gone, the tundra responds with peak emissions of methane.

The time at which the snow melts has varied throughout the measuring period by more than a month, and therefore the time during the summer when the maximum methane emissions occur also varies considerably.

The ground temperature and humidity, as well as the composition of vegetation are other factors that regulate the production and release of methane. And the annual measurements show that the total summer release can be up to 4-8 times greater in some years than in others.

"We were very surprised when the measuring stations revealed that there are also considerable emissions of methane in October-November. This type of discovery only comes when you have the measuring equipment in place and can measure throughout the whole season and for several consecutive years," says Torben Røjle Christensen.

Soil humidity plays a significant role in the amount of methane released from the tundra. Here, Kirstine Skov is measuring the amount of methane from flooded soils.

PHOTO: LARS HOLST HANSEN

The bacteria do not produce much methane in the winter, and the methane released in the early winter is therefore not linked directly to the current production. It comes from gas produced in the summer that is pushed out of the tundra as it freezes.

The frost forces the methane out of the tundra's upper, active layer of soil. In the Arctic, permafrost is like a concrete floor that seals the soil downwards. So the methane can only go one way when the autumn frost sets in, i.e. up into the atmosphere.

Even in the winter, when the tundra is covered with a thick layer of snow, the tundra releases methane. The researchers have measured the amount of methane through a 1.3-metre-thick snow cover, and can thereby assess that 15% of the annual emissions of methane from the tundra come during the snow-covered period. However, the researchers are still not sure how much of this methane finds its way up through the snow into the atmosphere.

Important part of the international climate debate

"We need many years of data. And we need to be on-site far into the Arctic winter to draw the full picture of the emissions of methane from the tundra," says Torben Røjle Christensen.

The many years of measurements have provided the most comprehensive data in the Arctic. The data has been included in the international models and reports to assess how the climate will change in the future.

In the future warmer Arctic, the permafrost in the tundra will slowly thaw, and how this will affect emissions of methane is an open question on which the researchers are now focusing.

The small plexiglass boxes on the Arctic tundra will continue to generate data that may give us a better understanding of the complex interplay regulating the global climate.

Further information:

Professor Torben Røjle Christensen, Arctic Research Centre and Department of Ecoscience, Aarhus University
Mail: torben.christensen@bios.au.dk;
Phone: +45 9350 9049

The many musk oxen in northeast Greenland gently graze around the researchers' test setups.
PHOTO: LARS HOLST HANSEN

KOBBEFJORD REVEALS INFORMATION ABOUT WATER MASSES OFF THE COAST OF GREENLAND

Climate change means that Greenland's coasts are experiencing greater fluctuations in the amount of freshwater flowing from land. Researchers are following developments closely in Kobbefjord near Nuuk, and now they can contribute detailed knowledge about how climate and weather fluctuations affect water volumes in different rivers.

By Signe Høgslund and Peter Bondo Christensen

A 55 m^2 brown field station stands at bottom of Kobbefjord, close to the river, the fjord and Kangerluarsunnguup Tasia, Badesø. The cabin is the base for extensive research and monitoring activities, and researchers are investigating the effects of climate change on nature on land, as well as life in the water and in the air.

"The monitoring programme in Kobbefjord is unique in the Arctic. The location is almost in our backyard, so we can follow nature all year round. This provides us with detailed knowledge on the relationships between climate and nature," says Katrine Raundrup from the Greenland Institute of Natural Resources, who is the project manager of the NuukBasic monitoring project.

One of the things being measured intensively is freshwater inflow.

Knowledge about water

Over the course of twelve years, researchers from Asiaq – Greenland Survey have measured the amount of freshwater flowing into Kobbefjord.

"We know that freshwater run-off into the Greenlandic fjords is changing. Our measurements from Kobbefjord can now give us a more detailed picture of what regulates the run-off," says Jakob Abermann, a researcher at the University of Graz, Austria and Asiaq, Nuuk.

For several years, there has been a great deal of focus on the run-off that takes place when the ice sheet melts in step with the warmer climate. On the other hand, there has not been much research into the inflow of

Measuring how much water is flowing in the river at Kangerluarsunnguup Tasia requires concentration, attention to detail and caution. PHOTO: ASIAQ freshwater from the ice-free catchment areas or areas with small glaciers.

"That's why we've set up stations to measure the water level at four different locations in Kobbefjord. The stations cover four different catchment areas for the fjord. So we know how changes in the weather and climate in the different types of catchment areas affect the flow in the different rivers," explains Kirsty Langley, a researcher at Asiaq and project manager of ClimateBasis, which is responsible for the hydrological studies in Kobbefjord.

Kobbefjord as a natural laboratory

Knowledge about the water inflow to Kobbefjord is linked to the other research activities in and around the fjord. Among other things, the researchers are monitoring changes in snow conditions, soil humidity and temperature, as well as emissions of climate gas from the soil.

The large algae in the intertidal zone of the fjord are also being surveyed. How do they grow? Does the composition of species change? Out in the fjord, the researchers are monitoring life at the bottom of the sea, including conditions for benthic fauna, and the amount of material converted in the fjord seabed.

Amounts of salt, light and nutrients help to determine the current state and changes in the fjord. In this context, rivers play an important role. They contribute freshwater, particles that shade the light, and nutrients that are more or less readily accessible to the organisms in the fjord.

Large differences within a short distance

The strategy of measuring several tributaries to the fjord has proved successful. The 12 years of data shows that the dynamics of the four rivers are completely different, even though they are only 15 km apart.

"The many measurements have shown us that differences in precipitation and sunlight, for example, have very different effects in different rivers. Sunny days in particular cause major differences in water inflow," says Jakob Abermann.

When the snow melts on warm days, a pulse of freshwater is formed. However, there are big differences in how quickly this pulse shows up in the four rivers, and the maximum inflow of water varies by up to half a day between the different systems. On a large scale, this means a lot for the dynamics of the fjords of Greenland.

Knowledge about the amount of freshwater flowing into the fjord can be used to understand the biological relationships being surveyed in the fjord.

During very heavy downpours, the researchers have seen more particles in watercourses and rivers, and these particles flow out into the fjord. And more heavy precipitation events like these are likely in the future.

From Kobbefjord to all of Greenland

If the researchers are to be able to predict how Greenlandic fjords will be affected by more precipitation in the future, for example, the measurements in Kobbefjord show that they will need to take into account far more elements than they had previously believed.

The research station in the bottom of Kobbefjord is a hub for monitoring climate and biology in the fjord.
PHOTO: KATRINE RAUNDRUP

The measurements will now be used to refine the models to predict the amount of freshwater that will flow into the Arctic fjords in the future.

“If we can get the models to reproduce our data, we can also predict what will happen to the fjords in the event of a future with more precipitation or more hours of sunshine, for example. This will bring our knowledge from Kobbefjord into play on a large scale to make models for all of Greenland,” says Kirsty Langley.

Over the next few years, data from Kobbefjord will provide insight into the total freshwater flow into the sea around Greenland.

A 55 m^2 field station does not take up a lot of space in Kobbefjord, but continuous data from this type of station in Nuuk, Disko and Zackenberg will tell us more about how nature in Greenland reacts to a warmer climate.

Further information:

Kirsty Langley, scientific programme manager
ClimateBasis Nuuk, Asiaq – Greenland Survey
Mail: kal@asiaq.gl; Phone (+ 299) 34 88 61

Jakob Abermann, researcher at the University of Graz, Austria and Asiaq, Mail: jakob.abermann@uni-graz.at
Phone: + 43 316 380-8302

Kobbefjord primarily receives freshwater from four different rivers, and ice is formed in the fjord during the winter. PHOTO: JAKOB ABERMANN

PHOTO :DORTE H. SØGAARD

NINE-DAY FEAST UNDER THE ICE: TINY ALGAE LIVING AS BOTH PLANTS AND ANIMALS GIVE LIFE A BOOST IN THE ARCTIC FJORDS

Researchers found it hard to believe their own figures when they saw the results of their measurements in northeast Greenland. Over nine spring days, phytoplankton in the fjord had absorbed half of the amount of carbon that the algae normally absorb during an entire growing season. And this was despite the fact that sea ice still covered the fjord. This led the research group on to a new key player in Arctic fjords, where the ice is getting thinner and thinner.

By Peter Bondo Christensen and Signe Høgslund

Microscopic phytoplankton are invisible to the naked eye. Yet, they are the bedrock that ensures food for all living creatures in the sea, from tiny crustaceans to massive whales.

Phytoplankton need light and nutrients to grow, just like houseplants on a windowsill and berries on a mountain. Algae, houseplants and all other plants grow through photosynthesis, absorbing carbon dioxide using sunlight.

A thick layer of sea ice – sometimes covered with snow – prevents the sun from penetrating into seawater under ice, thereby cutting off light from the algae to photosynthesise. But the sea ice is becoming thinner and thinner and it is melting earlier so that more and more light can penetrate down into the water.

Does this mean increasing amounts of phytoplankton, and thus food for more fish, whales and seabirds in the future Arctic? Researchers still do not have a clear answer to this question.

Plant or animal? Mixotrophic algae are somewhere in between

More light in the sea only generates a higher production of phytoplankton if there are enough nutrients – and this is often not the case in Arctic waters.

As the Arctic thaws, more and more fresh and nutrient-poor water is running out into the fjords and further into the sea. This lighter, fresher water forms a layer on

When the researchers move about the melting sea ice, they have to edge around the large melt ponds. A sled is useful for transporting the many measuring instruments and a rifle is compulsory if a polar bear shows up.

PHOTO: BJARNE JENSEN


PHOTO: BJARNE JENSEN

top of the saltier water like a lid, preventing nutrients from the bottom layers from penetrating to the surface where there is enough light for the phytoplankton to be active.

However, a new study from northeast Greenland has shown that so-called mixotrophic phytoplankton could play an essential role in the production of food in the Arctic Ocean.

Mixotrophic algae are small, single-celled phytoplankton that can both photosynthesise as plants but also get energy from eating other algae and bacteria. In other words, they can live like animals. This allows them to stay alive during the Arctic winter, when photosynthesis is limited by the very poor light and low concentrations of nutrients in the water. This means that they are ready to grow and photosynthesise when a little sunlight finally penetrates into the sea.

"Many mixotrophic phytoplankton can live in almost completely fresh water with very low concentrations of nutrients: the very conditions that will exist in the water layers close to the sea ice in Arctic waters just before it melts in the spring of the future," explains Dorte H. Søgaard, a postdoc from the Greenland Climate Research Centre, the Greenland Institute of Natural Resources and the Arctic Research Centre at Aarhus University, who lead the studies.

Explosive growth under the ice

As part of the marine monitoring under the GEM programme, a research team travelled to northeast Greenland to measure the production of phytoplankton un-

Dorte H. Søgaard, postdoc at the Greenland Institute of Natural Resources, has headed the studies of the mixotrophic phytoplankton. Here, she is studying a sample of the sea ice collected by the researchers.

PHOTO: DORTE H. SØGAARD

der the sea ice in Young Sound, a high Arctic fjord located near Daneborg. They intensively measured algae production throughout July and this resulted in surprising data.

During the last nine days before the sea ice broke up, several large melt ponds spread across the surface of the sea ice. Melt ponds make the ice more transparent so it is easier for light to penetrate to the water under the ice. And the researchers were right there when it happened, and saw for themselves how the mixotrophic algae instantly began to bloom under the sea ice.

The mixotrophic algae actually represented up to 60% of all the phytoplankton under the sea ice. This was very surprising, as it was the first time a bloom of mixotrophic algae had been measured under the Arctic sea ice.

"We measured the algae production over nine days until the sea ice broke up. And during this short period, the sub-ice algae produced up to half of the total annual plankton production in the fjord. Therefore, in order to understand the ecosystems of the Arctic fjords, it is crucial that we include this sub-ice production in the equation," says Dorte H. Søgaard.

New, complex food chains in the Arctic Ocean

As freshwater inflows increase in the Arctic Ocean, mixotrophic algae could become very important for the Arctic food web, and they may represent a large part of total production of food in areas in which the run-off of fresh water from land affects the salinity of the sea and limits the amount of nutrients in the surface.

"Mixotrophic algae's ability to capture prey while also carrying out photosynthesis gives them a great advantage in an Arctic Ocean that is becoming increasingly fresh and where the water stratification is becoming stronger. This could change the entire Arctic marine food web as we know it," says Dorte H. Søgaard.

The algae belong to a group called haptophytes. Many of these algae are toxic, and in northeast Greenland they bloomed in quantities previously found in the Skagerrak near the southern part of Norway. Here, the toxic phytoplankton have killed large numbers of salmon in Norwegian salmon farms.

Further information:

Dorte H. Søgaard, postdoc
Greenland Climate Research Centre
Greenland Institute of Natural Resources and the Arctic Research Centre at Aarhus University
Mail: doso@natur.gl; tPhone: +45 6116 4226.

Read the researchers' article here:

www.nature.com/articles/s41598-021-82413-y

When the Arctic spring sets in, the metre-thick sea ice begins to melt. Melt ponds on the surface of the ice bring so much sunlight into the underlying sea that mixotrophic phytoplankton begin to grow vigorously.
PHOTO: DORTE H. SØGAARD

GEM DATABASE

GEM data is a free and open data source making data available for international research and educational purposes. Data from the monitoring programs at Zackenberg/Daneborg, Nuuk/Kobbefjord and Disko can be found at http://data.g-e-m.dk


PHOTO: KATRINE RAUNDRUP

For more information:

The GEM Secretariat

Department of Ecoscience

Aarhus University

Frederiksborgvej 399

DK-4000 Roskilde

Mail: g-e-m@au.dk

GEM website: www.g-e-m.dk

GEM database: http://data.g-e-m.dk

WWW.G-E-M.DK