

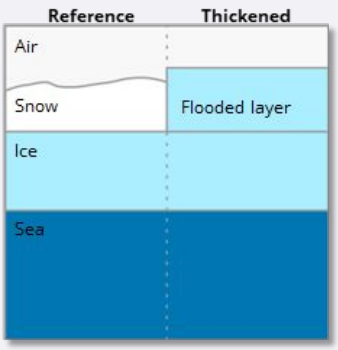
Svalbard Field Test

Research summary report September 20th, 2024

Thickening sea ice to adapt to a rapidly changing climate

Arctic ice thickening—pumping seawater on the sea ice surface during winter, to have more reflective ice left in summer—is a potential technique to maintain the natural solar radiation reflectivity of the ice, until CO2 emissions have reduced enough to slow global warming and allow the ice to be fully regenerative by itself again. This could be beneficial to maintain precious Arctic ecosystems, to support Inuit communities in preserving their traditional way of life, and as a regional cooling technique to counter the effects of climate change.

The technique is promising because the engineering is simple. Based on decades of practice in the creation of ice roads, there is a lot of knowledge about how to effectively accelerate natural freezing processes by pumping water on top of the ice. Ideally, if ice is thickened in winter by e.g. 40 cm, and the ice melts e.g. 2 cm per day, this would make the ice last longer and thus reflect sunlight for 20 additional days. This is potentially a very energy-efficient climate intervention—indeed, it is estimated that the amount of energy required for pumping is less than 0.1% of the solar energy reflected into space from the longer-lasting ice.



Schematic of Arctic ice thickening.

Arctic Reflections is an impact-driven start-up with the moonshot mission to preserve Arctic summer sea ice. In April, we conducted initial field tests in Svalbard, together with researchers from Delft University of Technology and the University Centre in Svalbard (UNIS). This enabled us to learn a lot more about the effectiveness of ice thickening, though there remain open questions for further research. This Research Summary Report summarizes the main findings.



It should be noted that these findings are preliminary and subject to further refinement, which will be done in a detailed technical report by the end of 2024. Next to this, to ensure full transparency, and to allow for independent scientific analyses, the gathered data as well as detailed data-gathering methods will be made openly accessible (Data in Brief, publication forthcoming). We welcome any feedback, comments or questions you may have about this research. Feel free to contact us at info@arcticreflections.earth.

April 2024 ice thickening tests on Svalbard

The field campaign was conducted in April 2024, as a joint project of Arctic Reflections with researchers from Delft University of Technology and UNIS (Svalbard). The tests took place at Vallunden Lagoon, connected to the Van Mijenfjorden via a narrow inlet, on Svalbard. Site A was our reference site, and next to this, we had three sites (B, C, and D) where we pumped water on top of the ice, using a standard ice-flooding pump with a flow rate of 210 m3 per hour. Snow on the ice cover mixed with seawater, creating the flooded layer that contributed to the overall thickened ice.

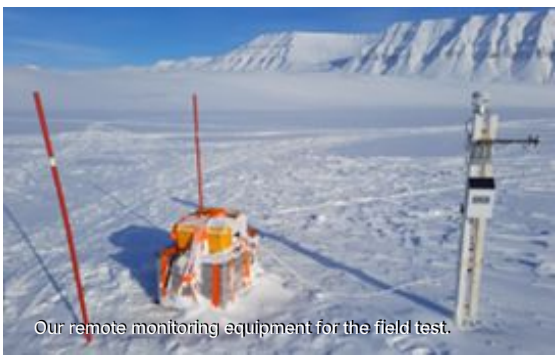
We installed the following remote measurement equipment:

Thermistor chain frozen into the ice to measure the temperature profile through snow, ice and seawater (with a sensor every 2 cm), and to infer snow and ice thickness at all 4 sites.

Net radiation meter, measuring incoming and outgoing radiation, both longwave and shortwave, in Sites A and B, which are used to determine surface reflectivity (albedo) and changes in radiation energy.[1]

A **weather station** (wind speed, air temperature, and atmospheric pressure).

A **timelapse camera** to visually monitor the sites.



Our remote monitoring equipment for the field test.



The pump flooding a test site.

Additionally, during the field campaign, we took extensive manual measurements every day, drilled almost 100 ice cores in total, and analyze temperature, across Sites A, B, and C. Moreover, we took manual measurements of ice and snow thickness, and freeboard (height of ice surface above water level).



Ice core sampling.

The combination of all these measurements, as well as visual confirmation from the timelapse camera and satellite images, allows us to draw conclusions from often complex data.

Our main objectives in the field tests were to:

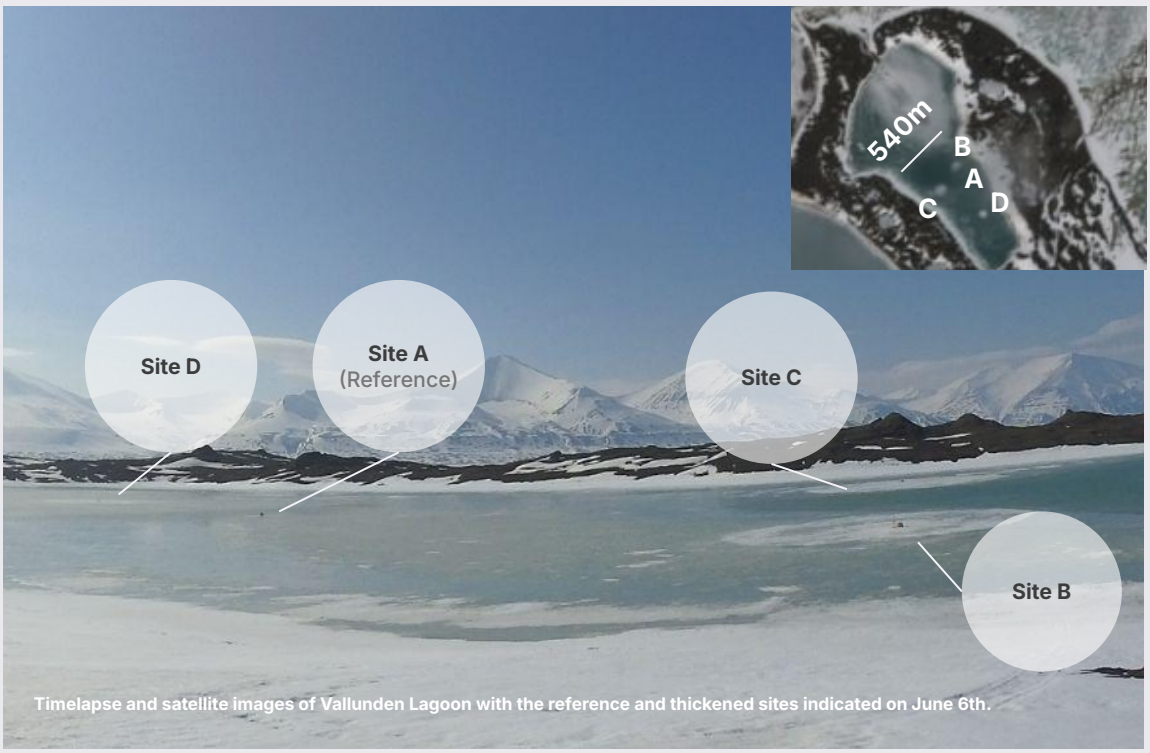
- Validate that ice can be thickened substantially during a 1-week field test, observe the influence of snow and of salinity, observe how flooding affects the temperature profile of the ice, and validate a net ice growth model.
- Validate that thickened ice lasts longer in summer than the reference ice and has a similar melting rate as the reference ice, and observe the influence of factors other than solar radiation on the melting process.
- Estimate how outgoing radiation is affected by flooding, both longwave (mainly during flooding) as well as shortwave (through albedo changes).



Main findings

Ice thickness was increased by around one-quarter of the original ice, and the melting rate of the thickened ice was similar to the melting rate of the reference.

- By pumping for an average of only 4 hours on the different sites,[2] we managed to flood the snow layer of around 20 cm,[3] and thicken the ice by 24 cm in total.[4]
- When the atmospheric temperatures increased, the ice gradually warmed, and then began to melt, and decreased in thickness.
- The melting period was identified as May 29th to June 19th, and at all sites, including the reference site, the melting rate was on average 4 cm per day.[5]
- If the full ice melt would have been a linear process (which it clearly is not), then this would have resulted in the 24-cm thicker ice lasting 6 days longer.
- The total area covered on the 3 pumping sites was about 0.8 hectares, based on satellite images analysis.[6]



Timelapse and satellite images of Vallunden Lagoon with the reference and thickened sites indicated on June 6th.

However, the thickened ice did not last as long as expected, due to non-linear melting effects. We think this is related to the test set-up (timing, location) and this may not be representative for any operations at scale. More research should be conducted to validate or invalidate that thickened ice lasts longer.

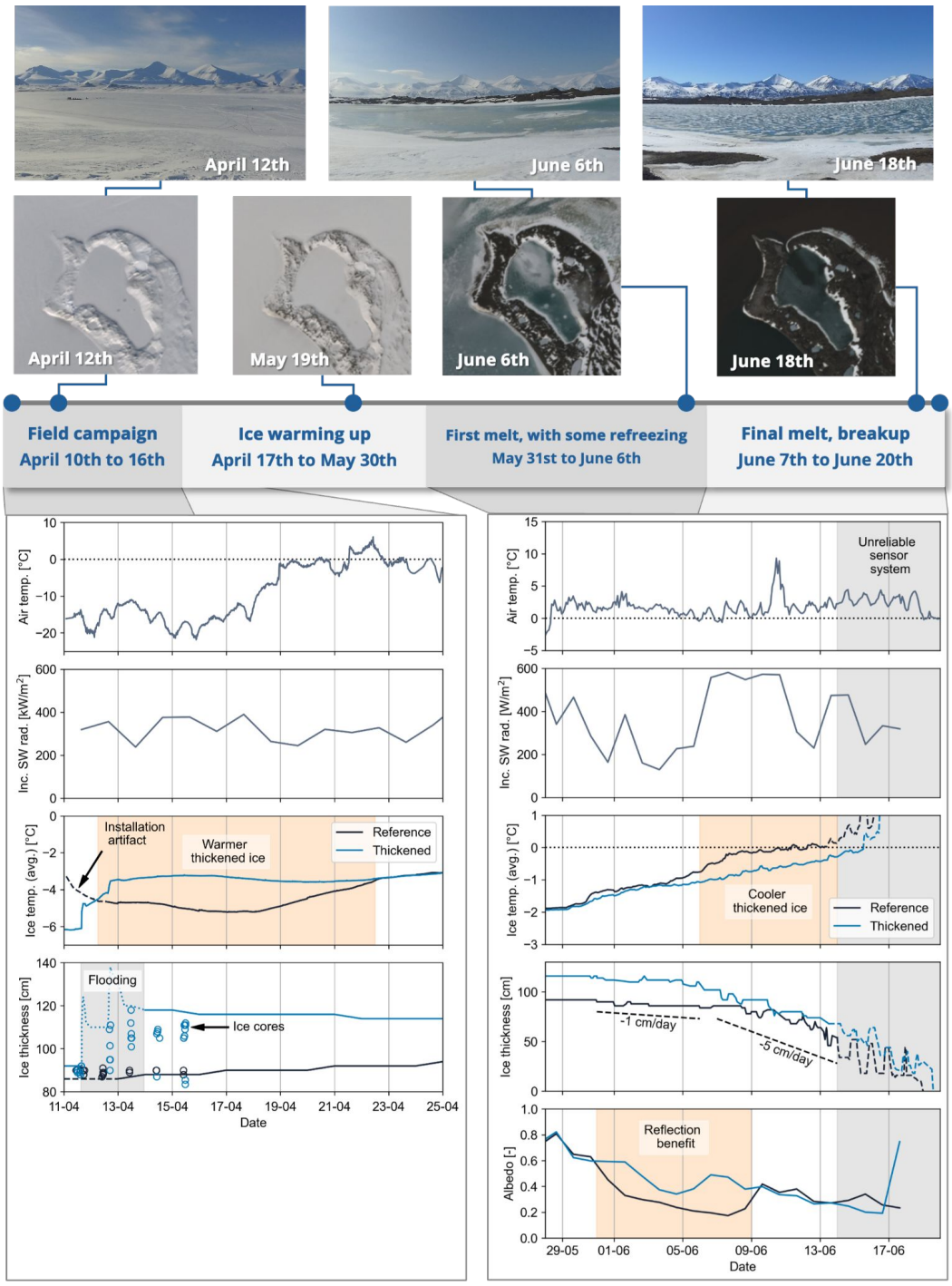
- The temperature profile of the thickened site did not sufficiently recover due to the timing of the field test late in the ice season—even though the air temperatures during the field test were cold enough to freeze the flooded layer,[7] the week after temperatures already reached 0°C.[8]
- The late timing also meant that the melting process was likely affected by the high salinity of the thickened ice—being 15-20 ppt (as a mixture of seawater and snow), compared to 3-8 ppt in the original ice.[9]
- The melting period consisted of two phases: the first occurred between May 29th and June 6th, and the second thereafter until June 19th (~2 months after the test).
- During the first melting phase, warming led to an average melting rate of ~1 cm per day and a loss of all snow cover. A large melt pool formed near two of the thickened sites, which may have influenced melting compared to the reference.
- During the second melting phase, high air temperatures and solar radiation led to a melting rate of about 5 cm per day (leading to an average of 4 cm per day for the two melting phases combined), and eventually complete loss of the ice cover. All ice washed away between June 19th and 20th due to breakup.
- However, the average ice temperature of the thickened sites was about 0.5°C cooler than the reference site in the period after June 7th.
- While the thickened sites appeared to last longer than the reference site, this increase in ice longevity was complicated by local effects of the large melt pond, and measurement uncertainty due to local melt pond drainage along the thermistor chains. Ultimately, the thickened ice only lasted for 2 additional days, depending on the local site conditions, when compared to the reference site.
- Conducting a field test earlier in the season and limiting boundary effects from the size of the flooded area will be required to validate the effectiveness of ice thickening to make the ice last longer in summer.[10]



The thickened ice had a higher albedo during a period of 8 days, which had a measurable and substantial net radiation benefit and associated cooling effect.

- The net outgoing effect on radiative energy was about 8.3 kWh per m^2 versus the reference site, which is a combination of temporarily lower shortwave (SW) radiative energy reflected around pumping (-0.7 kWh per m2),11 higher longwave (LW) outgoing radiative energy around pumping (1 kWh per m2), and higher SW radiative energy reflected during the melting (8 kWh per m2).
- The largest effect is in the SW radiation reflected during the melting period between May 31st and June 8th, when the average albedo of the thickened ice was 0.47 versus 0.29 for the reference site, giving an albedo difference of 0.18. For comparison, in May, the albedo at both sites was consistently around 0.75.
- The difference in albedo based on point measurements of radiation in Site A and B is supported visually by timelapse camera and satellite images, both showing the thickened sites being materially whiter than the rest of the ice.
- Physically, the modified radiative forcing effect we observed was due to a different phenomenon (snow-covered ice versus water-covered ice) than the phenomenon we theoretically expected (thickened ice lasting longer, leading to a situation of ice versus no ice). More research needs to be done whether this is a repeatable effect, or an artifact of certain boundary effects.
- For comparison, we had theoretically assumed an albedo difference of more than 0.5 between ice and open water (albedo of 0.06), about 3 times higher than the observed albedo difference of 0.18.
- Based on the unexpected albedo enhancement as a result of the prolonged snow cover, we can estimate the impact of our field test on the reflected solar energy. Note that the following numbers strongly depend on assumptions which are listed below, and want to caution drawing conclusions from these results.
- Assuming the point measurements are broadly representative for the entire pumped area of around 0.8 hectares, the net difference in radiative energy leads to a net outgoing radiation of around 60 MWh in total.
- Part of this energy could be trapped by clouds and not radiated back into the atmosphere, but since >90% of outgoing radiative energy relative to the site A was due to SW radiation on sunny days, this is expected to be minimal.[12]
- Comparing the net outgoing radiation with a theoretical difference in albedo between open water and ice for 6 days—the time it would take to melt the 24 cm thickened ice with 4 cm per day—indicates that the observed net outgoing radiation is about 1/3rd of the theoretical net radiation benefit. [13]
- We note that these numbers strongly depend on when the campaign is considered to have ended. Towards the end of the campaign, from June 8th onwards, the point measurement data became increasingly unreliable due to tilting of the measurement poles arising from melting. From satellite imagery,[14] we can determine that the albedo of the thickened sites remained higher for several days more than the reference site, although the point measurement data indicate otherwise on some days.
- We want to caution again that these numbers should not yet be used to draw conclusions about scaling this method. We did not have reliable data of the end of the campaign, nor have we finalized our analysis and gained complete understanding of the physical phenomenon leading to the enhanced albedo.

Timeline showing developments in ice temperature, thickness and surface albedo



Shown in the plots are air temperature, daytime average incident shortwave radiation, average ice temperature, ice thickness, and daytime average surface albedo. The comparison is made between Site A (Reference) and Site B (Thickened).

The energy required for pumping is less than 0.1% of the total energy reflected by the thickened ice.

- Total energy for pumping was about 26 kWh, computed from pumping a total of 13 hours with 2 kW of rated power.
- Compared to the total amount of solar energy reflected of about 60 MWh (which, as noted, is derived using many assumptions), this is only 0.05%.

The net effect of flooding on ice growth, and especially the positive effect of snow flooding on natural ice growth at the bottom of the ice could not be validated yet. More field tests, earlier in the season, are needed to validate net ice growth models.

- If sea ice without snow cover is flooded with water, the resulting ice thickness may be less than if the ice were to naturally grow from the underside, depending on the initial ice thickness and the number of freezing degree-days remaining in the winter season.
- Conversely, if snow on top of sea ice is flooded with water, the resulting ice thickness is likely more than the sum of the original and snow-flooded ice because the insulative properties of the snow are eliminated. Thus, the rate of underside ice growth will increase once the ice has cooled.
- The field tests were inconclusive in measuring these effects since the natural ice growth after the flooding period was minimal due to the limited number of freezing degree-days left in the ice season.
- While it is expected that flooding the ice earlier in the season would allow for more brine drainage from the flooded layer, this was not quantified in the field test. Ice salinity sampling from flooding until melting are needed to assess the impact of the brine and its rate of drainage on ice thickening and longevity.

Further validation of the positive impact potential of ice thickening is needed at a somewhat larger scale to exclude boundary effects and ensure repeatability.

- Boundary effects included increased freeboard of the thickened area in relation to melt ponds: the thickened ice had a greater freeboard compared to the surrounding ice and appeared whiter than the reference site.
- The snow was the main factor limiting water distribution over the ice area since the snow layer was saturated first before the water moved further.
- More modelling and measurements are needed on water flow through snow as a porous medium on top of the ice, to estimate scaling potential.

Further research needed

More field tests in different regimes, earlier in the winter, and across a larger area, are needed to fully demonstrate the effectiveness of ice thickening as an ice preservation and solar radiation management technique.

- Field tests earlier in the winter are needed for validating net ice growth modeling (especially in the presence of snow).
- Brine seems to get rejected over the course of the winter; thus, more measurements throughout the ice season are needed to validate that the higher salinity in the flooded layer drains prior to, and does not accelerate, ice melting.
- It is promising that the melting rates of the thickened ice and original ice are similar, but the question remains whether thickening ice by a few tens of centimeters makes ice last significantly longer in summer.
- Initial positive radiation benefits of ice thickening have been observed using both net radiation metering and satellite data, which is promising, but more work is needed to assess whether this is a repeatable effect, assess underlying assumptions and quantify the potential.
- Tests with various pumping strategies and across a larger area are needed to exclude boundary effects and to ensure field test outcomes are robust against site and scale variabilities.
- Snow plays an important role in the distribution of water over ice; understanding this relation better, and how far water can flow over snow-covered ice under different circumstances, is crucial to understand scalability potential.
- A broader interplay of ice flooding with weather (clouds, precipitation) is currently unknown, as are environmental impacts, especially on microbial life in brine channels.

Finally, the field test data analyses also inform potential alternative ice preservation strategies.

- Since melt ponds are known to be a dominant factor in accelerating melting, due to the heat they attract relative to white snow, this opens the question of whether draining melt ponds by drilling small holes might be an effective measure to reduce melting, especially locally. While this does not seem like a scalable strategy to preserve sea ice, drilling is very fast and efficient, and local communities could potentially use this method to preserve ice and allow for safer travel.
- Since the thickened ice can block incoming warmer water from the side, it could be potentially effective for ice preservation to thicken certain barriers, e.g. circular “dams”, protecting the inner part, and thus if done well, potentially reducing the required pumping volumes for a similar impact.

An Arctic acknowledgement

Arctic Reflections would like to thank Tim Hammer, Hayo Hendrikse, Laura van Dijke (Delft University of Technology) and Aleksey Shestov (University Centre in Svalbard) for the fruitful cooperation during the field test. We especially want to thank Tim and Hayo for their comments on an earlier version of this report. Next to this, we would like to thank UNIIQ, CarbonFix, VP Capital and CIEIF for their generous support, without which the field tests would not have been possible.



Notes.

1. Incoming shortwave radiation is optical wavelength, related to incoming sunlight, and outgoing shortwave radiation is reflected by the surface. For longwave radiation, outgoing is related to thermal emissions.

2. Pumping consisted of 3 hours at Site B and 5 hours at Site C. The pumping duration was not recorded at Site D. Note that Site A is the reference site and Sites B, C, and D are thickened sites.

3. Snow thickness was 17 cm at Site B and 21 cm at Site C. Coring was not performed at Site D.

4. Ice thickening was nominally 24±4 cm at Site B and 22±4 cm at Site C based on coring and thermistor chain measurements.

5.The melting rate was about 1±0.5 cm per day from May 29th to June 6th, and 5±0.5 cm from June 6th to 19th

6. Cross-comparing this with pumping data, we estimate ~0.3 hectares at Site B based on a nominal pump rate of 210 m3 per hour for a total of 3 hours and maximum flooded layer of 24 cm, and ~0.5 hectares at Site C based on a total of 5 pumping hours and maximum flooded layer of 22 cm. For Site D, this is unknown. Pumping data will overestimate areas, due to an unknown water run-off percentage.

7. From April 10th to 16th, during the pumping period, the air temperature was -16°C on average, with a maximum of -10°C and minimum of -22°C.

8. The air temperature reached 0°C on April 20th, 2024 for the first time in the season.

9. As sea ice forms, the salt is trapped in the ice in the form of pockets of high-salinity water, called brine. These brine pockets slowly migrate down through the ice towards the water over the course of the winter, called brine drainage. Brine drainage leads to lower concentrations of salts in sea ice, so the ice melts at a higher temperature, which is beneficial for extending the presence of sea ice during the melt season.

10. Boundary effects refer to the impact of influences on the edges of the thickened ice, which play a smaller role in the case of a larger thickened ice area.

11. The temporarily lower SW outgoing energy during flooding was caused by the water on the ice having a lower albedo than snow or ice. Within a day, a dusting of snow made this difference disappear.

12. Many assumptions have been made to perform the initial calculations. This analysis is subject to change with further refinement.

13. Here, we assume an average cloud cover of 81% in the theoretical case, and further assumptions on incoming angle of sunlight were made, depending on location and time of year.

14. It should be noted that satellite imagery covers at most one point of time during the day, so it does not capture intraday phenomena such as melting and refreezing of the surface.

We contribute to the following Sustainable Development Goals





We are endorsed by:

2021
2030
United Nations Decade
of Ocean Science
for Sustainable Development

