Newfoundland Field Test

Research summary report

2025



ARCTIC REFLECTIONS



Test site Newfoundland 2025

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1. Introduction

This report outlines our most recent research conducted in Newfoundland while considering our past research and current mission.

Motivation

The Arctic is warming 3-4 times faster than the global average, and this has reduced the Arctic sea ice volume already by 75 percent over the last 40 years. Even in the most optimistic decarbonization scenarios, the Arctic Ocean is predicted to experience ice-free summers before 2050. Without the perennial sea ice blocking the heat from the sun, the Arctic Ocean will warm, accelerating the climate crisis and potentially leading to a series of devastating climate tipping point.

Our mission

Arctic Reflections is an impact-driven startup with the moonshot mission to restore Arctic sea ice to counter global warming. With our climate cooling approach, sea ice thickening, we explore the benefits, as well as the risks, of pumping seawater from below the sea ice onto its surface during the freezing winter months. The hypothesis, which we are testing by flooding the sea ice surface, consists of two parts. The first is to promote ice growth from the top, which directly harnesses the frigid air and circumvents the self-insulation of the existing ice cover. The second is to reduce the highly insulative snow layer on the ice surface, which can potentially accelerate bottom growth of the ice cover. By thickening the sea ice, we seek to determine whether we can preserve Arctic summer sea ice and its natural reflectivity. Thickening the sea ice may also help unique Arctic wildlife and local Inuit communities who crucially depend on the sea ice for their way of life.

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2. Executive summary

Sea ice thickening – pumping water on the sea ice surface in winter, to accelerate freezing and have more reflective ice left in summer – is a climate intervention technique which can preserve summer sea ice and slow down the warming of the Arctic, while decarbonization proceeds.

Arctic Reflections, a Dutch-Canadian impact-driven startup, conducted a field test on sea ice thickening in subarctic Canada, to test a novel pumping platform and assess sea ice thickening in conditions which may reflect the Arctic in a warmer future.

We successfully thickened 9 hectares of ice by 10-25 percent, which was 10x larger than the previous field test in Svalbard.

Due to challenging weather conditions, such as rain and above-freezing temperatures, assessing if sea ice thickening made the ice last longer versus a control site proved difficult.

However, the thickened sites were clearly visible from space and marginally whiter than their surroundings once the snow cover was absent in the melting season, validating a phenomenon noted in earlier field tests.

Surprisingly, the flooded sea ice area below the snow layer, as inferred from thermal images, turned out to be 50 percent larger than the area inferred from the optical images, highlighting the novelty and effectiveness of applying aerial drone imaging with optical and thermal capabilities.

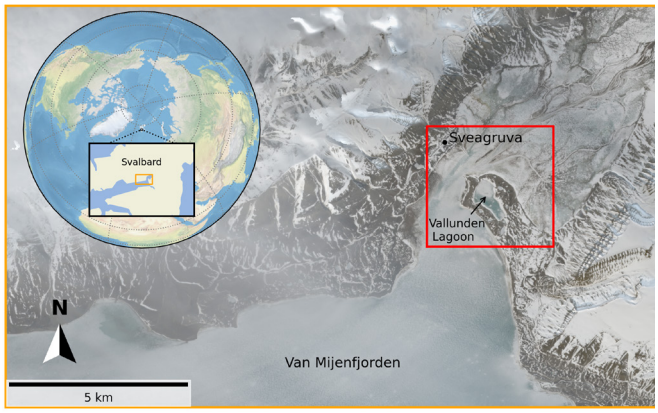
We learned many lessons in operations and logistics, which will improve our future field tests.



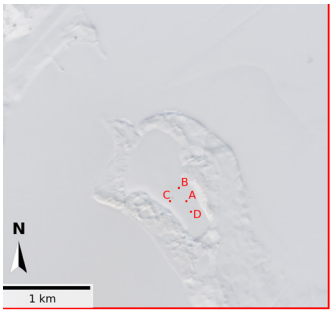
Co-founder Tom Meijeraan with one of the pumping platforms

3. Svalbard '24 : Lessons from the last field test

From March to June 2024, in collaboration with Delft University of Technology and the University Centre in Svalbard, we conducted a field test in the Vallunden lagoon near Sveagruva, Svalbard. We installed measurement stations to remotely monitor data such as ice temperature and thickness, solar irradiance, and weather conditions. Additionally, we drilled dozens of ice cores to investigate ice salinity and density. Small ice road flood pumps (EMV-160) were used to flood the snow in and around the measurement stations over the course of several days.



Map Vallunden lagoon





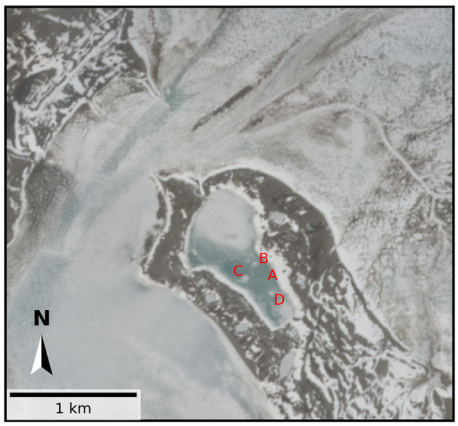
Test sites Vallunden lagoon

We found that our few hours of flooding, with a flowrate of about 210 m^3/h, each day at each site resulted in roughly a 25 percent increase in ice thickness at the center of the flooded sites. The total thickened surface area was about 1 ha. Surface albedo reduced during flooding but quickly rebounded when the sites were covered again by drifting snow. Ice salinity in the flooded layer shortly after was higher than typically seen in natural sea ice. The ice temperature was higher during and some time after flooding due to the heat from the floodwater, but cooled after that. The ice density in the flooded layer was slightly lower than typically seen in natural sea ice.



Svalbard flooding: small flood pumps were used to thicken the ice at the measurement stations

During the melting phase, over the period of about one week, the thickened sites were observably whiter than the control site, as seen in both satellite and local timelapse camera images; this disparity was also recorded by radiometers installed on the sea ice, showing a higher albedo in the thickened sites. Notably, the vertical melting rates between the thickened and control sites were found to be similar.



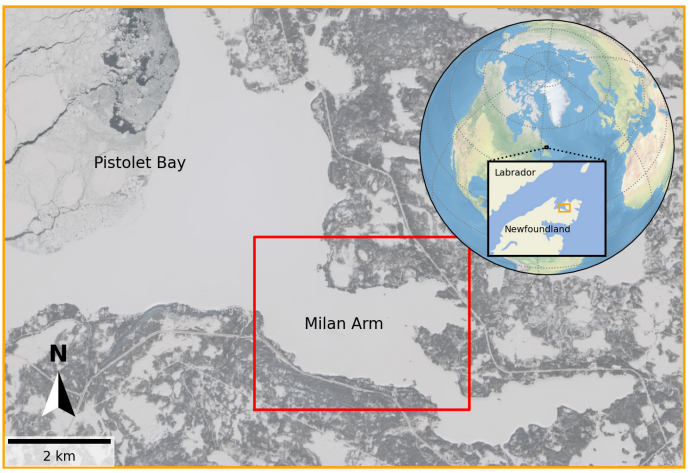
Ice from space: The thickened sites were visible from satellite in the melting phase

Ultimately, all ice broke up and washed away within two days due to a combination of wind, waves, warm inlet water from the fjord, and the rottenness (i.e. structural disintegration) of the sea ice. But prior to breakup, the ice at the thickened sites was colder than the control site, and therefore less rotten during the melting phase.

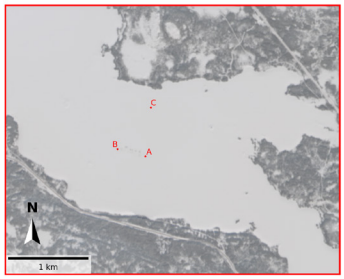
4. Newfoundland ‘25 : The latest from the field

This time we conducted a field test in the Milan Arm of Pistolet Bay in northern Newfoundland, Canada between February and May 2025. We installed new and improved measurement stations, and used larger, custom-made flood pumps. The scale of the operations was much larger, both in time and space than in our previous Svalbard field test. Though not in the Arctic, northern Newfoundland was selected to derisk the logistics, while applying the local knowledge of the sea ice conditions from our team. It also offered the opportunity to work with very variable weather conditions, which might mimic the conditions of the Arctic in the future.

As part of our mission of transparency, we have published a Data in Brief article from this field test in Newfoundland which outlines our methods and describes the data we collected.



Map Pistolet Bay





Test sites Pistolet Bay

4.1 Our setup

For our scientific equipment, we installed three measurement stations, each equipped with a thermistor chain system, radiometer and data logger, and a timelapse camera. Sites A and B were thickened, and Site C was the control site. At Site B, we also installed an anemometer. These instruments were mounted to a buoy and wooden support frame, which were anchored to the ice cover by ice screws. The measurement stations were designed to monitor the snow and ice cover thicknesses and temperatures, solar irradiance, weather conditions, and other observations such as flooding, melt pond evolution, and sea ice breakup. We also complemented our local measurements with images from the Sentinel-2 satellite, which were accessed via the Copernicus Browser and Sentinel Hub.

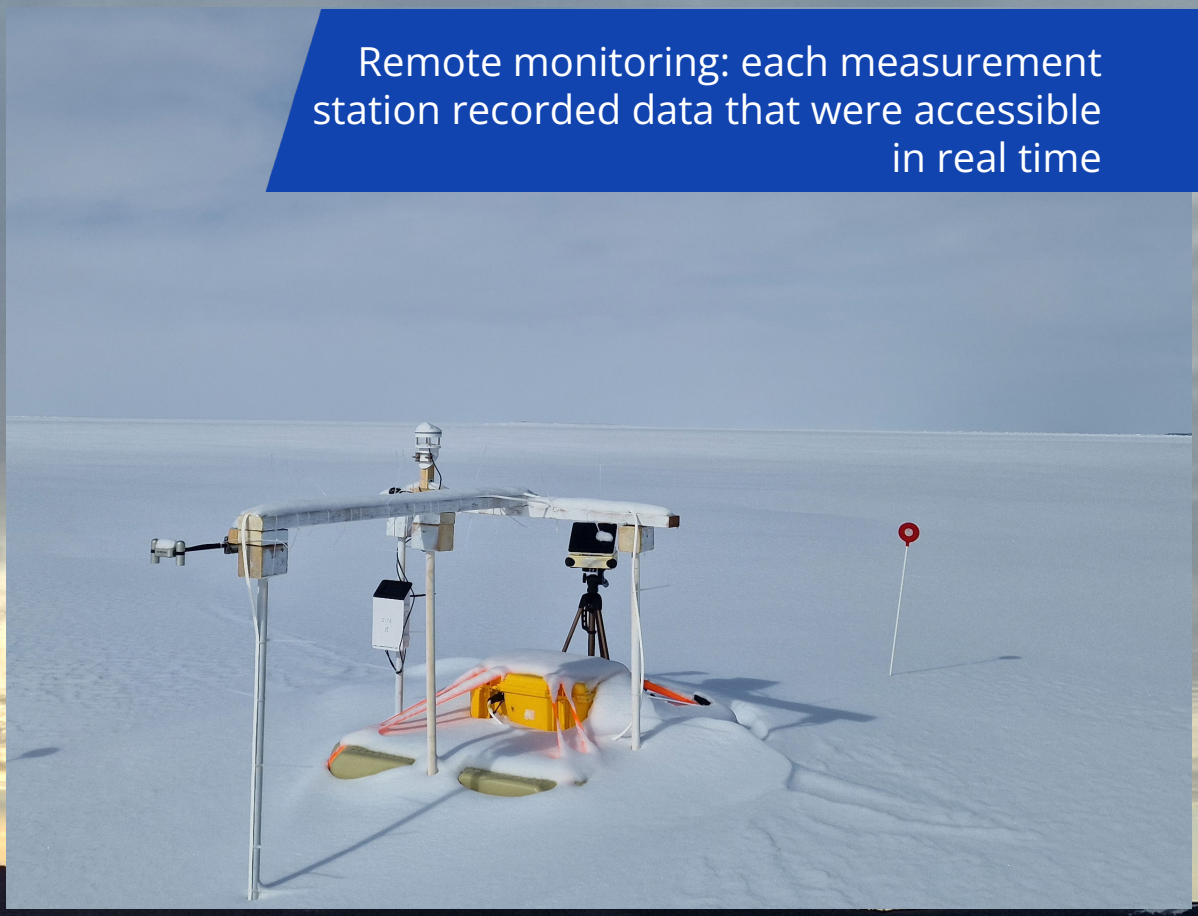
We also collected manual measurements of snow and sea ice thicknesses, ice temperature and salinity from ice cores, and slush composition from flooded areas. From the sky, our aerial drone recorded images of the flooding operations in both optical and thermal vision. For our flooding operations, we designed and assembled a mobile pumping platform, or Icemaker. We had two Icemakers, consisting of an amphibious vehicle called the Fat Truck 2.8 Wagon, an amphibious trailer, a self-contained hydraulic lifting and skidding system, an ice auger and a custom-made flood pump (Erikssons Mekaniska Verkstad AB).

The lifting and skidding system, located in the trailer, permitted the transportation and deployment of a customized 12-inch (30 cm) ice auger and the flood pump. The Fat Truck and trailer offered a safe and reliable mode of transport across the ice cover.



Icemaker pumping seawater next to one of the measurement stations

Remote monitoring: each measurement station recorded data that were accessible in real time



4.2 First impressions

Prior to deployment of our Icemakers, we surveyed the sea ice and performed dozens of ice thickness measurements, ensuring that the ice was sufficiently thick (42-54 cm) for safe operations on the ice cover. Confronting a subarctic climate, we noted the variability in the snow cover (0-30 cm), which was a product of liquid and frozen precipitation, strong winds (averaging 20 km/h with gusts as high as 55 km/h), and fluctuating temperatures (from -30 °C at night to about 6 °C during the day, averaging -7 °C). Visibility was occasionally a safety challenge when wind and snow conditions were severe.

While taking the snow and ice thickness measurements and installing the snow markers, we noticed the abundance of wildlife in the region. Onshore, tracks from moose, reindeer, lynx, hare, and birds were prevalent at the tree line. Evidence of seals was found some distance from the operations site on the sea ice. As part of our preparation and permitting, we had consulted local fishermen on wildlife prevalence, and during our field test operations, we took extra care to avoid operating in the vicinity of wildlife and their habitats.

Given the spatial and temporal variability in snow depth and compactness, we decided to survey a 25 by 25 m area near Site C to get a better picture of the snow properties. We found that, in that area, the snow was between 10-25 cm deep and had a density between 200 and 480 kg/m^3. The snow density varied not only in space but also with depth, the denser snow typically found near bottom of the snow cover.



Snow dunes: wind drives the formation of snow dunes, called sastrugi, which constantly change

4.3 Pumping water on the go

Deployment of the Icemakers in the Operations Phase proved to be a laborious but productive endeavor. During operations, each Icemaker was moved to a specific site, the frame was skidded out, and a borehole was drilled into the ice. The pump was lowered into the borehole and pumping commenced. Seawater from under the ice was pumped onto the surface through a water jet, flooding the snow cover.

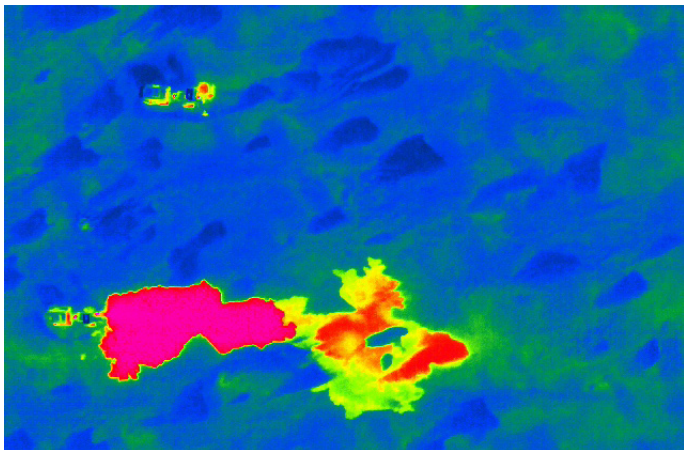
The water was thrown about 3-4 m and caused local erosion of the snow upon impact. The floodwater spread outward over time, initially in the direction of the water jet. With the combination of deep snow, moderately thin sea ice, and high flowrate of the pump (300-700 m^3/h), the floodwater tended to pool and deepen near the Icemaker. The average flooded area from a single session amounted to roughly 1000 m^2. Pumping sessions tended to be 10-30 min, depending on the snow conditions and direction of water distribution. Once finished, the boreholes were plugged with snow or covered with a bucket to reduce floodwater drainage. The buckets were removed once the flooded areas froze. In total, we flooded approximately 0.1 km^2 or 9 ha of sea ice in 84 flooding events over six days. With the previously mentioned flowrates, and with a total of 18.5 h of pumping, we estimated a total flooded layer of 6-14 cm over that area. These values correspond well with our thickened ice measurements, discussed later.

Wind and seawater jet directions did not appear to determine how the water distributed over and through the snow after about a minute or two; rather, the snow depth and topography were the most prominent influences on widespread floodwater distribution.

On days with thick snow cover, the floodwater pool tended to become as deep as 40 cm at the erosion site near the pump. This depth included the combination of ice bending, local snow erosion, and pooling of the floodwater. On occasion during flooding, cracking could be felt and heard as the ice bent under the weight of the water, and a few circumferential cracks were observed. In cases when the floodwater began to spread toward the Icemaker, we shoveled snow dams to slow the flow.



Two consecutive pumping sessions as can be seen optically (above) and thermally (next)



On one particular day, 9 March, with about 5 cm of snow depth, the floodwater spread up to 80 m and remained shallow (<15 cm), highlighting the impact of snow depth on floodwater distribution. These observations emphasized the importance of the effect of snow depth on floodwater distribution, which warrants further study.

> **“ Our Icemakers made drilling and pumping with large pumps a swift process**
> - Cody Owen

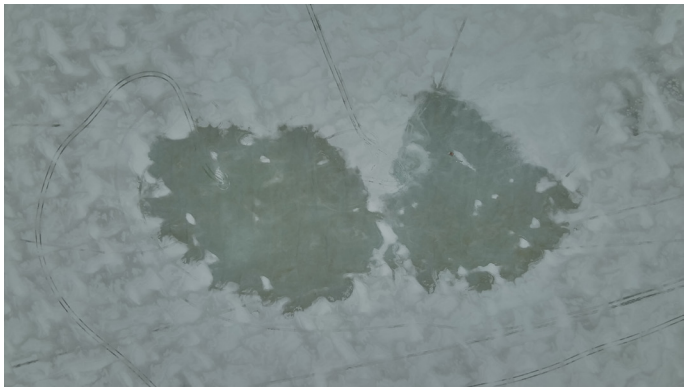
Flow through snow

To estimate the direction and spread of pumped water during each session, and to evaluate how snow and ice surface composition, environmental conditions, and pumping duration influenced flow distance and subsurface (i.e. beneath the snow surface) water transport, a series of optical and thermal images were captured during and several days after pumping with the aerial drone. Across all sites, thermal imagery captured a total flow area of approximately 9 ha, or 50 percent more than the 6 ha from optical images, indicating that water often traveled beneath snow surface beyond visible detection. The pump sites ranged between 60 m^2 to 7000 m^2 in area.

In many cases, especially when natural lighting was insufficient, thermal images proved to identify the pumped areas more clearly. However, after a few days (depending on the environmental conditions) when a thick layer of ice formed on the pumped areas, the thermal images could no longer be used to identify the pumped areas. The larger flooded area observation from thermal imaging was confirmed by manual measurement transects of snow, slush, and ice composition through select flooded sites some days after flooding. Manual probes confirmed the presence of slush underneath the snow of distances ranging from 4 to 14 m from the visible pumped area.

We did not observe a clear time dependence for the difference in visible compared to pumped area under the snow surface. On the one hand, the wetted area could become larger over time, because water would keep permeating underneath, further increased by the deflected ice rebounding slightly over time. On the other hand, the area could become smaller over time, due to water drainage through the borehole if that was not adequately plugged.

Preliminary investigation was carried out on snow channeling for improving floodwater distribution, but this proved challenging without more dedicated equipment. Specific snow channeling and trenching experiments are planned for the future.



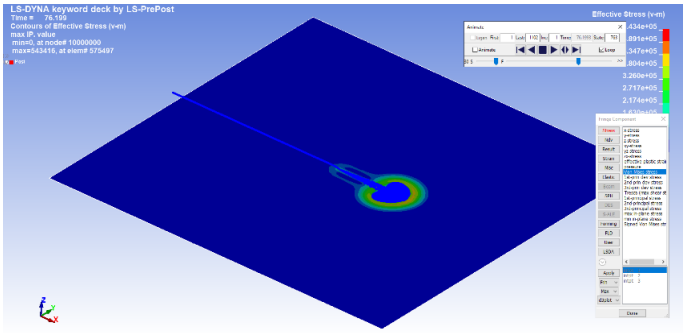
Aerial view: Pumping sessions with little snow depth means larger flooded areas.

Modeling the flow

The flow of water over ice is a critical factor in the operational planning and safety of activities where water is pumped on ice surfaces. Understanding this process is essential for evaluating the scalability of ice thickening as a method for forming thicker and more stable ice layers over large areas when pumping from a single location. A key parameter in this context is the distance that water can travel across the ice surface, particularly when a snow layer is present, as snow significantly alters flow behavior and infiltration. To investigate this phenomenon, a series of Smoothed Particle Hydrodynamics (SPH) numerical simulations were performed to model the flow of water over sea ice under varying environmental and physical conditions, which is the topic of a separate paper.

The numerical modeling captured the effects of surface roughness, snow porosity, and ice deformation under hydraulic loading. The modeling approach consisted of two phases: channel flow simulations for calibration, and large-scale flow simulations over ice. In total,

47 simulations were carried out, systematically varying static and dynamic friction coefficients and viscous damping to assess their impact on flow velocity, turbulence, and pressure distribution.



Modeling: Snapshot of water flow over ice simulations

The simulation results revealed that ice bending under water weight and snow layer thickness strongly influence water spreading and pooling patterns across the ice surface. Under favorable conditions, up to 1900 metric tons of seawater could be safely added on smooth ice of 1 m thickness with a 5 cm snow cover, while rough or thicker snow limited this to 550–800 metric tons.

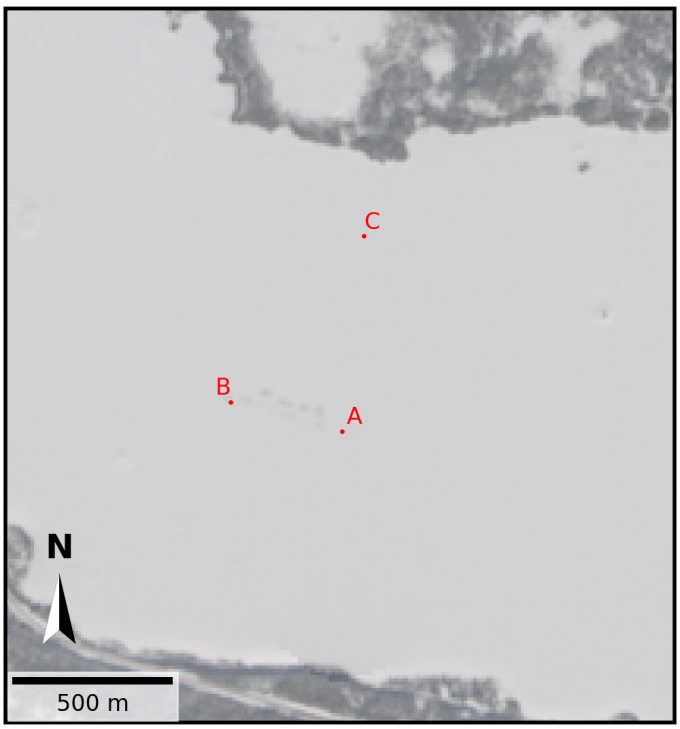
Ongoing simulations with 0.5 m-thick ice, informed by the Newfoundland field data, aim to verify these findings against experimental data, establishing a robust modeling framework for future large-scale ice flooding projects. Initial results indicate that reducing the ice thickness from 1 m to 0.5 m reduces fivefold the safe pumping time.

> “ The model simulation results were instrumental in allowing us to safely operate on the ice
>
> - Soroosh Afzali

4.4 Lasting impressions

Due to the relatively warm air temperatures and drifting snow, our flooded sites sometimes took several days to freeze. As each flooded site began to freeze, a top layer of ice would form that would soon be covered with snow. Beneath this cover was a slush layer with a mixture of snow and floodwater that progressively solidified. Once this slush became ice, we could then measure the total ice thickness, including the newly formed ice. Based on the ice cores and thermistor chain readings, we found that we added about 10 cm of snow ice (ice made from the flooding of snow) to Sites A and B, a roughly 20 percent increase in ice thickness.

The thickened sites were visible from space, both during the Operations Phase and what we called afterwards the Warming Phase and the Melting Phase.



View from space and drone: Flooded areas were visible the day after pumping

Snow dams were used to reduce flooding around the Icemaker



Into the ice

Flooding of the ice during the Operations Phase caused some warming of the upper part of the ice cover, but the warming was minimal (<0.5 ℃) due to the relatively high air temperatures and correspondingly high ice temperatures in the upper part of the ice. The ice at Site C, the control site, was colder on average than at the thickened sites by about 0.5 °C between 1 and 6 March. This difference was eliminated by the rain on 7 March.

Surprisingly, significant warming and rain on 7 March, during the Operations Phase, led to natural flooding and thickening of all sites, including the control site, by around 10 cm of additional ice thickness when measured on 9 March.



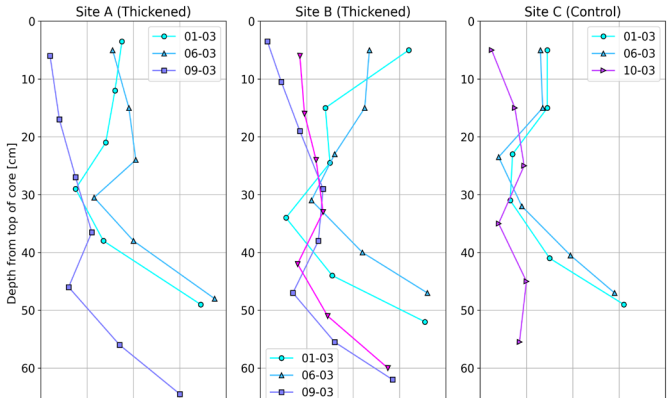


Snow to rain: Site C went from cold snow on 5 March to warm slush on 7 March (above and below)

Unfortunately, this natural thickening made comparison between the thickened sites and control site ambiguous. However, what was very interesting was the effect of the natural flooding on ice temperature and salinity.

The rain and warm air raised the mean ice temperature at all sites by at least 0.5 °C, with the greatest increase occurring at Site C with about 1 °C of warming. Additionally, the introduction of rain caused the salinity of the top 20 cm of the sea ice at all sites, even the control site, to decrease by at least 60 percent when measured between 9 and 10 March. The rain appeared to have partially melted the top surface of the ice and snow cover, and and then mixed with the briny slush, reducing the salinity of the snow ice which later formed on top of the natural sea ice. Note that bulk salinity of the sea ice was typical (1-7 ppt) prior to flooding.

After flooding, during the freezing of the floodwater, the floodwater (sandwiched between the congelation ice below and the newly formed snow ice on top) salinity was high (44-47 ppt; seawater salinity in Milan Arm was 32-34 ppt) beneath an initial ice layer which rejected brine into the water below. Following the warming and natural flooding from rain on 7 March, the upper 20 cm of the ice at all sites had a significantly lower salinity. The bottom 20 cm of the sea ice appeared unaffected by the natural flooding.



Bulk salinity profiles of the sites during the Operations Phase

On 9 March, due to the above-freezing air temperature and cold seawater, pumping at Site B led to a slight cooling (0.5 °C) of the ice that lasted for at least one week while Sites A and C warmed.

We also collected and prepared ice cores and seawater samples for ecological analysis. While the results were difficult to interpret due to the limited number of ice cores and the absence of a baseline, the gained experience will be useful to properly conduct future experiments to assess the influence of ice thickening on microbial life.

> **“ Local insights helped us mitigate potential impacts on wildlife**
> - Tom Meijeraan



Sea ice cores: In situ ice temperature and later salinity measurements were core data



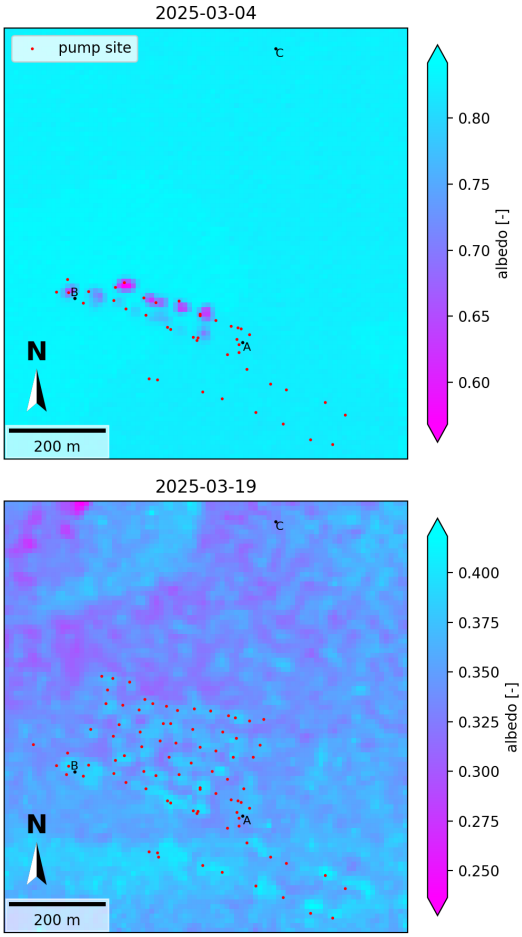
Life in sea ice: Analysis by Waardenburg Ecology revealed microscopic life in the sea ice and water

Surface reflections

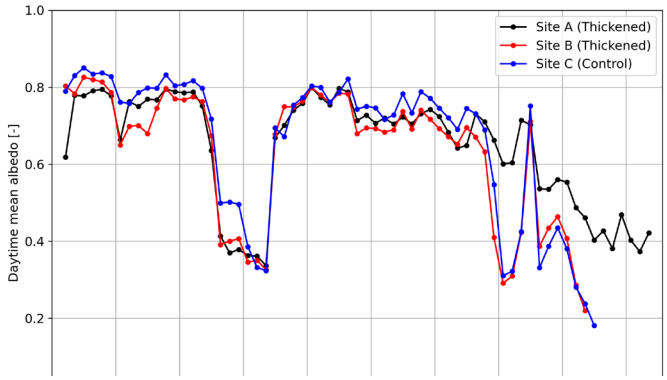
The albedo of the surface across all sites was generally similar throughout the measurement period. Albedo was temporarily lower during and immediately after flooding occurred at the thickened sites, but freezing of the surface and snow drift recovered the albedo within half a day or so. Snow depth varied between the sites, which led to differences in lowered albedo during the rain event on 7 March. Sites A and B had less snow depth than Site C due to artificial flooding in previous days.

The natural flooding, though at all sites, led to a greater thickness increase at Site C as observed in the delayed albedo decrease and by visual confirmation with the timelapse camera. The higher snow depth at Site C mixed with the rain and formed thicker snow ice than that at the other sites.

A significant albedo drop occurred on 18 March during another rain event and continued during several days of above-freezing temperatures which melted or mixed with the snow and later reformed as snow ice by 23 March. Snowfall recovered the albedo on 24 March.



Albedo maps during the Operations Phase (4 March) and Warming Phase (19 March) from satellite images



Albedo over time influenced by flooding, rain and warming and melting

Cold, snow-covered sea ice had an albedo of 0.8 on average, which is typical. Rain-induced flooding caused the albedo to drop to about 0.4 (typical of melt pond on sea ice) but quickly recovered to 0.8 once the surface froze and snow drifted over the site.

The albedo consistently dropped below 0.8 from 2 April onward, due to a mixture of freezing rain and warmer air temperatures. Consistent melt pond coverage at Sites B and C from 15 April onwards led to an albedo around 0.4, with a short period of refreezing and snow coverage on 21 April.

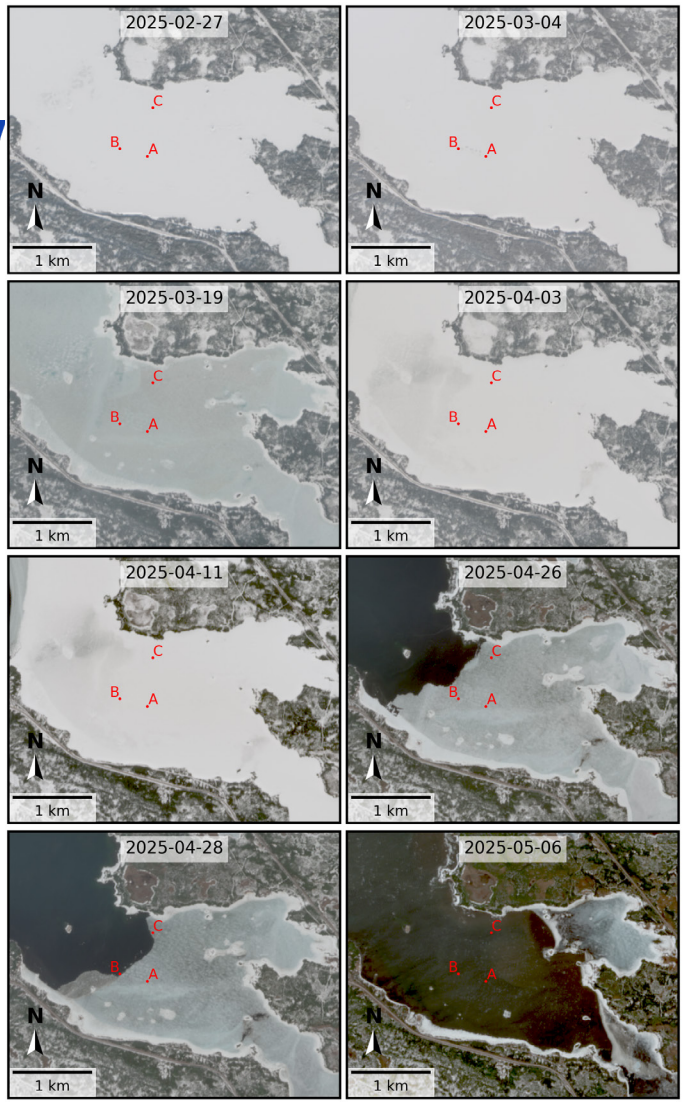
Based on the higher albedo values at Site A, it can be inferred that the surface melt and melt pond formation was delayed when compared to Sites B and C. It is speculated that this delay was caused by Site A being farther from Pistolet Bay and the retreating ice edge, but the exact reasons are unknown.



Low albedo: Melt ponds on 18 April at Site B

End of a season

Although the effect of ice thickening was visible from satellite, this did not clearly lead to longer-lasting ice cover. The sea ice in Milan Arm broke apart mechanically, starting from Pistolet Bay at the end of March and proceeding into Milan Arm by the end of April. All sea ice in Milan Arm was gone by the middle of May.



Sentinel-2 satellite images of the region over time showing the change in snow and sea ice coverage during and after the field test

> **“ We successfully increased our sea ice thickening area by tenfold in Newfoundland compared to our field test in Svalbard -** Fonger Ypma

5. Conclusions

These field tests in Newfoundland have provided us with a wealth of data and practical operational and logistical experience about a somewhat larger scale of ice thickening experiment.

While the subarctic conditions, with very variable temperatures and precipitation (both snow and rain), were useful to research ice thickening in extreme circumstances, they were less suitable for reliable experimentation to assess the longevity of thickened versus un-thickened sea ice.

Going forward, we will continue to collect even more comprehensive data on the impact of ice thickening on sea ice longevity for the sake of validating ice thickening as a robust climate intervention.



6. Future Research

This leaves several key questions for our future research:

- How effective is flooding the snow layer at disrupting the thermal insulation of the snow and accelerating bottom ice growth?
- How and at what rate does brine drain from the flooded layer?
- How is the ice composition influenced by sea ice thickening?
- What is the relationship between snow properties and floodwater distribution over and through snow?
- How much thickening and over how much area is necessary for a measurable impact on sea ice longevity?
- Why is there a higher albedo observed at the thickened sites during part of the melting phase?
- What are the impacts of sea ice thickening on sea ice ecology?

We will be looking to answer these research questions in upcoming field tests, which will be funded by a grant from the ARIA Exploring Climate Cooling programme.



A newly flooded site stands out in the surrounding snow on a sunny day

7. Acknowledgements

This research would not have been possible without the support of our partners and advisors. We would like to thank UNIIQ, VP Capital, FincoEnergies, and Rabobank for their financial support, Veerle Schiet for contributing to the design of the measurement stations, Erikssons Mekaniska Verkstad AB for the design and fabrication of the flood pumps, TWD for the concept design of the mobile pumping platforms, Metazet and Hefcom for the detailed design and fabrication of the lifting systems, and Maurice's Service Centre in St. Anthony for providing the means to assemble, modify, and deploy the mobile pumping platforms.

We are grateful to Anneke van der Oever, Ruben Fijn, Bahram Sanjabi, and Waardenburg Ecology for their instructions on collecting and preparing the biological samples, and for analyzing the biological samples. We are very thankful to the local community of St. Anthony for their support and encouragement. We want to especially thank John Taylor for assisting with identifying safe access to the sea ice from shore in the Milan Arm and for recovering the measurement stations in the melting season. Finally, we would like to thank Peter Flynn (Emeritus Professor at the University of Alberta) and Shaun Fitzgerald (Professor and Director of the Centre for Climate Repair at Cambridge University) for reviewing this report.



The Arctic Reflections team in Newfoundland. From L-R: Fonger Ypma, Cody Owen, Soroosh Afzali, Tom Meijeraan and Willem Schellingerhout (*not pictured here)*



14 LIFE BELOW WATER

13 CLIMATE ACTION

ARCTIC REFLECTIONS

We contribute to
Sustainable Development Goals