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Going with the floe

An Arctic expedition in pursuit of climate clues


Photo: P. Itkin

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Current affiliation of authors and persons quoted: see p. 108
N-ICE2015 scientific participants and medics: see p. 109
References / further reading: see p. 110

Published by the Norwegian Polar Institute
Tromsø, Norway
2022

Printed by Bodoni

Fram Centre, P.O. Box 6606
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ISBN 978-82-7666-449-2

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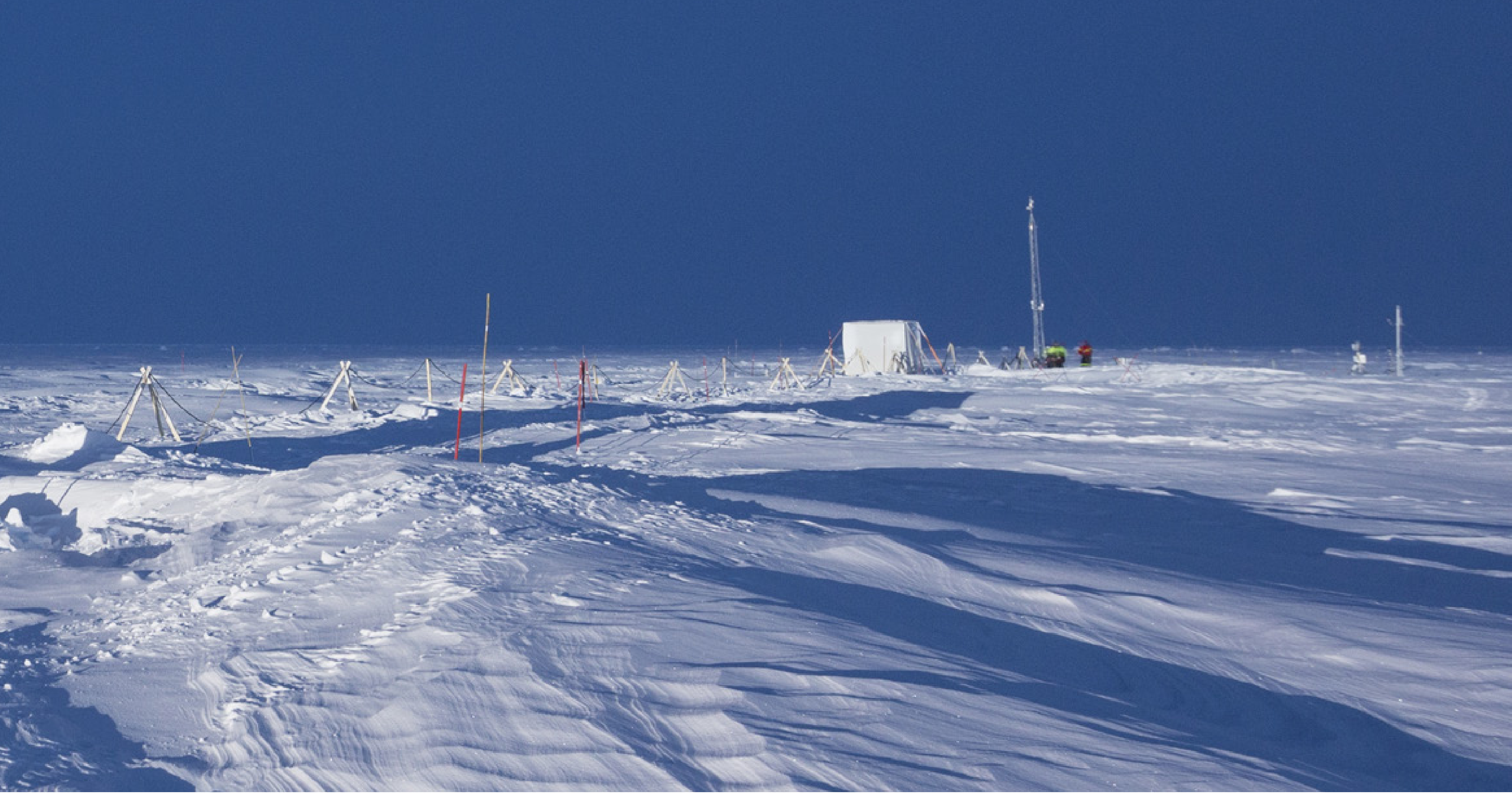


Photo: P. A. Dodd

Preface

This is the story about a special voyage, the people on a research vessel, the surrounding sea ice, the ocean below, the atmosphere above and all that happened during six months in icy waters not far from the North Pole. First and foremost, it is a story about what the experts learnt about the changes of the sea ice and the ongoing climate changes in the High Arctic while they were on board, and how this knowledge was disseminated to the public and the scientific community.

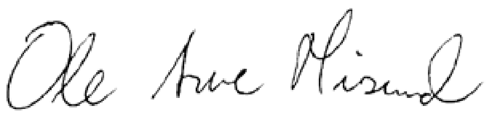
The Norwegian Polar Institute (NPI) is a government institution under the auspices of the Ministry of Climate and Environment. Our mandate is to give advice to Norwegian authorities, represent Norway in international bodies and oversee legislation related to Norwegian claims in Antarctica. The knowledge that we convey is based upon our research – most of which has been gathered by doing fieldwork – and that of other renowned institutions. We cooperate closely with international partners.

Starting in 2009, the institute was given extra funding to intensify our research through the Centre for Ice, Climate and Ecosystems (ICE). The Norwegian Young Sea ICE Expedition (N-ICE2015) was part of this effort. The aim was to gather data from the new, first-year

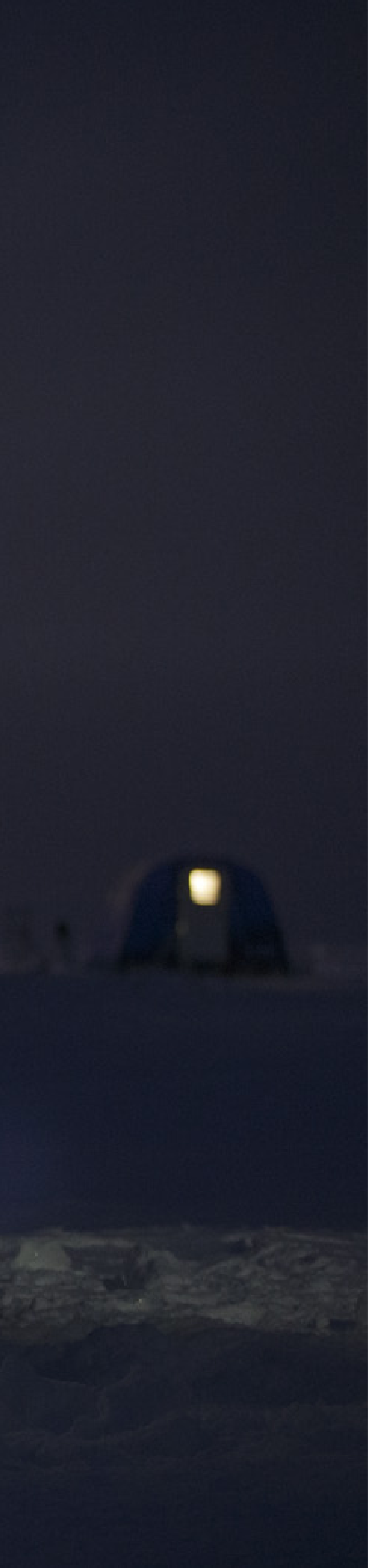
Arctic sea ice pack from the winter period to the onset of summer melt. The scientists monitored the entire system of polar winter ice, ocean and atmosphere, and the living organisms found inside the ice and in the ocean. The expedition brought us a step closer to understanding the interaction between the atmosphere, the sea ice and the ocean – and the changes that are taking place right now. The story about this drifting ice camp is a prominent example of how scientists strive to provide more and better knowledge for the benefit of us all.

Photo: J. Wallenschus

Tromsø, Norway,
March 2022



Ole Arve Misund
Director, Norwegian Polar Institute



Scientists Woosok Moon and Joo-Hong Kim, from the Korea Polar Research Institute, install meteorological instruments on the sea ice in the dark early afternoon. Photo: N. Cobbing

The drifts of the *Fram* and the N-ICE2015 (*Lance*) expeditions in the Arctic, 120 years apart.

CHAPTER 1

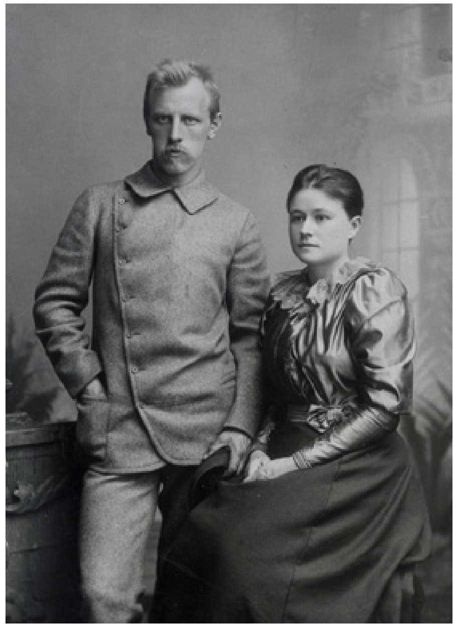
Science in the grip of sea ice

Ocean currents transport enormous amounts of energy around the globe and shape local and regional climate. The aim of the Norwegian Polar Institute's N-ICE2015 expedition to the High Arctic was to explore, explain and help predict the future of the sea ice in the Arctic Ocean in the area where inflowing warm Atlantic water meets cold Arctic water masses. Numerous explorers and scientists before us paved the way to this understanding, and others have followed, revealing more and more of the Arctic's secrets.

The *Fram* in the hold of the ice in May 1896. The ship had electric lights, and the windmill helped run the dynamo. Photo: F. Nansen

Fridtjof Nansen and his wife Eva, shortly after their wedding in 1889.
NPI photo archives

Fram – built for the ice



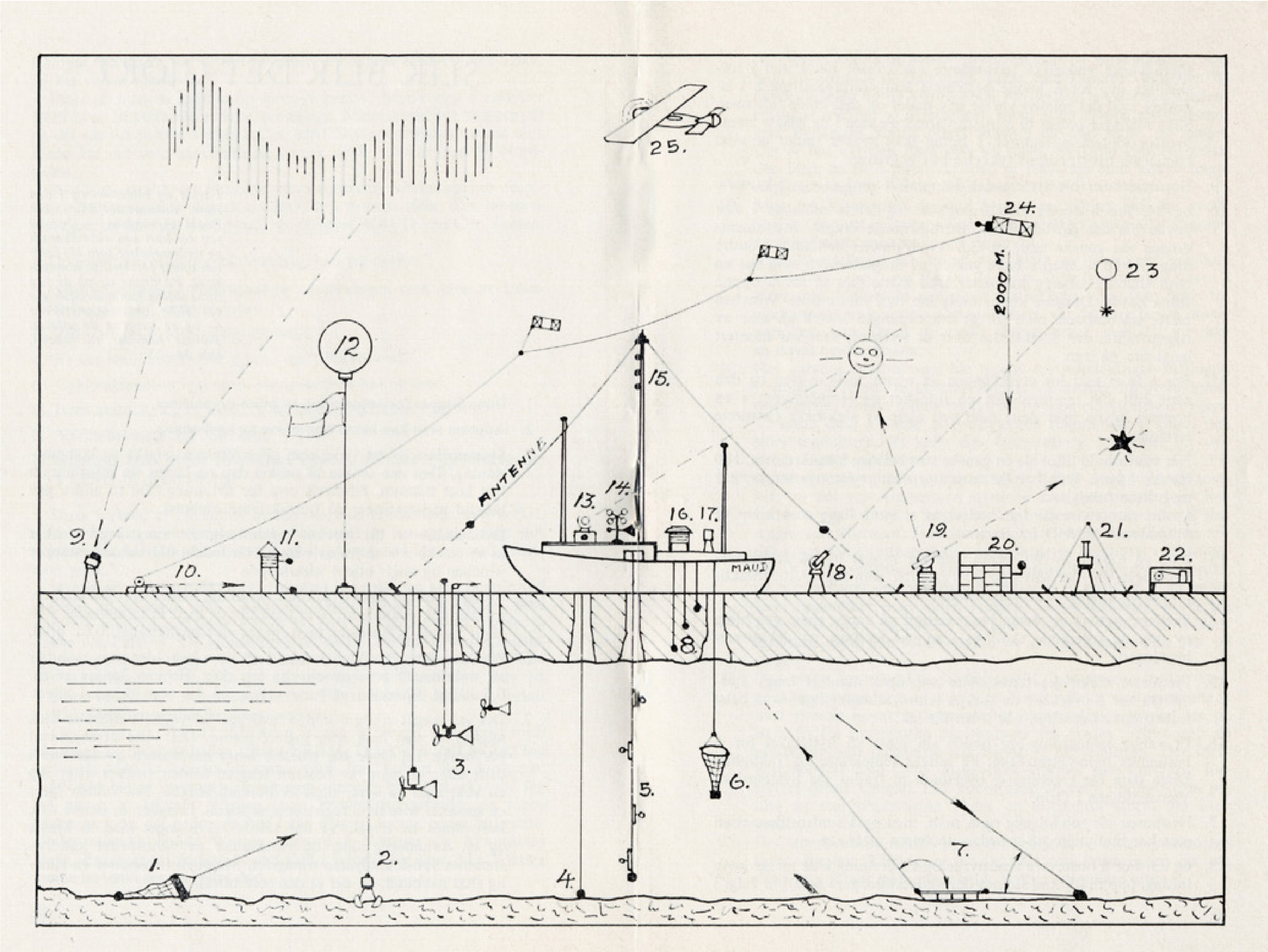
In October 1892, the Norwegian scientist Fridtjof Nansen launched an unusual ship, the *Fram*. Nansen hoped that when her rounded, reinforced hull was squeezed in the vice-like sea ice the vessel would be lifted upward rather than crushed, the common fate of ships trapped in the Arctic's icy waters. He was proven right. The *Fram* stayed afloat, and the work done during the three years when the ship drifted across the Arctic Ocean was a great scientific success. Some years earlier, Norwegian meteorologist Henrik Mohn had suggested that there was a transpolar ocean drift. Nansen's drift with the *Fram* was the final proof of it.

> *At the time, there were several theories about what the central Arctic Basin consisted of. Was there new land – islands coming up from the ocean? The first Fram Expedition, in 1893 to 1896, proved that the central basin of the Arctic Ocean was not a virgin land mass or covered by large glaciers. It was all ocean, nearly 4000 metres deep, with a layer of ice on top. Nansen was convinced that better knowledge about ocean depths, ocean temperatures and sea ice formation, thickness and movements would tell us about the Earth's climate.*
>
> **Harald Dag Jølle,** NPI polar historian and author of two biographies of Fridtjof Nansen

In more recent years, several other expeditions and scientific efforts have provided us with increasingly greater insights into the Arctic. Some have been of a similar nature to the *Fram* and the N-ICE2015 expeditions, with ships and equipment placed in the grip of sea ice as bases for research.

The *Maud* through the Northeast Passage

Norwegian explorer Roald Amundsen led the *Maud* Expedition, which lasted from 1918 to 1925. His ambition was that the ship would drift across the Arctic Ocean and



Scientific instruments deployed in the ocean and on the ice around the *Maud*, sketched by engineer and explorer Odd Dahl, who took part in the expedition.


СП33

possibly across the North Pole, but the ice conditions were challenging and the ship got stuck in the ice north of the Bering Strait. The *Maud* did, however, sail through the Northeast Passage, between the Pacific and Atlantic Oceans, along the coasts of Norway and Russia.

The scientific leader of the expedition was Harald U. Sverdrup, who later became director of the Norwegian Polar Institute. A substantial amount of scientific data was collected during the seven years the expedition lasted. This was mostly oceanographic and meteorological data.

Drifting ice stations

Although Nansen's endeavour with the *Fram* was a success, he thought that the Arctic Ocean could be more thoroughly explored by establishing research stations on ice floes. The first person to try out this theory was the Canadian–American Arctic explorer Vilhjalmur Stefansson, who established a drifting ice station in the Beaufort Sea in the American Arctic in 1917-1918. Taken ill, Stefansson could not participate himself, but he left it to his associate, Norwegian–Canadian Størker Størkersen (Storker Storkerson), to lead the first drifting ice station ever. The crew made oceanographic and meteorological observations.

The next research station that used the drift ice as a means of scientific exploration was the Soviet North Pole-1 station, which was established in 1937 on an ice floe only 20 km away from the North Pole itself. During the nine months this station was in operation, the ice floe travelled 2,850 kilometres. Twelve years later, the second Soviet station was up and running, and stations situated on ice floes were in constant operation until 1991. On 28 June 1972, an ice floe with a drifting station (the North Pole-19) passed over the North Pole for the first time. Several drifting stations were also in operation after the year 2000. The North Pole-22 station operated for a record-breaking nine years on a single ice floe, from September 1973 to April 1982.

Norwegian scientists occasionally worked on Russian stations near the North Pole in the early days. Even during the Cold War, in the 1960s, Norwegian Polar Institute scientist Torgny Vinje was allowed to visit a drifting Soviet ice station. On three occasions during the 2010s, Norwegian Polar Institute scientists visited the temporary Russian "Barneo" ice camps near the North Pole to conduct sea ice surveys and deploy autonomous measurement devices.

The Russian North Pole-33 drifting station in April 2005.
Photo: S. Gerland

A total of 41 Soviet/Russian drifting ice stations were established between 1937 and 2015. They were discontinued when adverse sea ice conditions made establishing camps on the ice too dangerous. The USA also ran drifting ice stations for a few years, between 1952 and 1965.

SHEBA science programme

In September 1997, the Canadian icebreaker *Des Groseilliers* was frozen into the Arctic sea ice north of Alaska. The expedition was part of the US National Science Foundation programme Surface Heat Budget of the Arctic Ocean (SHEBA), designed for studying atmospheric, sea ice and ocean processes throughout a whole year in the Arctic.

The ship acted as a base for scientific observations. The study gave new insights into the processes happening to the Arctic sea ice throughout the seasons, and it provided important knowledge for use in global climate models. Baseline data from the expedition has since been widely used by scientists.

The schooner *Tara*

Between the autumn of 2006 and early 2008, a 36-metre, aluminium-hulled schooner carried out a transpolar drift over the Arctic Ocean from Siberia to Greenland. The *Tara*'s voyage was part of the intensive polar research efforts during the International Polar Year 2007–2008. The ship's rate of drift with the ice was far quicker than that of the *Fram*, 112 years earlier. Although the size of the schooner did not allow for a large number of people on board, automated instruments collected data and an international science team flown in during April 2008 conducted extensive surveys around the vessel.

The *Tara*'s journey was linked to one of the largest EU research projects to date, Developing Arctic Modelling and Observing Capabilities for Long-term Environmental Studies (DAMOCLES). DAMOCLES, led by the French Pierre and Marie Curie University (UPMC), focused on the potential for a notably reduced sea ice cover and the impacts this might have on the environment and on human activities, regionally and globally.

Circumpolar Flaw Lead System Study

Another important International Polar Year study was the Canadian-led Circumpolar Flaw Lead System Study, when the Canadian research icebreaker the *CCGS Amundsen*

The *Tara* on her drift from Siberia to Greenland.
Photo: M. Nicolaus

overwintered in the Cape Bathurst flaw lead throughout the annual sea ice cycle of 2007–2008. The circumpolar flaw lead is a wintertime perennial characteristic in the Arctic Ocean, when the ice pack moves away from the coastal fast ice and creates stretches of open water. The multidisciplinary study included physical and biological sciences as well as Inuvialuit traditional knowledge.

A hovercraft in the Arctic Ocean

The privately funded FRAM-2014/2015 Expedition involved a hovercraft, the *Sabvabaa*, which drifted with an ice floe 1900 kilometres across the Arctic Ocean. The hovercraft and its ice drift station were deployed off the East Siberian coast by the German research icebreaker the *Polarstern* on 30 August 2014 and drifted for a year. Norwegian scientist Yngve Kristoffersen and his companion Audun Tholfsen gathered data on geological history, oceanography, sea ice and weather conditions.

Lance – a grand old lady's farewell to science

With her ice-strengthened hull and helicopter platform, the Norwegian Polar Institute's research vessel the RV *Lance* was the obvious choice when the institute decided to carry out the Norwegian Young Sea ICE Expedition (N-ICE2015). Moreover, the ship had a larger than average fuel capacity and her main engine could be shut down, which was useful for this kind of operation.

The expedition was to become the high point of the *Lance*'s career as a research vessel. The ship had started out as a platform for fishermen and sealers in the Arctic and later she served cartographers when they investigated and mapped the sea bottom. For many years she was a floating base for polar scientists in their quest to understand the changes that are going on in the polar oceans, and for some time she also served the Norwegian Coast Guard. Then, in 2015, the nearly 30-year-old ship was frozen into the Arctic sea ice for half a year, anchored to drifting ice floes. The *Lance* had to be relocated several times as the ice drifted rapidly and the fairly thin ice-floes disintegrated and could no longer harbour the ice camp set up around the ship – a sign of the new ice regime.

The N-ICE2015 expedition was one of Norway's most important efforts to better understand what is happening in the Arctic Ocean in a changing climate and to procure data that will improve our models of future conditions. This book will explain why and how.

Polarstern and MOSAiC

The most comprehensive and expensive research expedition to the Arctic so far started on 20 September 2019, when the German research vessel the *Polarstern* set sail from Tromsø, Norway, nearly five years after the field campaign of the N-ICE2015 had finished. The destination was the shelf sea areas off Siberia, Russia, where the ship was to be frozen into the ice, drifting with the ice much like the *Fram* and the *Tara*. The aim was to gather climate data for the international research project Multidisciplinary Drifting Observatory for the Study of Arctic Climate (MOSAiC). The results support improved sea ice forecasting, regional weather forecasting and climate predictions.

MOSAiC was designed to improve our understanding of interconnected atmosphere–ice–ocean–ecosystem processes in the central Arctic, in a similar fashion to N-ICE2015. The Norwegian Polar Institute shared scientific expertise and logistics

A committee of emperor penguins greet the *Lance* on a research mission to Antarctica in 1992. Photo: J.-G. Winther

The *Kronprins Haakon*, Norway's state-of-the-art icebreaking research vessel. Photo: L. Hislop experience with the German Alfred Wegener Institute when they were planning the project. The *Polarstern*'s full year in the ice was interrupted only by an exchange of participants near Svalbard and a relocation to a new ice floe when the ship drifted out of the ice earlier than anticipated. Again, this was a sign of the dramatic changes that have taken place since the drift of the *Fram*. With their different research projects, scientists from institutions in 20 countries took part in the expedition.

The Nansen Legacy

Following the N-ICE2015 expedition, and drawing inspiration from the great polar scientist Fridtjof Nansen, Norway's biggest ever research effort in the Arctic was launched in 2018. Funded by the Ministry of Education, The Research Council of Norway and the participating institutions, the Nansen Legacy project will run for at least six years, concluding in 2024. Representing ten of Norway's most prominent universities and research institutions, more than 200 researchers – including more than 70 early career scientists – take part in the project. It is headed by UiT The Arctic University of Norway, with co-leaders from the Norwegian Polar Institute and the University of Bergen. In addition, some 40 people are involved as technicians, project coordinators, communication advisers and board members.

The aim of the Nansen Legacy is to create a scientific basis for long-term, holistic and sustainable management of the marine ecosystems and human presence in the northern Barents Sea. The project is also meant to unite and strengthen the Norwegian Arctic research community.

Much of the research and data collection is carried out from the *Kronprins Haakon*, the research icebreaker that replaced the *Lanc*e and made her maiden journey to the Arctic in 2018. Unlike the N-ICE2015 expedition, the ship is not drifting with the ice. Instead, a series of shorter scientific expeditions to the same region are carried out to reveal the conditions and processes taking place there at different times of the year.

Timeline

1893–1896
The *Fram* Expedition

1917–2015
Drifting ice stations

1918–1925
The *Maud* Expedition

1997–1998
The *CCGS Des Groseilliers*/SHEBA

2006–2008
The *Tara* Expedition/DAMOCLES

Photo: N. Cobbing

2007–2008
The *CCGS Amundsen*/ Circumpolar Flaw Lead Study

2014–2015
The *Sabvabaa*/ Fram-2014/2015 Expedition

2015
The *Lance*/N-ICE2015 expedition

2018–2024
The *Kronprins Haakon*/ The Nansen Legacy

2019–2020
The *Polarstern*/MOSAiC

CHAPTER 2

A project takes shape

Acknowledging that the research efforts in the Arctic were too scarce, especially in winter, the Norwegian Polar Institute set forth to investigate the ongoing changes. The past decades had seen rapid changes in the Arctic sea ice pack. The sea ice had become thinner and the older multi-year ice pack had been largely replaced by ice that was younger than two years old. These changes suggested that the entire sea ice system was now functioning differently than before. The scientists struggled with a disturbing question: Is the knowledge we have from only a decade ago still valid?

Early spring in the Arctic.
Photo: N. Maaß

Dramatic sea ice changes

To predict the future of the Arctic sea ice and its effects on the climate, ocean and ecosystems, good knowledge of the state of the system today – and an understanding of the governing processes of today and tomorrow – is needed. September 2012 was, and still is, the month with the lowest Arctic sea ice extent since continuous satellite-based sea ice observations began in 1979. It was evident that our knowledge was out of date. The vast Arctic sea ice cover had changed rapidly and dramatically in recent years, yet our understanding was still based largely on observations made during an earlier regime, when thicker and older ice dominated the icescape in the Arctic Ocean.

The N-ICE2015 expedition targeted this knowledge gap. It was decided to bring about unique and much needed direct observations, especially from the polar night period. This would allow scientists to better understand how the rapid shift to a younger and thinner sea ice regime in the Arctic affects sea ice dynamics and the exchange of energy. Learning more about how this impacts the local and global climate, and the ecosystem that is associated with the ice, was also important goals.

> *The major weakness of climate models is to predict the exchange between the ocean, the atmosphere and the surface. What will happen with the climate when snow and ice disappear? There will be heat coming from the ocean when there is no ice cover. N-ICE2015 was designed to contribute towards a conceptual picture of what is going on and provide better data that could improve the climate models.*
>
> **Kim Holmén,** NPI International Director

Despite the Norwegian Polar Institute's know-how and logistical capacity for large marine and terrestrial scientific expeditions, freezing the *Lance* into the Arctic sea ice for nearly half a year was a massive undertaking. A great deal of planning, coordination, cooperation and determination made the expedition happen – and substantial funding.

Most Norwegian scientific projects are funded through The Research Council of Norway. However, involving heavy operational and logistical costs, the application was not straightforward, and the Research Council found they could not grant support.

A man looks small in the vast expanse of sea ice, but the impact of humankind on the Arctic may be great.
Photo: A. Meyer

NPI Director Jan-Gunnar Winther in Tromsø on 7 January 2015, about to wave farewell to the *Lance* as she began her journey to the North. Photo: G. S. Jaklin

Yet Norwegian Polar Institute Director Jan-Gunnar Winther was adamant that such an expedition would significantly advance our knowledge of climate change in the Arctic.

> *It was plain to see that the time was overdue to make further investigations in the Arctic Ocean, and the idea of a "Nansen Light" seemed like the right thing to do. It is incredible how a pioneer like Fridtjof Nansen can inspire scientists over 100 years later. The N-ICE2015 expedition was founded on the same basic idea as the Fram Expedition – and the remoteness, harsh climate and dark winters of the Arctic Ocean meant that it was still little investigated and poorly understood.*
>
> **Jan-Gunnar Winther,** Director of the NPI (2005–2017)

With extra financial backing from the Ministry of Climate and Environment for upgrading the ship, the project went ahead. The total costs of the expedition – including the ship and logistics – mounted to around 50 million NOK. A substantial part of this came from the Norwegian Polar Institute's core funding through the institute's

Centre for Ice, Climate and Ecosystem (ICE). Additional funding came from the Ministry of Foreign Affairs. The Research Council supported several of the smaller scientific projects that were carried out on board. A number of participant institutions provided in-kind support.

> *Another incentive for undertaking such a massive task, was to involve and educate more young scientists in Arctic research. Post-doctoral scientists were recruited, most of them young female scientists.*
>
> **Nalan Koç,** NPI Research Director and Cruise Leader on Leg 5

Later on, funding from the Ministries of Foreign Affairs and Climate and Environment made it possible for early career scientists to work with the data and to further research collaboration between Norwegian, Canadian and American scientists in a project called "ID Arctic".

Young, thin ice replacing old, thick ice

There was no doubt whatsoever that the Arctic sea ice was in the midst of a dramatic transformation. Not only had the extent of the vast, floating ice shrunk, the average thickness had nearly halved from about 3 metres some decades before. This was exemplified by Fram Strait, a stretch of ocean between Svalbard and Greenland that has been monitored by the Norwegian Polar Institute for decades. Averaging about 3 metres, the sea ice thickness in the strait was relatively stable during the 1990s. Then the ice became thinner, and this thinning became pronounced about 20 years later. The changes in sea ice could only be properly investigated by being right there, during the coldest time of the year. The region north of Svalbard is also key to understanding the fate of warmer Atlantic water flowing in from the south and the sea ice that has drifted across the Arctic Ocean before it exits through the Fram Strait.

The SHEBA Expedition led to a much deeper understanding of the physics of the Arctic sea ice. The *Tara*'s transpolar drift and the Circumpolar Flaw Lead System Study north of Canada during the International Polar Year in 2007-2008 also yielded valuable contributions. However, the ice had changed substantially since then. The scientists were at a loss when it came to understanding interactions between the atmosphere, the ice and the ocean in this new ice regime.

A typical scene in the High Arctic: a large sea ice floe covered with snow. The "road" in the middle was earlier an open crack – a lead – in the drift ice which has refrozen. Photo: T. Taskjelle

In the big picture, we are trying to understand why the Arctic sea ice has declined so dramatically in the past 15–20 years. The old, thick ice dominating the Arctic pack ice before is now more and more replaced by younger, thinner seasonal ice. There are very few measurements made in the Arctic and there are no continuous field measurements (from winter through summer) made in this "new" state of ice. The Arctic is changing rapidly, and we are struggling to keep up.

Lana Cohen, NPI atmospheric scientist, blog post

Sharing data – the new normal

To deal with this knowledge gap, the Norwegian Young Sea ICE (N-ICE2015) expedition was designed to study how the thinner drifting Arctic sea ice pack functioned, how it interacted with the atmosphere and the ocean and how it affected the marine ecosystem from the onset of winter to the beginning of the summer. With such an ambitious scope, many disciplines had to be included. The scientists wanted to study ecology, biology, biodiversity, oceanography, sea ice, ocean acidification and atmospheric dynamics and to make use of and improve remote sensing tools.

> *While the N-ICE2015 Expedition had the overarching objective of providing a basis for a better understanding of processes and the coupled ice–ocean–atmosphere system in the new, thin sea ice regime in the High Arctic, the final target was to contribute to improved computer models to predict future conditions more accurately. This was a somewhat hairy goal, at least in the short term, and it also meant that we had to include scientists from different disciplines and different institutions, which was a challenge because of the limited number of berths on the ship.*
>
> **Mats Granskog,** Expedition Scientific Leader, NPI

There was a broad understanding that the unique direct observations made by all the scientists involved in the campaign would be made freely available to the international research community, to help bring its knowledge up to speed with the actual situation in the Arctic and ultimately to improve modelling the future. To understand the sea ice system in the Arctic, observations of key processes had to be made in the atmosphere, snow and ice and the ocean, along with observations of biological activity.

> *Data sharing is becoming the new normal. Earlier, scientists would hang on to their data until they had finished publishing their own research using the gathered material. Now it is far more common to share the data within months, or once the first scientific results have been published, so that others doing similar research can make use of the latest data. It was important to us that all scientists who took part in the expedition committed to sharing their data.*
>
> **Harald Steen,** Head of the ICE Centre and Expedition Leader, NPI

Photo: P. A. Dodd

The main questions put forward by the scientists were:

- How, when and where does warm Atlantic water flowing in from the south melt the ice?
- How does the thinner ice respond to changes in the atmosphere, like changes in winds, warming events, passing storms and snowfall?
- What are the effects of snow on the ice?
- How does thinner ice affect ice dynamics, and how can we improve ice drift models?
- What are the effects of the changed sea ice system on the ice-associated ecosystem?
- What are the effects on local and global weather systems?

Finding answers to these questions required a long-time stay in the ice during the dark, cold winter months and also during spring, when the sun returns to the Arctic, the sea ice starts to melt and phytoplankton and ice algae start to grow.

Careful preparations and test cruise

How do you plan for a feat like this? One of the challenges was to determine just how far into the ice the ship should be allowed to go, between the Svalbard archipelago and the North Pole. Since the *Lance* was to act as a floating base for scientists, most of them spending three to six weeks on board, the starting point for the drift had to be within flying range of a mid-sized helicopter that could land on the ship's helicopter platform. There was also the question of safety for the participants. What if someone was injured or taken ill? It was important not to cross the point of no return for the search and rescue helicopters that would have to fly in from the nearest well-equipped settlement – Longyearbyen in Svalbard.

Self-rescue in icy water – a vital component of the expedition members' survival training
Photo: S. Gerland

Shooting practice before entering polar bear land.
Photo: M. Fernández-Méndez

Before setting off there was a substantial load of planning and preparations to be made. Firstly, the ship had to be able to endure the challenges of spending months on end in freezing temperatures. Next, the participants had to be prepared for the worst to happen. There was safety and survival training, like self-rescue in cold water, first aid, warding off polar bears and much more. To avoid unpleasant surprises during the expedition, a short test cruise was carried out in February the previous year. The *Lance* was frozen into the ice north-west of Spitsbergen, the Svalbard archipelago's main island, for two weeks.

Carrying out a test cruise proved to be a wise move. It showed that some of the equipment on board was no longer fit for a long stay in the ice at low temperatures. Much had changed since the *Lance* was a vessel used for fishing and hunting seals in the Far North. Extra gear had to be mounted on the ship for the research tasks and the laboratories had to be upgraded. Of utmost importance was the right equipment in the event of fire on board. One of the worst things that can happen when a vessel is trapped in the ice is a devastating fire, according to one of the *Lance*'s two captains, Johnny P. Hansen. During the test cruise they worked out how to use a lifeboat as

During a test cruise in 2014, the scientist and the *Lance* crew test equipment and make other preparations for their long stay in the ice the following year.
Photo: P. A. Dodd

a shelter on the ice, with a specially designed heater and survival kits inside. This would allow them to survive on the ice in the event of having to abandon the ship.

One of the key premises for carrying out the expedition was the service of a suitable helicopter. The Governor of Svalbard kindly released slot time for a Super Puma helicopter operated by the company Lufttransport. With access to a helicopter sorted, sites on the ice where the helicopter could land in case of emergency had to be established every time the *Lance* reached a new location in the ice.

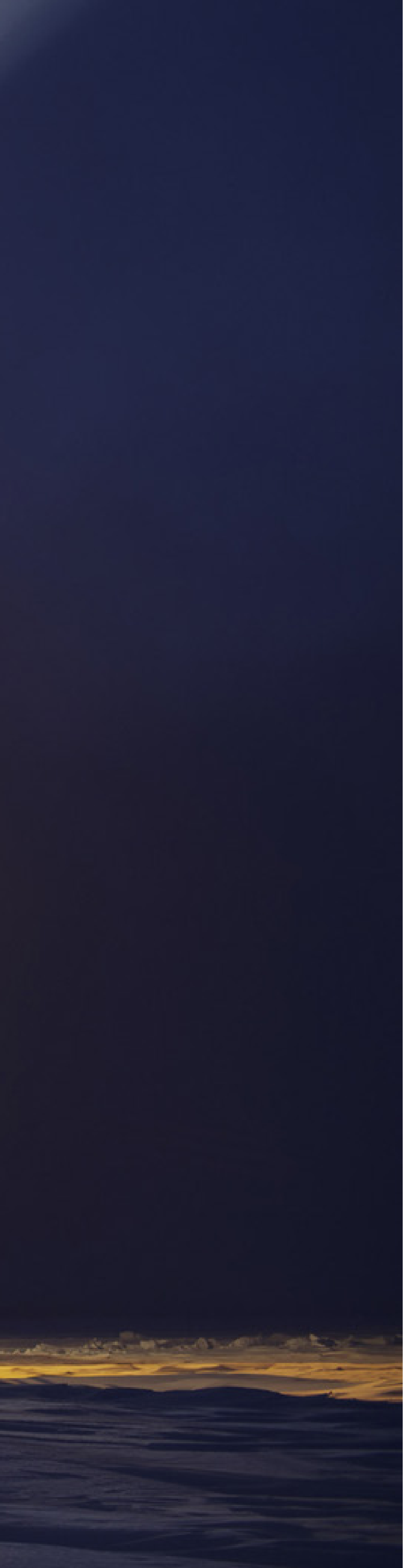
During the summer before the expedition, another important preparation was placing helicopter fuel depots as far north in Svalbard as possible. This would give more options for helicopter visits and personnel exchanges. Also, additional logistics and safety staff were hired.

> *The cooperation between the Governor of Svalbard, the helicopter company and the Norwegian Coast Guard was crucial to the project. Without proper planning, good teamwork and the skills of the people involved, the result may have been quite different. I would say that this was an excellent example of cooperation between government bodies and private operators.*
>
> **John Guldahl,** Section Leader in the NPI Logistics and Operation Department and Cruise Leader on Leg 3

Training expedition participants before taking off in the helicopter.
Photo: J. Wallenschus

Partners from the University Centre in Svalbard (UNIS) assist when N-ICE2015 participants undergo field training in Longyearbyen. Photo: A. Meyer

Invitations were sent to national and international partners in the research community that had complementary expertise that would fit the aims of the expedition. Little by little, the expedition was taking shape as partners from the US, Russia, Germany, France, South Korea, Japan, Poland, Denmark, Finland and the UK accepted the offer. Eventually 32 scientists from 11 countries in addition to Norway ended up taking part in the N-ICE2015 expedition. Scientists with several projects from Norwegian institutions were on board the *Lance.*



CHAPTER 3

Experts adrift

Seventy researchers, 22 support staff and 20 ship crew were on board intermittently during the *Lance*'s stay in the ice. They represented institutions from 12 countries. The expedition started from Tromsø on 7 January 2015 and set out from Longyearbyen, in the Norwegian archipelago of Svalbard, on 11 January, where the ship docked again on 24 June after a job well done. In the early hours of 15 January, the *Lance* reached 83°N 22°E, 756 kilometres from the North Pole and 364 kilometres from the nearest land.

For the first weeks, the *Lance* does not budge from the snug embrace of the moving sea ice at 83° north. The ship's powerful searchlights illuminate the science work on the surrounding ice. Photo: N. Cobbing

A helicopter comes in for landing on the *Lance*.
Photo: J. Wallenschus

Singing ice

The *Lance* started her drift at 83°N and she drifted with the ice, serving as a research base for the personnel, while the surrounding ice floes served as a research "play-ground". The ship drifted east, west, mostly south and occasionally north again. The expedition ended up having four drifts, attached to different ice floes. They spent 111 days anchored to the ice floes, with the research camp up and running.

Sea ice is constantly on the move, and the thinner the ice, the more unstable it is. The movements of the floes are mainly driven by the wind and to a lesser extent by ocean currents. The force of these drivers and the strength of the ice pack itself largely determine how the ice moves.

The expedition encountered ice that drifted much faster than expected, and it was also very dynamic. As the *Lance* changed direction along with the shifting wind directions, those on board could watch the ice break up on the ship's radar and with their own eyes. The ice shifted around and leads opened up. Metre-thick ice floes – several kilometres long and weighing easily more than a million tonnes – were pushed together, forming piles of ice blocks – known as pressure ridges – at their edges. The cracking and "singing" of the moving ice pack could be heard on the ship.

The N-ICE2015 expedition was divided into six legs, and most of the participants spent six or three weeks on board, depending on the duration of the leg. A few even stayed for two or three legs. Some of the exchanges of personnel were made using the helicopter stationed in Longyearbyen, assisted by the Norwegian Coast Guard icebreaker and offshore patrol vessel the *KV Svalbard*.

Finding the perfect floe

When the *Lance* first reached the pack ice, the *KV Svalbard* provided a vital helping hand. For decades the Norwegian Coast Guard have occasionally assisted research expeditions in the Far North as part of their social mission – an extremely valuable arrangement for science, as well as an important exercise for the Coast Guard crew. The *Lance* is ice-strengthened but she is not an icebreaker and she could not be expected to plough through the 1.5 metres of snow-covered ice to reach the planned starting point of the drift.

The two vessels rendezvoused at a point north of Sjuøyane, at 81˚N. The plan was for the *KV Svalbard* to open up the ice so that the *Lance* could follow to the first mooring site, preferably at 84˚30' N (like the *Fram*), but conditions were so challenging that their progress stopped at 83˚14' N. It was pitch dark, the temperature was down to 15 ˚C below zero and the ships faced rough ice for more than 100 nautical miles. The *Lance* struggled to follow when the Coast Guard ship made sharp bends, zigzagging

The Norwegian Coast Guard ship the *KV Svalbard* assists the *Lance* on her quest to find the perfect ice floe at which to anchor. Photo: H. Steen

The *KV Svalbard* in the Arctic sea ice. Photo: P. Leopold

between ice floes and weaker parts of the ice cover, trying to find the optimal route to save time and fuel. A couple of times the leads behind the *KV Svalbard* were closed up by the moving ice before the *Lance* could pass through, and she got stuck. To free her of the grip of the ice, the *KV Svalbard* had to turn around and come as close as a metre and a half from her bow. The operations went smoothly, a testament to the seamanship on board both vessels.

The search for a suitable ice floe went on for a couple of days, as floes that were too thin or too small were rejected. The daytime darkness made the search even more challenging. After finally finding a suitable floe and having made a nice, open "parking spot" for the *Lance* to anchor at, the *KV Svalbard* made her way back south again.

> *The* KV Svalbard *was Norway's only icebreaker at the time, but we had never been so far north before. In fact, hardly anybody had been so far north, in the ice, this dark time of the year. It was extremely challenging, and we really got to test our ship and the crew. We assisted the* Lance *on three occasions – acting much like a plough truck. We had to adjust our movements so that the* Lance *could follow, since the ice collapsed and the leads were gone, even though she was only 60-100 metres behind us. It was a little like dragging along a reluctant child who does not want to go for a walk – we had to go back and help. Every time this happened it went more smoothly due to our increased knowledge of equipment and techniques, and our previous experience. So, this was truly a win–win endeavour.*
>
> **Endre Barane,** Captain, *KV Svalbard*

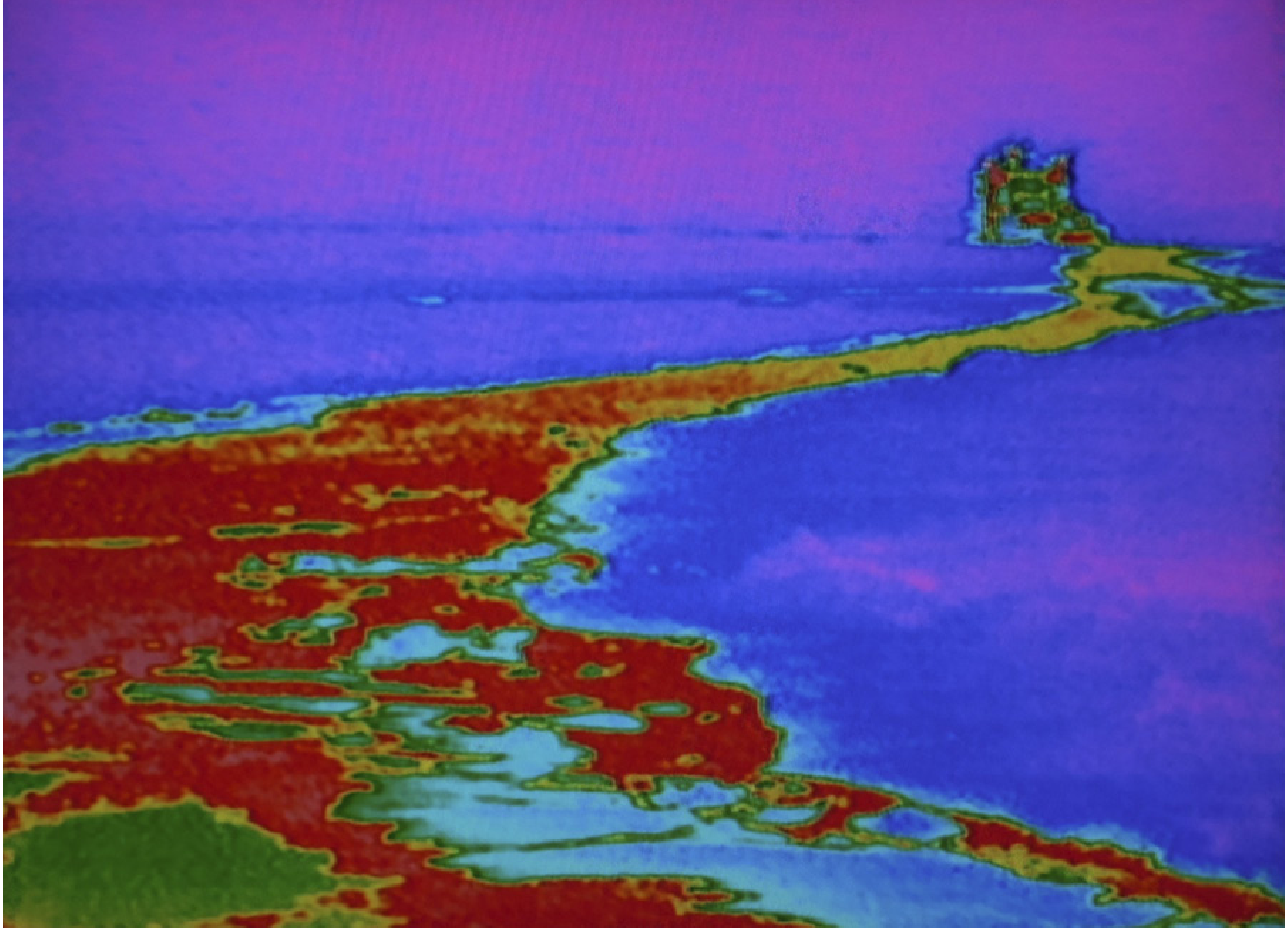
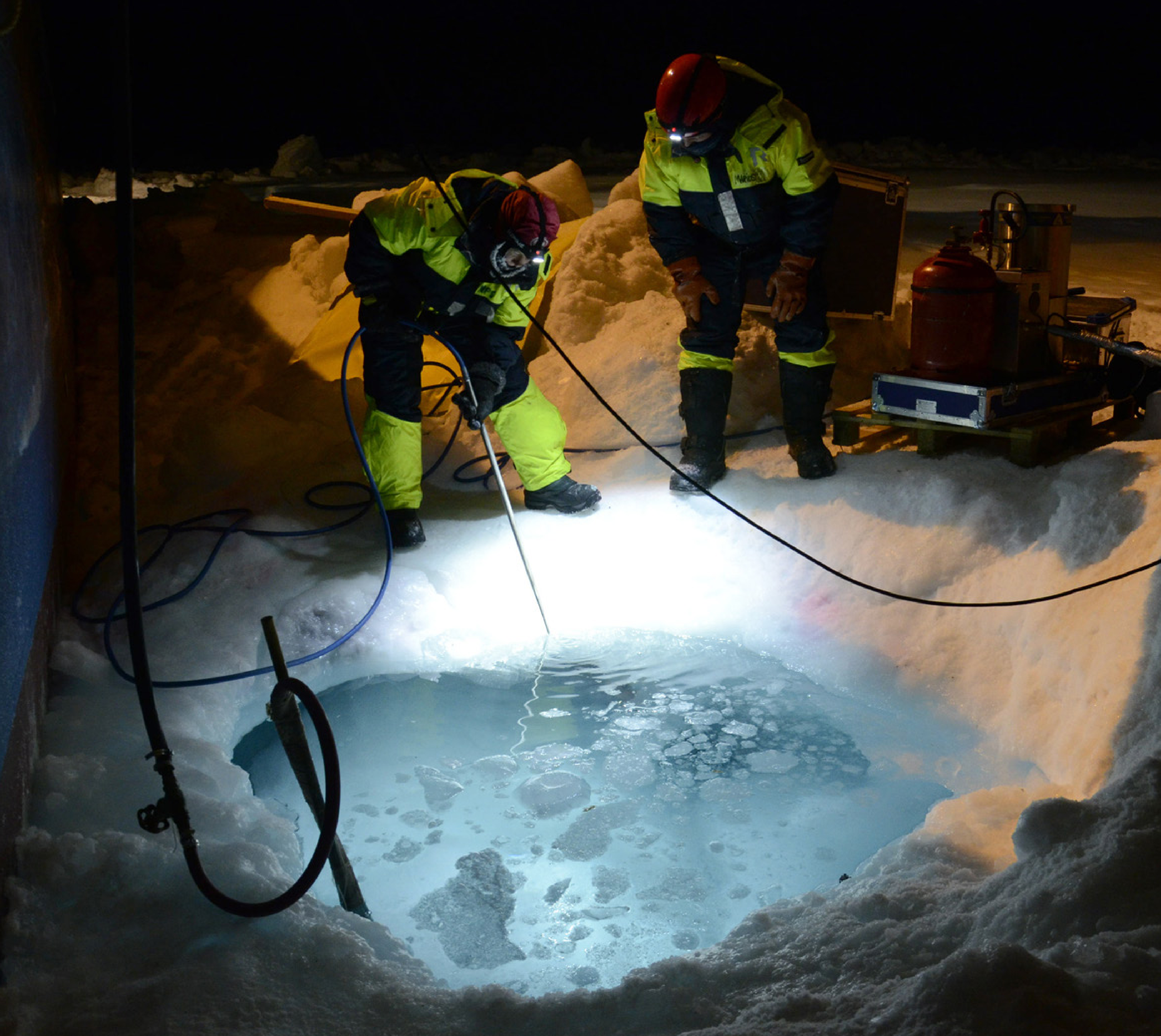


Image from a thermal camera on board the *Lance*, showing the open lead left by the *KV Svalbard* as relatively warm (red) and the surrounding cold ice and snow. Photo: G. Liston

On 15 January, at 83°14' N, 21°31' E, the *Lance* finally reached her destination at the first ice floe. Leg 1 of the endeavour had started. She was well in the ice and scientific equipment was set up within half a kilometre from the ship. From here on, the ship would drift with the ice, anchored to large sea ice floes, while the scientists made measurements of the ice, ocean, atmosphere and ecosystem from the ship and their on-ice camps.



CHAPTER 4

Dark times – exciting work

It took five days to establish the first research camp. The members of the expedition reported no major problems, despite temperatures dropping as low as -37 ˚C. There was no daylight, but two strong searchlights from the ship could be directed at will, offering some work light up to about half a kilometre away. There was also an infrared camera on board that could help locate living creatures on the ice around the ship – be they human or polar bear. The backbone of the ice camp was the powerline that supplied electricity from the ship to the research camp and the scientific instruments on the ice.

Scientists use steam to make a hole in the ice so equipment can be lowered down in the ocean. The equipment, including a CTD rosette, nets and sensors, took samples and measurements from surface level down to as much as 4200 metres deep. Photo: J. Wallenschus

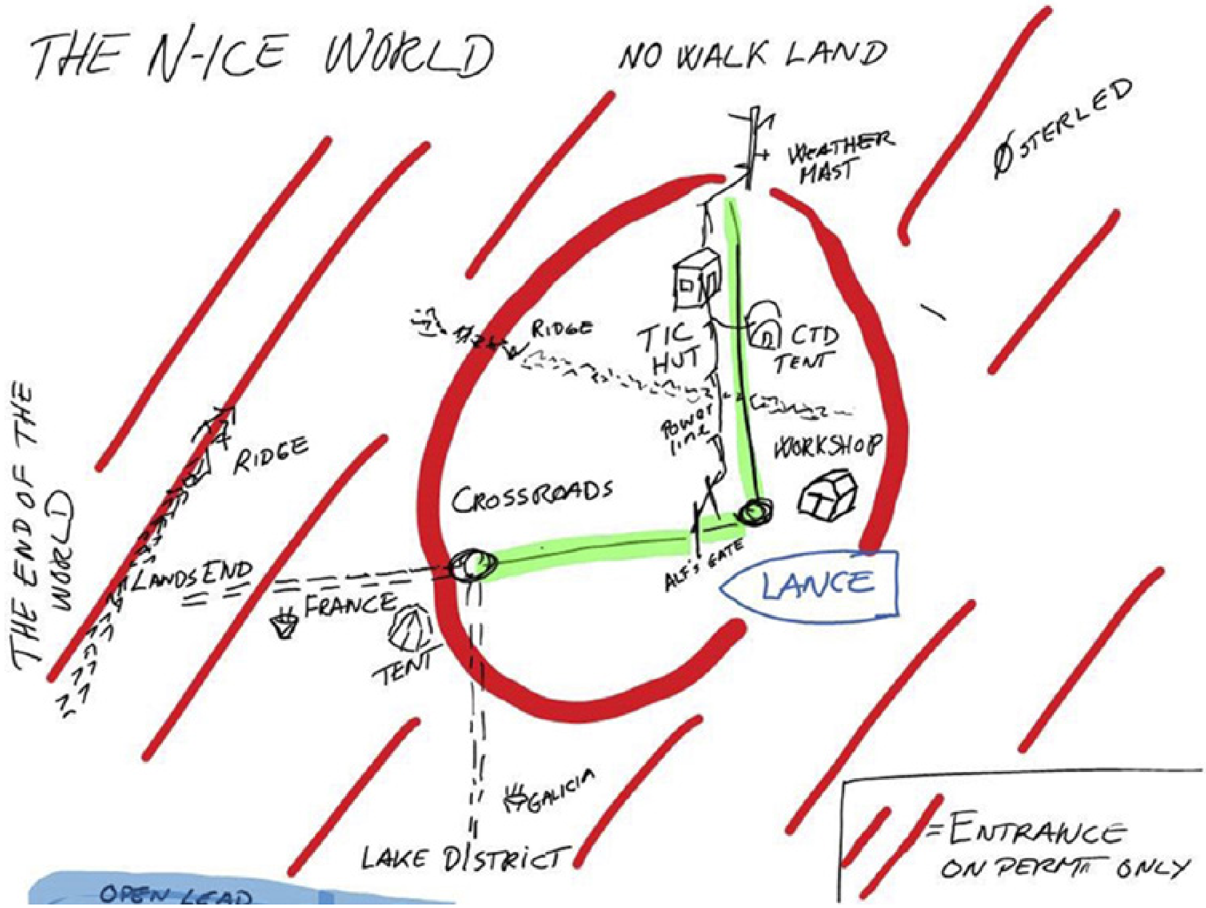
The N-ICE world

After the scientists had thoroughly mapped the ice floe around the *Lance*, identifying all the important features like flat snow surfaces and ridges, they set their plans into action and the ice camp took shape. Bearing in mind that the work on the floe might go on for months, they selected special areas for snow sampling and snow depth measurements where the snow would remain untouched.

Among the gear in place on the ice were a 2 m × 2 m lightweight shed (TIC hut) to house the electronics for oceanographic instruments deployed through the ice; a heated tent – with an oceanographic winch inside – atop a custom-built sledge weighing several hundred kilos, for sampling water and measuring salinity and temperature at various depths; and a 10-metre tall weather mast and instruments measuring chemical and physical variables in the air, as well as sensors in the ice for calibrating satellite measurements. Devices for measuring turbulence above and below the ice were also in place. Setting up a powerline stretching several hundred metres from the ship to the equipment on the ice took some effort in the cold.

With the research camp set up on the ice by the ship, work in the 24-hour darkness begins. The heavy snow that came with storms added to the challenge.
Photo: M. Granskog

"The N-ICE world", the cruise leader's sketch map of the research camp on the first ice floe, set up in the darkness of the polar night period. Ill.: H. Steen



Cruise leader Harald Steen made a drawing of "the N-ICE world". In the 24-hour darkness of the polar night, the footprint of the ice camp was limited by the reach of the *Lance*'s searchlights. Inside the main area were the TIC hut housing underwater turbulence instruments, the sledge tent for the CTD winch (temperature and salinity measurements) and the weather mast. Beyond lay "No Walk Land", the pristine sector of the ice camp where wind and turbulence were measured.

In the top right corner of the drawing, "Østerled"– a Viking name for lands to the east – represented a 4-kilometre wide lead that opened up during a storm from the north. The lead gave the scientists a chance to study new ice formation. Straight ahead from the *Lance*, a path led to "Land's End", the edge of the expedition's giant ice floe and the beginning of a first-year floe, where young sea ice was studied. In “France”, French scientists tested a new ocean profiler and placed a buoy; a second one was placed in “Galicia”. In the “Lake District” to the south, there was at one point an open lead. The scientists observed the lead’s development and sampled the ice as it froze over.

> *Getting the installations in place was an all-hands-on-deck operation. The sledge, which has a hole in the floor for lowering the CTD instrument that does water measurements, had to fit perfectly above the hole we had made in the ice. It was a doable task with 20 scientists at hand. We also had to make a hole next to the ship, for the ship’s CTD. Making a hole in flat ice is often relatively uncomplicated, but next to a ship that has ploughed into the ice is a different story. One-metre thick ice floes are stacked higgledy-piggledy, and frozen together into a thick concrete-like substance. Ordinary drills and tools are no good. Raw power, steam and tireless effort were our tools as we worked our way through the ice. It got a bit chilly as well, on the coldest days.*
>
> **Harald Steen**

During the first five weeks, the *Lance* was frozen in a floe that mainly consisted of second-year ice and stretched out for several kilometres. The large floe was surrounded by moving and dynamic first- and multi-year ice floes.

Although the ship did not shift a centimetre in relation to the ice floe to which she was joined, both ship and floe were in motion on the ocean. It was pitch-black, 30-40 °C below zero, mostly little wind and clear. Scientists working on the ice would measure the thickness of the snow and ice along lines. On board the ship, they continuously measured CO_2 levels of the seawater and collected samples from the deep ocean, along with plankton, which was also analysed. Weather balloons were released from the deck or the ice twice a day.

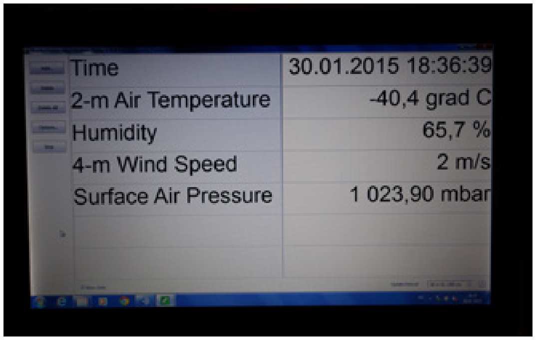
After the initial rush to set up the camp, the scientists and the technicians carried out their routines and work with little time to spare. There were fewer distractions than at home. With no mobile phone coverage, Internet or TV, they could look forward to sending short e-mails, playing PlayStation games, watching movies and listening to Norway’s P1 radio station when the reception was good.

The daytime darkness did not, however, limit all activities beyond the lights from the ship. On occasion, the scientist would go beyond “Land’s End”, their activities

Polona Itkin on a mission to deploy buoys in the drifting ice. Photo: B. Rotmo

only lit by their headlamps, which cast light some 20-30 metres. Scientist Polona Itkin and skier Ottar Skog, assisted by Arctic explorer and polar bear guard Bengt Rotmo, took on a challenging task. To get the bigger picture of the moving ice it was essential to deploy remote buoys in the drifting ice away from the ship. In pairs, they set out in the dark winter's day. They went on skis, which were better suited than snowmobiles to crossing the many leads and ice ridges. The cruise leader on board the *Lance* was prepared for a quick rescue mission should there be a mishap.

> *Most of Arctic science happens behind computer screens, in the silence and comfort of our offices. But as scientists we sometimes need to go out there and stick our hands, ears and noses into the cold, dark and windy world we are exploring. I had to dig up the snow, ski over leads and ice pressure ridges, learn how to handle scientific instruments while keeping myself warm. I have heard the noise of howling winds and breaking ice. Back in the office, I looked at the data we collected with a better understanding of what I'm studying. My N-ICE experience has marked me for life and made a better scientist out of me.*
>
> **Polona Itkin,** NPI sea ice scientist



Expedition leader Harald Steen admitted that "It got a bit chilly". On 30 January, the temperature dropped below -40 °C. A little later the temperature was down to -43 °C. Photo: M. Bratrein

Storm and 40 below

The first low pressure event came during the first days of February. On 30 January, the temperature dropped to 40.4 °C below zero. The weather forecast, especially made for the expedition by the Norwegian Meteorological Institute, indicated that a gale was approaching. Securing the camp became urgent. The scientists and logistics experts worried about leads opening up between the ship and the people and instruments on the ice. People stranded on the other side of a lead could not cross it on a snowmobile or walk around it, as these leads could stretch for many tens of kilometres. Inflated boats and rafts had to be ready.

Luckily, the first storm did not do any major damage and the work on board the ship and in the ice camp carried on. The *Lance* was still frozen in the second-year ice floe, which was surrounded by moving and dynamic first-year ice floes, with a

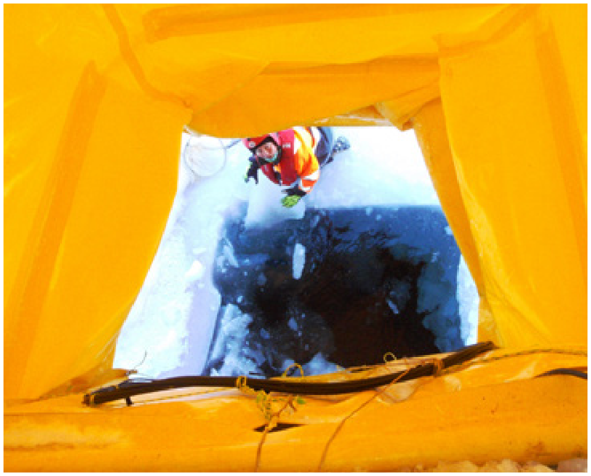
With the day's work done, the scientists enjoy an occasional dip in the hot tub on the deck of the ship. Photo: J. Wallenschus maze of pressure ridges, older frozen leads and newly formed leads. The scientists on board kept track of the situation using the ship's radar and satellite ice maps.

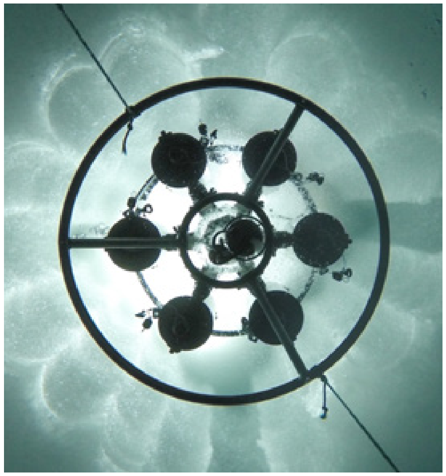
The Norwegian Polar Institute's physical oceanography team focused on the warm Atlantic seawater that flows into the Arctic Ocean through the gaps between Greenland and Svalbard to the west and Svalbard and Novaya Zemlya to the east. The warmer water mixes with the cold Arctic Ocean and changes the conditions in, and on, the ocean.

> *As the warm Atlantic water flows in at depth, it is separated from the Arctic sea ice by a layer of cold surface water. If heat from the Atlantic water penetrates this layer and melts the sea ice floating on the surface, it could strongly influence the thickness and the extent of the Arctic sea ice. This is why we're determined to find out more about these mixing processes.*
>
> **Paul A. Dodd,** NPI oceanographer, blog post

During the following weeks in the ice, the daylight slowly returned to the High Arctic and the *Lance* drifted north with the pack ice. Every morning, the scientists would start their chores on the ice and on board, and the science work progressed. The N-ICE2015 machine was like clockwork despite the challenging conditions. Then the drift suddenly changed, turning southward. The distance to the ice edge, 130 kilometres away at first, shrunk by 5 kilometres per day. Some days the drift of the ice floe was as much as 35 kilometres and the speed was 0.8 knots. On the morning of 15 February, N-ICE2015 leader Steen reported that the wind shifted from west to east: *"We are on our way picking up speed, currently drifting at 0.8 knots (about 1.5 km/h) with a 10 m/s tail wind. Pretty impressive, one might say."* He signed off saying, *"All is well at 81°48' N 20°26' E."*

Leg 1 was coming to an end. Everyone documented their routines and prepared for the handover to the fresh crew and expedition participants, who were supposed to carry on the work on board and in the well-established ice camp. A sudden lurch of the ship on their last evening, 17 February, signalled cracks in the ice floe that had opened up shipside. A large meteorological instrument (LIDAR) recently installed on the ice next to the ship was about to disappear into the deep. Hectic activity preserved this and other installations close to the ship, which were taken on board





Lowered over holes in the ice, custom-built tents protect instruments – such as a CTD rosette, which reveals the salinity, temperature and pressure in water samples from different depths – from the freezing cold air when they are pulled out of the water.
Photos: L. H. Smedsrud and P. A. Dodd

in a hurry. Early next morning, the ice was still breaking up. Clear skies and a pleasant -28 °C couldn't make up for the fact that there was barely time to properly hand over to the incoming crew of scientists and technicians.

Leg 2: Keep calm and carry on

Carrying the fresh batch of participants and a helicopter, the *KV Svalbard* once again came to assist the *Lance*. Thirty-four scientists and crew were safely delivered to the *Lance*, and 30 left. The exchange took four helicopter flights. Taking advantage of the short time they had together with the incoming researchers, leaving scientists passed on essential information. From the air, those leaving could see that the situation with the ice was a lot more serious than they had imagined. The vast ice fields had broken up into small floes and there was complete disorder around the ship. The new expedition participants quickly had to dismantle the equipment remaining on the ice, an impressive effort in the 30 centimetres of freezing cold slush that covered the floes.

Having deposited the leaving expedition members in Longyearbyen, the *KV Svalbard* returned to the *Lance* two days later to help relocate her further into the ice. On 24 February, a suitable floe was found at 83°00' N 27° 20' E. Relocating cost the N-ICE2015 field campaign a week of data collection. This particularly affected the ice thickness and snow time series, as the same ice and snow could no longer be followed. In hindsight, the scientists recognised the value of achieving similar findings on a new ice floe.

The atmospheric team from the Norwegian Polar Institute had brought instruments for measuring the atmosphere on the surface of the ice floe and above it. The 10-metre high tower was outfitted with sensors measuring the temperature, humidity, wind and radiation, as well as energy and gas fluxes. To learn more about conditions higher up, the scientists from the Korean KOPRI and German AWI institutes released helium-filled weather balloons bearing sensors that measured temperature, humidity and wind as they rose up through the atmosphere and transmitted their data in real-time to the ship. This data was also transferred in near real-time to the global network of meteorological data, so it could be used in weather forecasts.

Atmospheric scientists from Washington State University aimed laser beams at the sky to measure the properties of clouds. Clouds are important as they limit how much of the sun's heat reaches the surface of the sea ice, but clouds also trap heat at the surface, like a blanket. These two effects vary between the seasons.

After nine weeks in the ice, the *Lance* was still going strong and there had been no serious accidents or injuries. Safety drills kept people on their toes. Working in the dark, with dynamic ice, polar bears, snowmobiles and heavy gear a part of everyday life, it was not hard to imagine that dangerous situations could arise.

Cruise leader Harald Steen finds a spot to work on the ship's bridge during the darkness of the day.
Photo: J. Wallenschus

The *Lance* sails through a lead in the ice made by the Coast Guard.
Photo: N. Cobbing

A Korean scientist releases a tethered balloon. Hoisted up and down with a winch, it measures temperature, humidity and winds in the lower atmosphere.
Photo: T. I. Karlsen

But there had been challenges. At the beginning of March, sounds and other clues told the experienced captain that there was increased pressure on the vessel's hull. Nearly a week later, the *Lance* was lifted up by the pack ice.

> *The pressure of the ice came from the starboard side. At six o'clock in the morning we saw an ice floe coming towards us, on top of the floe we were moored to. It was larger than a football pitch, and it moved quite fast. It hit the side of the vessel, then it fell back on top of the ice. There were already two layers of ice there, so now there were three, measuring nearly 16 metres to the top of the hummock ice ridge. The whole vessel was lifted about 1.5 metres up.*
>
> **Johnny P. Hansen,** Captain, *RV Lance*

The captain knew the vessel well, and he was never afraid that the old *Lance* would be crushed by the ice. Although she was not an icebreaker, the hull was reinforced steel and she was very strong. To make sure that everything was in order, a camera was lowered down under the ice to check the rudder and the propeller. Luckily, nothing had been damaged.

Pages 56-57 → The *Lance* is hard to spot in the mighty Arctic landscape. Photo: N. Cobbing

The US National Aeronautics and Space Administration (NASA) flies over the science camp to take measurements of the ice. Photo: G. Spreen

Aircraft overhead

Most of the scientists spent three or six weeks on board. The turnover of personnel meant that many researchers could participate in the expedition and a wide range of projects could be carried out. Some partners, however, never set foot on the *Lance*. NASA's Operation IceBridge, an extensive American project in the Arctic and the Antarctic, flew a C-130 Hercules airplane over the ice camp on 19 March, measuring the thickness of the sea ice and the snow on top of it.

We normally use satellites, aircraft and helicopters to take measurements from above, in addition to ground surveys. This flight operation, which was conducted simultaneously with measurements on the ice, gave the NPI and international scientists an opportunity to exchange and compare the data, which was added value for both parties.

Sebastian Gerland, NPI Section Leader and sea ice scientist, Cruise Leader of Leg 4

The flight over the site lasted only a few minutes but had been planned a long time ahead. The airplane flew all the way from western Greenland and returned there immediately. The IceBridge data helped the N-ICE2015 scientists interpret the information gathered in and on the ice around the *Lance* and place it in a larger geographical context. In turn, the data collected in the ice camp improved NASA's interpretation of their airborne measurements. It was a rare opportunity to combine on-ice observations with an overflight.

The British Antarctic Survey, in collaboration with the Technical University of Denmark and the European Space Agency, also took the opportunity to better their understanding of the development in the Arctic sea ice through a dedicated airborne campaign. Their EU project Ice, Climate, Economics – Arctic Research on Change (ICEARC), linked physical social sciences with indigenous peoples' knowledge and economics to better understand the socio-economic impact of Arctic sea ice loss. The Norwegian Polar Institute was a partner in the project. The British Antarctic Survey's Twin Otter aircraft, equipped with radar, aerial photography equipment and lasers that scanned back and forth over the sea ice, made two overflights of the area around the ice camp. The unique combination of data from the flights and on-the-ground measurements that N-ICE2015 researchers collected at the same site would improve the accuracy of satellite-derived values of sea ice thickness and sea level height.

Making observations on the ground, from the air and from space simultaneously, gave us a better understanding of the physical characteristics of the sea ice. The laser scans paired with photographs made it possible to build a 3D model of the ice. We ended up with a very accurate mosaic of what the ice field looks like.

Jeremy Wilkinson, British Antarctic Survey sea ice scientist

Heading south

Daylight gradually seeped back to the Arctic in March. The scientists were no longer totally dependent on the ship's searchlights and their own headlamps. Much valuable work was getting done and loads of good data were retrieved from the *Lance*'s icy surroundings in the Far North.

Daiki Nomura and Anna Silyakova studied the chemistry of greenhouse gases in seawater, sea ice and the atmosphere, collecting samples of seawater and the top of the sea ice for analyses. They measured the fluxes of carbon dioxide and methane – important greenhouse gases – from the snow and the ice surface.

> *The water samples will later be analysed back home for concentration of dissolved gases, which will provide information on how carbon dioxide, methane and bromoform are distributed in the water column under the sea ice, down to a depth of 1000 metres. We also collect ice cores from different places around the ice floe, which varies in thickness from 40 centimetres to 3.6 metres.*
>
> **Daiki Nomura,** Hokkaido University (Sapporo, Japan), and **Anna Silyakova,** UiT The Arctic University of Norway (Tromsø), blog post

With Leg 2 of the expedition coming to an end and Easter right around the corner, the *Lance* was to sail back to Longyearbyen for a planned break. It had been estimated that the ship would drift southwards, out of the ice, so going back to Longyearbyen to refuel and change crew and expedition participants was convenient.

As the *Lance* headed southwards towards Longyearbyen, the extent of the Arctic sea ice cover was much larger than when they entered the area – reaching all the way down to the island of Nordaustlandet. The ice was compact, compressed by the wind, and the ship made slow progress. But the old lady was sturdy, the crew were skilled and the expedition reached Longyearbyen in time for Easter.

The *Lance* was suddenly surrounded by cracked-up ice floes and leads on 18 February. Just a couple of hours earlier, the ice floe around the ship had harboured the sheds, tents and instruments of the research camp. Photo: N. Cobbing

CHAPTER 5

Springtime discoveries

On 15 April 2015, the *Lance* was again ready to head out for another three months in the ice. Data and samples gathered during the first three months had been offloaded, along with equipment and supplies that were no longer needed; new equipment was brought on board. The time in Longyearbyen waiting for everything to be in place had been well spent preparing the gear and rehearsing its use, as well as doing safety training, especially with polar bears in mind.

Scientific diver Piotr Kuklinski checks a sediment trap that collects biological material that dribbles down from the ice and the meltwater just below it. Photo: P. Leopold

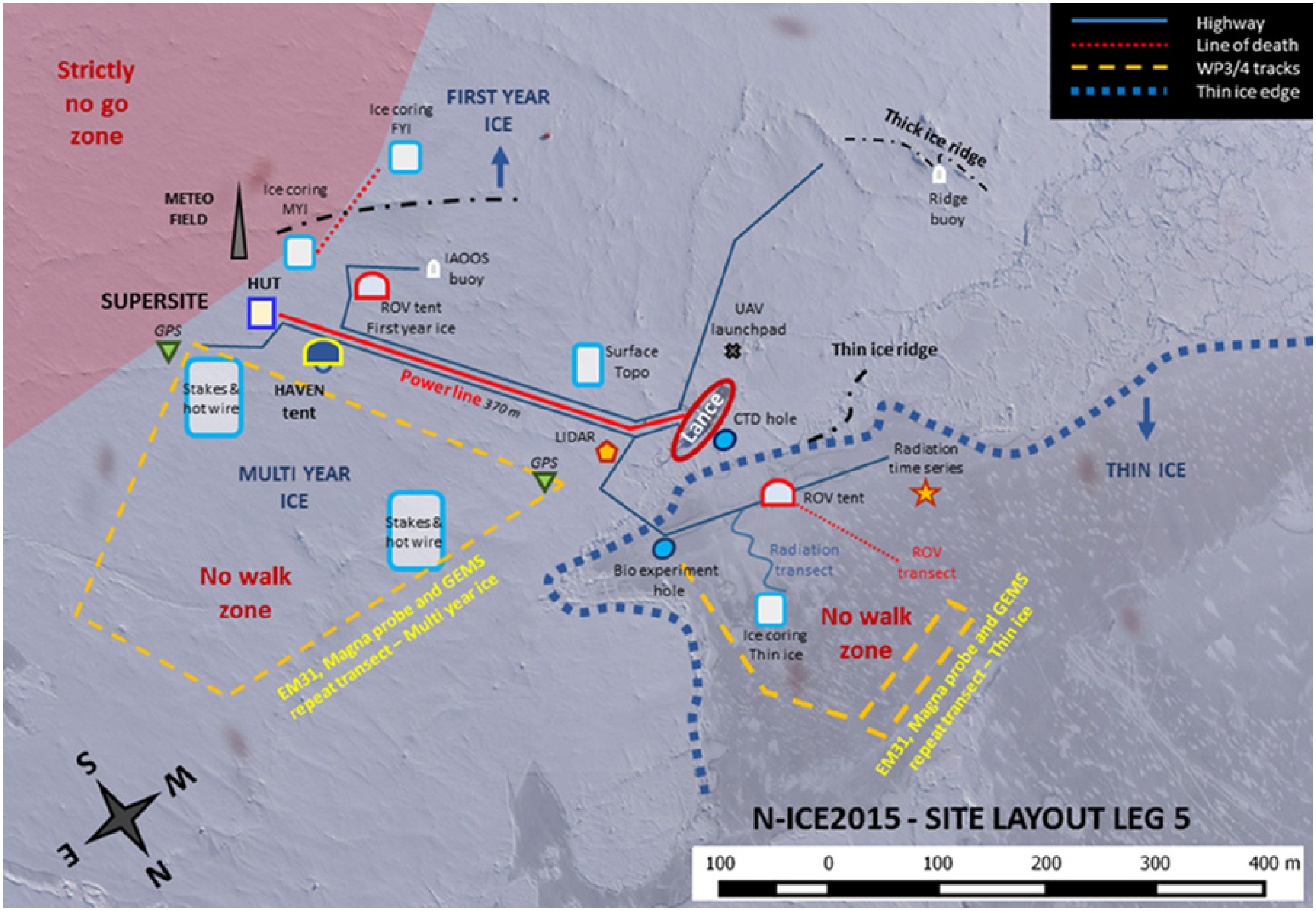
Solar radiation and the ecosystem

The *KV Svalbard* again escorted the *Lance* into the ice. It was another tough voyage, since the ice is at its thickest this time of the year. They found a satisfactory ice floe just beyond 83° N, where the *Lance* anchored up. Working conditions were significantly better, though, as the daylight had returned. The plan was to drift passively with the ice floe until it was no longer suitable for work. After this drift southwards had ended, the *Lance* would head north again, find a new floe and the work would continue. There would be special focus on studying the effects of solar radiation and the functioning of the ecosystem, using a helicopter, remotely operated vehicles (ROVs), drones and divers.

A helicopter was now stationed on board and was used for measuring the thickness of the thinning sea ice cover over large areas and for installing drifters and buoys so ice movement and thickness could be monitored far away from the ship. Although spring had come, conditions were still wintery on Leg 3 of the expedition. The cold air was moist and the helicopter produced its own local ice fog, which made take-off and landing difficult. When the helicopter landed on the ice, it could not stop for long – not even for an hour – as it was sensitive to the cold and parts might freeze.

The overall goal of the expedition was to understand the effects of the Arctic's new sea ice regime on energy fluxes, ice dynamics and the ice-associated ecosystem as well as on the local and global climate. One of the researchers' secondary aims was to understand how the ocean's heat mixes upwards towards the sea ice and how much this contributes to ice melting.

> *The N-ICE expedition was like nothing I could've imagined. It was really intense, with lots of storms, and at times it felt lonely. I was one of 20 scientists on board. My job was to measure as many things in the ocean as possible: how heavy the ocean is, its temperature and salinity, and the currents: where and how fast the water is flowing. So I drilled holes in the ice and dropped various instruments into the ocean below, every few hours. Each drop of seawater has a story. With the observations I collect, I can tell where the water has been, where it's going and how it's impacting sea ice!*
>
> **Amelie Meyer,** NPI oceanographer



Site layout for the research camp on Leg 5. The site was the same for Legs 3 and 4, as the *Lance* was attached to the same ice floe during these three legs of the expedition.

The researchers also wanted to find out more about the effects of solar radiation on the first-year sea ice in the region and how this ice is affected by the atmosphere, snow and ocean. Because there had been a general loss of sea ice in both thickness and extent but also growth in places due to snowfall, it was necessary to quantify the changing mass of the Arctic sea ice and its snow cover. Other important tasks were to measure the dynamics of the drifting ice, understand the ice-associated ecosystem

Philipp Assmy, NPI, examines samples of marine algae in the lab on board. Photo: P. Kuklinski

and model future changes. Ice cores were drilled and cut and sections of them were melted and filtered for analysis of physical and chemical parameters. Looking for small invertebrates and ice algae, the scientists also examined the ice cores for biological activity.

Leg 3 of the expedition was well on its way.

Green soup versus clear waters

The Midnight Sun shone all through the night as spring settled on the High Arctic. Temperatures were mostly between -10 and -20 °C, which made work much easier than during the first two legs of the expedition. Slowly life in the slumbering marine ecosystem awoke, and the ice pack and the ocean started to take up the heat from the sun. The seasonal cycle of snow and ice melt was beginning, and the scientists were eager to study everything about it.

The scientific work had been planned for years. More activities were interdisciplinary during this part of the expedition: geophysicists, atmospheric scientists, chemists and biologists worked together. There were more open cracks in the ice – leads – and the processes happening above, in and below the thin new lead ice were highly interesting.

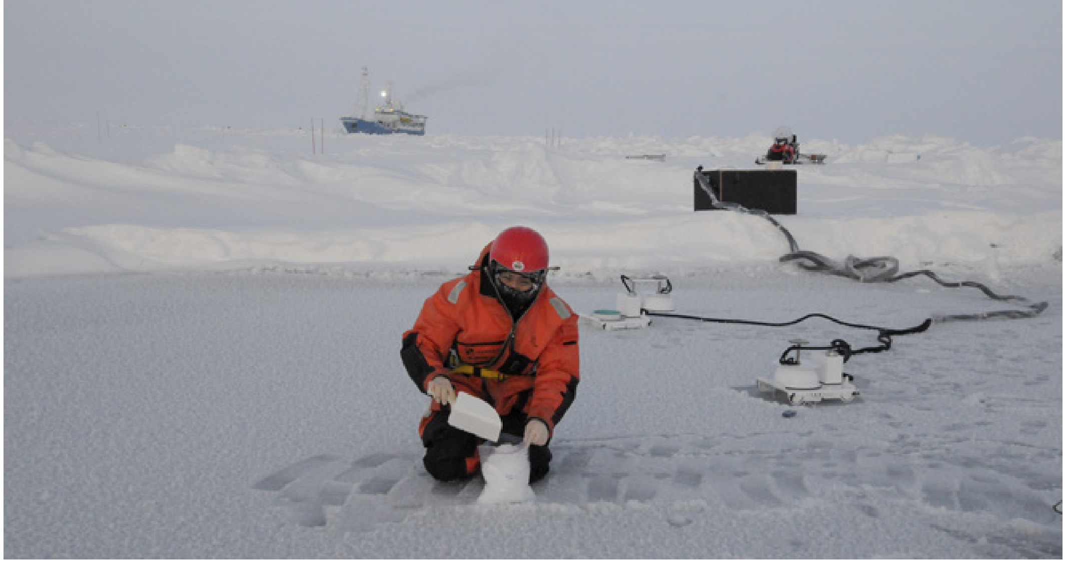
Helicopters bring new scientists, technicians and crew to the *Lance*, and those leaving are flown back to Longyear-byen. Photo: H. Hop

When the Lance *came to the ice floe she is still moored to, about three weeks ago, the main workplace for the scientists was a first-year sea ice floe [later found to include older ice] off the starboard side of the ship. By now, an earlier open lead off the port side is covered by thin sea ice, making it an excellent additional working site, and a scientific hotspot.*

Sebastian Gerland, report on 11 May

A sudden crack in the ice forms an open lead on 20 April. Only metres away, research equipment has to be relocated without delay. Photo: P. Leopold

Studies of thin sea ice in leads are rare. Compared to thicker ice, the thinner, snow-free ice that forms on leads allows for much larger energy fluxes between the atmosphere and the ocean. Because the sun's energy penetrates this type of ice much more easily than thick multi-year ice, some of the ecosystem-related processes that typify spring start there first. Better knowledge of leads is very useful when it comes to developing more realistic climate models. The ice on the lead off the *Lance*'s port side

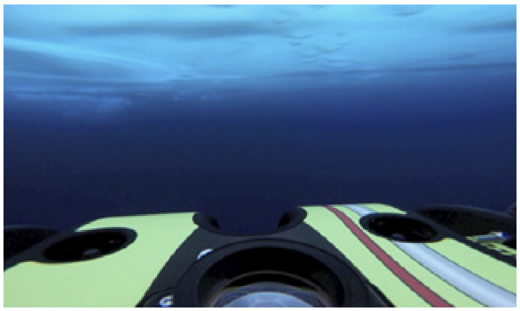


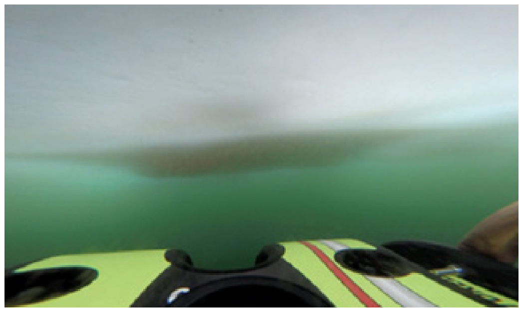
A scientist scoops up snow samples, while instruments on the lead ice measure CO_2 gas levels. Photo: D. Nomura

thickened to 15 centimetres over a few days – strong enough to carry the scientists who investigated the processes of the lead system.

While the ROV logged the effect of solar radiation below the ice, another radiometer collected complementary data on the ice surface. This allowed the scientists to measure how much energy entered the sea. It also gave a very good general impression of the underside of the ice and changes in the transparency of the water just below the ice.

C. J. Mundy, of the University of Manitoba in Canada, operated the ROV, video-recording conditions underneath the ice. The ocean was so full of phytoplankton and zooplankton that the scientists compared the visibility to driving a car in a snow blizzard – or "green soup", as Mundy put it – whereas a few weeks earlier the water had been as clear as bottled drinking water and snowmobile tracks on the surface of the ice could be seen from the submerged ROV.





ROV footage from 12 May shows clear, blue water. On 26 May the conditions have changed: the water now resembles green soup on account of the under-ice bloom. Photo: C. J. Mundy

An amphipod seems to study its reflection in a bubble under the sea ice. Photo: P. Leopold

Meanwhile, divers collected samples of ice algae as well as the single-celled organisms known as ciliates and ice-associated zooplankton.

> *We were four scientific divers who did 88 dives below the sea ice from 21 April to 19 May. At first, the water was pitch dark because of the 1.5-metre thick ice covered by 40 centimetres of snow, and it took some stamina to jump into the nearly -2 °C cold and dark water. The first plunge with headlights and research gear was a mental challenge – you literally couldn't see anything away from the light cone. The project was very exciting, as we collected samples from even before the production and ascent of zooplankton in the ocean started and could follow the development along the way.*
>
> **Haakon Hop,** NPI marine biologist and scientific diver, participant in Legs 3 and 4

The timing was perfect for the biologists. The first weeks the divers found only over-wintering zooplankton under the ice, which included small cyclopoid copepods, pelagic sea slugs called sea angels and comb jellies. The zooplankton, including the relatively large Arctic copepods, are food for jellyfish, fish and even whales. Then, around mid-May, calanoid copepods that had overwintered at depth suddenly arrived below the ice, increasing rapidly in abundance towards the end of May. Understanding these massive under-ice blooms of life will give insights into the Arctic future, when there will be far less ice in summer.

> *The calanoid copepods had come up before the ice algal bloom had started and had to swim and wait for a week or so for the bloom to get going. Interestingly, the bloom didn't start below the newly formed ice, but at the ridges around its borders, where light levels were lower. The ice algae are shade-adapted, so too much light is harmful. The first brown layer that we found below the thin lead ice was not ice algae at all. It turned out to be a small and fast ciliated species that is responsible for red tides further south. Leads in the ice act as windows to the water column and, thus, become hotspots for biological production during spring.*
>
> **Haakon Hop**

A species of the group of marine slugs known as sea angels, *Clione limacina* spends the winter under the Arctic sea ice. Photo: P. Leopold

Hot dogs and a parade

The scientists worked hard but it was not all toil and moil on board the *Lance*. Norway celebrates the country's national day – Constitution Day – on 17 May, when, in 1814, the constitution that declared Norway an independent kingdom from Sweden was signed. Across the country, flag-waving Norwegians gather in the streets to join or cheer on parades of marching bands, schoolchildren and a spectacular array of clubs and associations showcasing their activities. On board the *Lance*, the Norwegians invited everyone to take part in the celebrations. Hot dogs – the traditional 17 May snack – was served and there was a grand parade on the ice around the ship.

Doing mostly routine measuring and sampling for up to 12 hours a day on an ice floe can be exhausting and monotonous. Everyday life on board included work in the ship's laboratories, meetings and discussions, suiting up for the cold and undressing and – last, but not least – meals. Getting together for a meal gave the participants a sense of normality and broke up the monotony. Though the days might seem to run together, everyone knew that on Saturdays there would be a traditional Norwegian meal of rice porridge and sour cream porridge, with herrings on the side. Social gatherings are crucial for the morale of people in harsh surroundings, isolated from the rest of the world.

The expedition celebrates Norway's Constitution Day, on 17 May, according to tradition, with a parade and flags. Since there is no brass band on board, the creative crew make use of metal boxes to beat the rhythm.
Photo: M. Granskog

Legs sinking deep down into the wet snow, stumbling, sliding and falling, but great fun all the same. Photo: F. Lamo

One morning in June, the captain walked up and down the bridge with a yellow football under his arm and a smile on his face. Two crew members on snow-mobiles made a field of compact snow on the ice and the pitch was ready for the match of the year: the *Lance* crew team versus the N-ICE2015 team. It was great fun for everyone, even though the crew members kept singing "We are the champions" for the rest of the day.

The Lance *crew were very professional and gave us great support. The food was excellent. The work environment was extremely fascinating and inspiring. I have been on many scientific cruises, but what I remember best from this one is the enthusiasm of the people around me. As cruise leader, I had to see to it that the scientists and the technicians got enough rest and took the time to eat. They would gladly work around the clock if they could. In the early spring the white ice twinkled in the sunlight day and night, and the beauty of the surroundings was breathtaking.*

Nalan Koç

The beeping sound of science

The questions the N-ICE2015 scientists had could only be answered by thoroughly examining the sea ice. The qualities of snow and sea ice show variation even within centimetres; over kilometres the differences can be enormous. During Legs 3 and 4, the ice floe to which the ship was tethered had thickened. At the beginning of Leg 5, the new ice on the port side of the *Lance* was around 25 centimetres thick, with a topping of 4 centimetres of snow. Now it was thinning day by day. Around the rest of the ship there was older ice, mostly 1.2 to 1.5 metres thick, with snow depths between 20 and 60 centimetres. The sea ice ridges reached down to 16 metres and rose 4 metres above the ice surface.

Every few days, the scientists measured the snow depth and sea ice thickness with high precision instruments along a 1-kilometre standard track. The instruments' beeping became known as "the sound of science". The researchers also performed more extensive transects in the area, 3 kilometres around the *Lance*, allowing them to

"The sound of science" on its way into action. The snow depth probe is pushed down through the snow to the top of the sea ice. As many as 1000 measurements of snow depth were taken on some days. Pulled along on the sledge are electromagnetic instruments that measure sea ice thickness and porosity (the amount of water in the ice). The antenna sticking up from the backpack is attached to a GPS that gives the position for the measurements taken.
Photo: A. Rösel

compare their home floe with the surrounding ones. *"Is our floe a typical site for this region? Yes, it is!"* Marcel Nicolaus of the German Alfred Wegener Institute reported on 5 June.

On 5 June, the participants of Leg 5 had their last day on the ice floe. The floe had drifted southwards and was now breaking up. The research instruments had to be taken back on board, no easy task with cracks appearing in the ice all around the ship.

> *This must be one of the world's most intensively studied ice floes. Researchers have been crossing, poking, drilling, measuring and sampling it for the past 7 weeks. We have studied not only the floe and its snow cover, but also the air above and the water below. Our floe drifted southwards, at times at speeds reaching 1.1 knots, and eventually it became part of the marginal ice zone. We drifted mainly across the Yermak Plateau. Water depths plunged from 500–600 m across the plateau to now 2200 m on the way down to the abyss.*
>
> **Nalan Koç,** blog post

The marginal ice zone – where the sea ice cover meets the open sea – is very dynamic compared to the conditions deeper in the ice-covered area. Northerly strong winds tossed the ice around, and leads were opening and closing constantly. The *Lance* also seemed to hit upon a polar bear "highway". Curious bears paid several visits, showing particular interest in the red poles the scientists had stuck in the ice. There were also more seabirds – northern fulmar, black-legged kittiwake, ivory gull and Brunnich's guillemot were frequently sighted.

The time had come to head back into the ice north of Svalbard again. A suitable floe was found, and the busy bees on Leg 5 established the new camp there in just one day, on 7 June – quite different from the dark days in January when it took a week to do the same. Everything was ready for the final leg of the expedition to begin.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CHAPTER 6

The final break-up

Flying conditions were superb when the Super Puma helicopter flew in new crew, scientists and technicians to the *Lance* and fetched those who had finished their work. From their airborne vantage point, the newcomers spotted the first ice at 80˚2' N. When the helicopter reached 80˚40' N, the ice cover consisted of large floes with dense ice. They found the ship at 81˚06' N, about 36 km from the ice edge. With a drift of up to 0.9 knots (1.8 km/h), it would not be long until the drift would take them to warmer waters and the open ocean further south.

As the last ice floe to which the *Lance* was anchored rapidly disintegrated, the research camp gear floated on several small floes. Photo: M. Granskog

If you were an Arctic alga, where would you like to live?

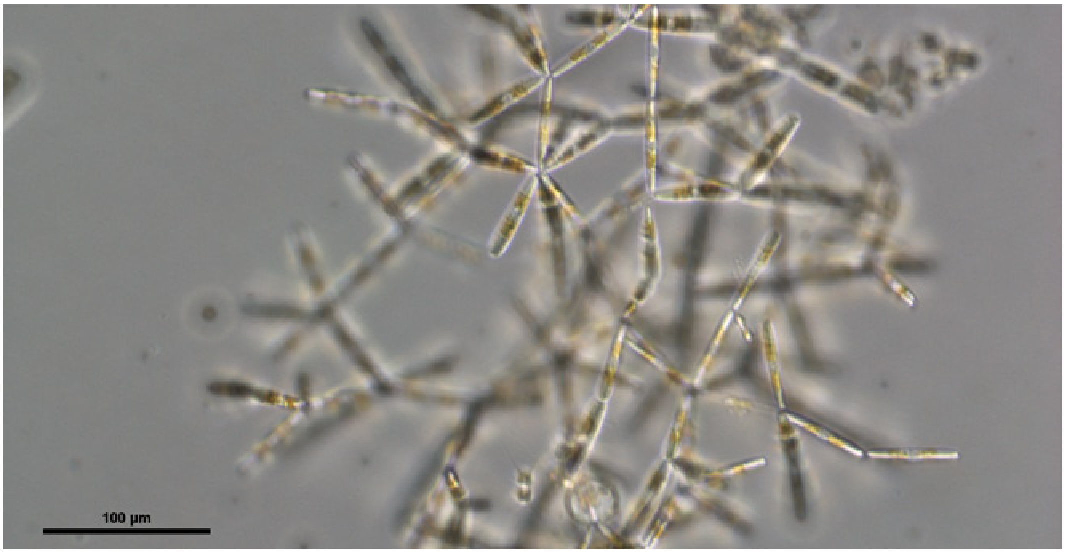
This time, the scientists wanted to document the process of ice melt from above and below by keeping their instruments up and running on the floe until the last moment. Wave motion is stronger where there is less sea ice, so there was a chance that waves or swell would suddenly break the ice floe apart.

The biologists sampled the ice every day to see how the ice-associated system works. With snow on top of the sea ice, preventing light from penetrating, the Arctic Ocean seems a dark and barren place. Yet the microscopic, unicellular algae called phytoplankton thrive in this special environment. They are among the smallest organisms on the planet, but they run its largest ecosystem, the oceans.

When, late in May, the ice and the water started to turn brownish-green even with thick snow on top of the ice, excitement spread among the biologists.

> *We had drifted into a massive phytoplankton bloom growing below the sea ice, covered by 40 cm of snow. This came as a surprise to us as very little light penetrated the snow-covered ice. The answer was found in large cracks in the ice, so-called leads, that acted like windows to the water below and triggered the large under-ice phytoplankton bloom.*
>
> **Philipp Assmy,** NPI biologist

The diatom *Nitzschia frigida* is among the dominant species of ice algae in the Arctic Ocean. Old sea ice acts like a seed bank for the algae in the coming spring season. If the old sea ice disappears, ice-associated algae like this one will be threatened. Photo: P. Assmy



Mats Granskog concentrates on reading the computer screen outside, in bright daylight, to control an instrument which measures radiation. Photo: S. Gerland

Ice algae also profited from the newly formed ice in the leads. In fact, the levels of light were so high that the ice algae produced "sunscreen" to protect themselves against the damaging ultraviolet radiation. The ice algae living in thicker ice with heavy snow cover grew slowly, as they did not have the benefit of much light coming through.

We know that there are single-celled algae living in the water and in the ice (phytoplankton and sea ice algae). And we also know that there are small shrimp-like animals (zooplankton) that like to feed on them. But the phyto-plankton and the sea ice algae are tiny and cannot be spotted by the eye, so to find them we have to ask ourselves this: If I were an Arctic alga, where would I like to live? I like sunlight and nutrients, and my enemies are zooplankton and strong currents. Thick ice and snow prevent sunlight from reaching the sea water, which is where the nutrients and the grazers are. Therefore, sea ice algae are usually found in higher concentrations at the bottom of the sea ice. However, during our observations on our home floes during Legs 5 and 6, we discovered greenish, brownish layers of algae thriving in a variety of environments.

Mar Fernández-Méndez, NPI biologist

At these latitudes, sea ice starts to melt towards the end of June. The forces driving the melt are solar radiation and heat accumulated in the ocean. Although there was no melting at all on some days, on other days the scientists saw warm water chew up tens of centimetres of ice. The metre-thick ice floe was about to disintegrate.

The Line of Death

The work on the ice and on board went smoothly. Previous experience had ironed out kinks in handing over to new batches of researchers and technicians and setting up camp. Reports that earlier participants had sent back to their institutes had prepared new arrivals for what was coming. One thing they had to learn fast, though, was the lingo.

> *Coming on board the* Lance, *jumping into experiments that had already been running for several weeks, I had to learn that there is a specific language on board. It was not a question of whether there was more English or Norwegian spoken on board, but we used a lot of names and abbreviations that I had not met before.*
>
> **Marcel Nicolaus,** Alfred Wegner Institute sea ice physicist, blog post

Biologists check for algae bloom in melt ponds on top of the sea ice. As the weather gets warmer, melt ponds form on the sea ice and melt the ice from the top.
Photo: M. Fernández-Méndez

"The Supersite" needed to be checked every morning. In this area the main installations were a weather mast and turbulence and radiation sensors. Photo: N. Cobbing

At the beginning, the N-ICE2015 "world" had been established with special names for the different locations and installations. Now, toward the end of the expedition, some of the scientific activities had changed, bringing new terminology. The oceanographers ran what they called an "MSS marathon": they lowered a microstructure sonde (MSS) into the ocean through a hole in the ice, measuring differences in water movements at a very fine scale all day long. Back on board afterward, they would disappear into the Play Station Lab. This was a recreation room originally equipped with a Play Station but, as everyone was too busy to make use of it, a high-precision salinometer – which determined the saltiness of seawater – was set up there.

The atmospheric scientists conducted "Supersite checks", which included daily check-ups of the weather mast, a turbulence mast and the precipitation bucket that collected any kind of precipitation. Out on the ice was the strict no-go "Line of Death", beyond which surface radiation was measured so the surfaces had to be left untouched.

Cracking up and wrapping up

The N-ICE2015 Expedition was drawing to an end. During Leg 6 the ship had drifted along with a rather thin ice floe, which was several kilometres across at the outset, near the ice edge north of Spitsbergen. Day by day, winds and currents pushed the floating ice closer to the open ocean. The scientists felt that every day might be their last on the floe.

> *We followed the fate of the floe with great interest to understand the factors controlling the melting of sea ice of the region. It was a challenging time of the year to work on the ice, as it was thinning rapidly. We had to be careful when moving about, wearing our survival suits and safety gear at the ready. It was also a period that had seldom been observed. All the more rewarding for us to follow it to the bitter end.*
>
> **Mats Granskog**

When the break-up finally came, on 19 June, it was more abrupt than anyone could have expected. The expedition's home floe had almost reached open water when cracks suddenly appeared by the ship's side. Within minutes the floe had disintegrated into smaller floes, no bigger than some tens of metres.

A small boat navigates around a multitude of small ice floes to retrieve equipment after the floe had broken up.
Photo: M. Granskog

The last ice floe disintegrated within a couple of hours on 19 June. The research camp had to be hurriedly evacuated as the ice broke up and shifted around. Photo: M. Granskog

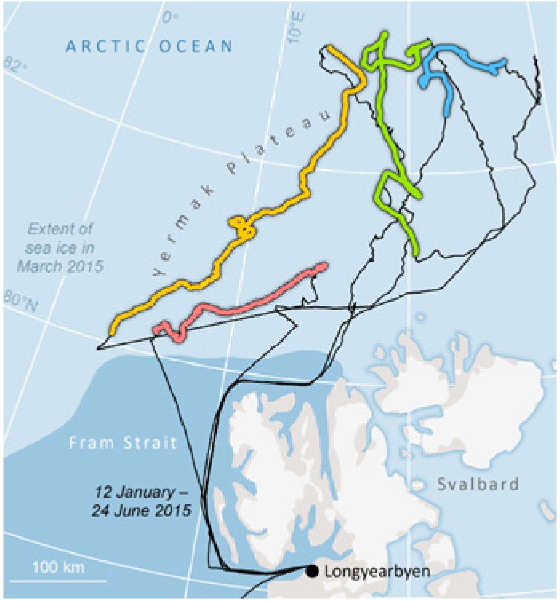
There was hectic activity on board. Our equipment and camp were spread out over several of these small floes, and we started a rescue operation to salvage the gear. Luckily, with all our previous experience, this was done swiftly and safely, despite the challenging conditions. We managed to salvage all the equipment that was floating away, and no one was injured during the operation.

Mats Granskog

The last days of Leg 6 were spent drifting alongside the small floes to find out what happened to them and how they melted. Also, how did this and the suddenly larger areas of open water affect the biology in the water column? Delicately manoeuvred, the ROV was deployed below the mobile ice pack, its support team on the ice and a rubber boat ready.

When the *Lance* sailed into the port of Longyearbyen on 24 June, the field phase of the N-ICE2015 was over. There had been no major safety incidents during the six months in the sea ice. *"Pretty amazing, considering the harsh conditions, the remoteness of the ship and the long working hours"*, according to Harald Steen and Mats Granskog. Safety training had been given by experienced personnel at the NPI, but not everything can be prepared for.

During the N-ICE2015 expedition, the *Lance* drifted with floe 1 (green) from 15 January to 21 February, floe 2 (blue) from 24 February to 19 March, floe 3 (orange) from 18 April to 5 June and floe 4 (red) from 7 to 22 June.



Overall, the field campaign has been a great feat, and all the participants and support personnel have to be given all the credit for the success. Throughout the campaign the ship's crew have worked marvellously and helped us when a problem needed to be solved. They also used their experience from earlier tests to improve what could have gone wrong in the cold. They are simply the best. The kitchen made it impossible to lose weight despite the long hours of calorie-burning activities in the cold.

Mats Granskog and **Harald Steen**

The conclusion of the field campaign was by no means the end of the N-ICE2015 project. For the scientists it was the beginning of a new, busy phase. It was now time to analyse and make sense of the heaps of data that had been amassed. Quality control, processing and understanding the data, writing scientific articles and sharing what had been learnt with the global scientific community and the general public would continue for several years.

Norwegian Young Sea ICE Expedition (N-ICE2015)

Project owner and coordinator

Norwegian Polar Institute (NPI)

Norwegian collaborators

Norwegian Meteorological Institute (MET Norway)

Norwegian University of Science and Technology (NTNU)

The University Centre in Svalbard (UNIS)

University of Bergen (UiB)

UiT The Arctic University of Norway (UiT)

International collaborators

Aarhus University (AU), Denmark

Alfred Wegener Institute (AWI), Germany

Arctic and Antarctic Research Institute (AARI), Russia

British Antarctic Survey (BAS), UK

Cold Regions Research Engineering Laboratory (CRREL), USA

Colorado State University (CSU), USA

Danish Meteorological Institute

European Space Agency (ESA)

Finnish Environment Institute

Finnish Meteorological Institute (FMI)

Hokkaido University (HU), Japan

Korea Polar Research Institute (KOPRI)

National Aeronautics and Space Administration (NASA), USA

Pierre and Marie Curie University (UPCM)
– now Sorbonne University/CNRS, France

Technical University of Denmark

University of Manitoba (UM), Canada

University of Porto, Portugal

Washington State University (WSU), USA

Woods Hole Oceanographic Institute, USA

Photo: A. Meyer

CHAPTER 7

Visitors from far and near

Scientific knowledge and technological innovation are of great benefit to our society. They are crucial for major decisions on how to best manage important ecosystems like the oceans and the rainforest, cut emissions and promote new energy supplies. The world's decision makers must receive scientifically sound advice. It is equally important that the general public stay up to date on the latest research. The N-ICE2015 expedition reached out widely.

Visitors arriving by helicopter were met by this breathtaking view of their destination.
Photo: S. Sikora

Big media

The Norwegian Polar Institute posted updates about the expedition on its social media platforms and the institute's website hosted a regular blog written by the scientists on board. To reach a much larger international audience, prominent media representatives were invited to visit the N-ICE2015 expedition.

> *We had limited space to transport media and visitors, so we targeted some of the best. A story combining climate research, tough fieldwork and a sense of adventure with historic ties was definitely of interest, and we were pleased to see that they accepted our invitations.*
>
> **Stig Mathisen,** NPI Information Section Leader

The N-ICE2015 expedition made the front cover of *National Geographic* magazine in several countries, including Portugal (January 2016).

During the dark polar night of Leg 2 of the drift, a journalist and a photographer representing the renowned National Geographic Society visited the *Lance*. Through their magazine and social media and Internet platforms, they reach millions of readers and viewers throughout the world. National Geographic tapped British photographer Nick Cobbing for the assignment.

> *I knew from earlier visits to Svalbard that the transition from complete winter darkness to the bright summer period is a very short time, some call it the Blue Light. A soft blue that wraps around everything. That I could visit at the time when the light was at its best helped to make the photographs more atmospheric, it made the pictures what they are. That brief light gave the story its unique character.*
>
> **Nick Cobbing**

The British Broadcasting Corporation (BBC) also took the time to visit. They made a documentary about the expedition for BBC World and other platforms. The Norwegian Broadcasting Corporation (NRK) made news stories from the *Lance* for Norway's no. 1 TV channel.

The NRK also brought along four aspiring scientists. The 13-year-olds were taking part in *Oppdrag Nansen (The Nansen Mission)*, a documentary aimed at educating young people about the alarming effects of global warming in the High Arctic. The idea for the documentary came after the NRK had learnt about the *Lance* expedition. Hundreds of teenagers from all over the country had applied to participate. The chosen youths were given many different assignments by the producers during their stay in the Arctic.

Royals on the ice

Two very special visitors arrived in April. Norway's Crown Prince Haakon and Crown Princess Mette-Marit had been invited to the *Lance* by the Minister of Climate and Environment, who joined them.

> *I invited the Royals because they are very interested in what happens around climate research. And there is no way to gain better insight than to come up here – to the* Lance, *which is frozen in the ice at 83° N – and meet very dedicated scientists and see it all with their own eyes.*
>
> **Tine Sundtoft,** Minister of Climate and Environment

The Crown Prince has a special interest in polar and environmental issues and he has visited Svalbard on several occasions, as well as Greenland. The Royal couple were eager to learn first-hand about the work being done on the N-ICE2015 expedition.

> *We wanted to come here and visit this project because it is spectacular and ambitious.*
>
> **HRH Crown Prince Haakon of Norway**

The expedition's scientists were only too happy to share their enthusiasm for polar science with the visitors. Among other things, the Crown Princess and the Crown Prince popped into the divers' tent to learn about the organisms thriving just below the ice.

It is quite special to see the divers jump into this ice-cold water, going down under 1.5 m thick ice where it is pitch dark, and take samples of animals living there … That they can do research under such conditions … I have great respect for the science work done here. We have learnt a lot.

HRH Mette-Marit, Crown Princess of Norway

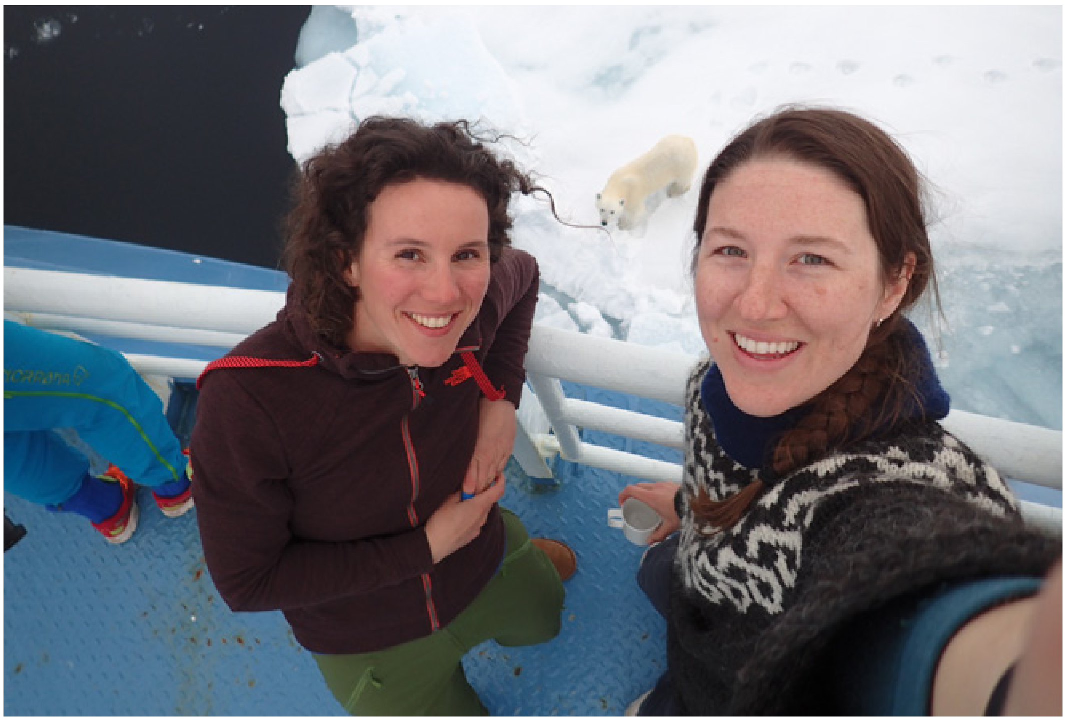
Haakon Hop explains his fieldwork to Crown Prince Haakon and Crown Princess Mette Marit inside the divers' tent. A pleased NPI Director Jan-Gunnar Winther oversees the session. Photo: P. Leopold

The Royal Family subsequently posted a video on YouTube documenting their encounter with the experts in the Far North.

Four-legged visitors

The expedition also sparked the interest of four-legged visitors. The High Arctic is polar bear country, which had to be taken into consideration when planning the expedition. The bears – the world's largest carnivores – could appear at any time, a danger to humans and equipment, even when the ship was situated 130 km away from the ice edge. Carrying weapons and looking out for bears would have been too much for the scientists to handle in addition to their work on the ice. The expedition needed designated polar bear guards, armed with powerful head torches, rifles, explosive flares and the means to communicate with the *Lance*.

Young polar bear males spend their time hunting all year round – they have no need to den as they have no cubs. Some wander very far north in summer, hunting for ringed seals and other prey where there is still a summer ice cover on the ocean.



In a selfie snapped by scientists Amelie Meyer and Allison Bailey, NPI, is the bear a visitor or a local inhabitant? Photo: A. Bailey

A polar bear guard looks out for bears. This aspect of the expedition's safety was taken very seriously, as there was a real threat from hungry or prying bears. Photo: F. Lamo

Whereas some polar bears merely inspected the strange objects that humans had apparently deposited on the ice for their amusement, bolder bears played with, and damaged, the gear.

One young bear showed particular interest in the expedition's activities. Likely driven by hunger, it lumbered toward the little shed housing instruments for underwater measurements. The bear crossed a lead that had just frozen over and passed a tent and the mast mounted with meteorological sensors. As it passed the footprints left by the researchers who just recently had taken snow samples, the polar bear guard pulled the trigger of the flare gun. One warning shot was enough: the young bear retreated and headed off to hunt elsewhere.

On a different occasion, a group of scientists working a couple of kilometres away from the *Lance* carried weapons but had not brought a polar bear guard along. From the ship's bridge, the expedition leader kept close watch through binoculars.

Polar bears are intelligent and curious, and this bear was not the only one to sneak into the camp and amuse himself with the scientific equipment. Photo: M. Porcires

Suddenly, he spotted a bear on the ice, slowly closing in on the scientists. He hurriedly dispatched two polar bear guards to cut off the bear using snowmobiles.

Good planning and pre-emptive action meant that neither bear nor human was harmed during the expedition.

A message to the climate summit

Upon the *Lance*'s return to Longyearbyen, UN Secretary General Ban Ki-Moon was there to greet the scientists on board. He was keen to learn what was happening in the Arctic, prior to the 2015 United Nations Climate Change Conference (COP 21), which was to be held in Paris. He also met with two of the *Oppdrag Nansen* teens in Longyearbyen. He was so taken by their story that in his address to the summit he mentioned their achievements and what they had learnt about climate change. In addition, the youngsters were invited by Norwegian authorities to attend a side event at COP-21.

> *Reaching out to influential stakeholders like we did with the N-ICE2015 expedition means that even more decision makers get the message and will understand why the ongoing changes in the Arctic are important for the whole global system.*
>
> **Gunn Sissel Jaklin,** NPI Communications Director

CHAPTER 8

Mission accomplished: the results

The N-ICE2015 expedition found that in the area north of Svalbard the ice pack comprised mainly first- and second-year sea ice, less than 1.5 metres thick: the researchers were studying the new Arctic. They were surprised to find that the ice was covered with a thick layer of snow that made the ice grow slower. The many winter storms had a substantial effect on the Arctic sea ice. Warm and moist air and snow influenced the ice from above and mixing of the seawater layers, caused by the wind, brought heat to the sea ice from below.

With the expedition coming to an end, the scientists dismantle the weather mast. Photo: J. Wallenschus

Warm, wet storms

Early on in the expedition, the participants were surprised by the number of severe storms they encountered deep in the ice-covered Arctic. In 2018, the key findings of the expedition were gathered in a special peer-reviewed publication of the American Geophysical Union (AGU) entitled *The Norwegian Young Sea Ice Cruise 2015*.

> *A recurring theme in many of the findings is the impact of the frequent storms that passed through the study area during the experiment … Storms entering the Arctic Ocean from the Atlantic are characteristic for this region, setting this region apart from other parts of the Arctic. The thin ice pack is more vulnerable to external forcing, as exemplified by its dynamic response to winds, and this may have lasting effects on the functioning of the ice pack.*
>
> **Mats Granskog,** NPI, **Ilker Fer,** University of Bergen/Bjerknes Centre for Climate Research, Norway, **Annette Rinke,** Alfred Wegener Institute, Germany, and **Harald Steen,** NPI, introduction to the AGU publication

Storms can have a big impact in the Arctic.
Photo: B. Rotmo

After measuring sea ice thickness, scientists Lana Cohen, Anja Rösel and Anna Silyakova head back to the ship. Photo: A. Meyer

The storms made the work challenging, but they also came with a revelation: storms can have big impacts in the Arctic, bringing lots of warm air, moisture (snow) and strong winds that affect sea ice drift and ocean mixing. Intense storms are a normal part of Arctic weather, but they are becoming more frequent and longer lasting. The N-ICE2015 campaign provided the first direct observations of the effects of such storms in the Arctic Basin, giving scientists the opportunity to understand and quantify some of these effects.

The expedition yielded a wealth of research in the fields of hydrography and ocean dynamics, snow and sea ice, atmospheric science, biogeochemistry and ecology. In the years since the expedition took place, these findings have been shared with t he global scientific community through international scholarly journals.

The ocean

N-ICE2015 scientists came away with unique data sets on hydrography, ocean currents and ocean mixing, especially in winter, and how currents respond to storms. To investigate these topics, the Norwegian Polar Institute collaborated with several national and international partners, including the University of Bergen's Geophysical Institute and the Bjerknes Centre, both of which contributed oceanographic expertise and instruments. They were chiefly interested in air–ice–ocean dynamics over longer climatic timescales as well as the details of ocean mixing.

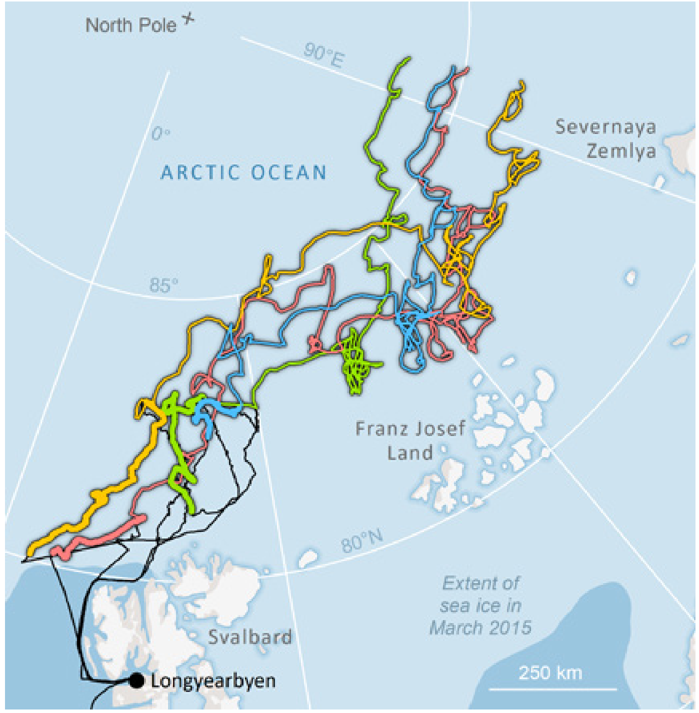
> *Our PhD students used state-of-the-art instruments during N-ICE2015, and we learnt a lot about how the layers in the ocean mix under different wind strengths. We also got a better idea of how sea ice melts in response to the ocean temperature, the mixing at different depths and the depth of the colder surface mixed layer. These observations have given us the rare opportunity to evaluate our analytical and numerical models, so we can predict future changes in the Arctic sea ice cover. I'd say that, with N-ICE2015, the NPI staked out a course for European polar research.*
>
> **Lars H. Smedsrud,** prof., polar oceanography, University of Bergen/Bjerknes Centre for Climate Research

Researchers on N-ICE2015 found that storms were important for the fluxes – exchanges – of heat, salt and nutrients in the ocean. The heat fluxes were also affected by a complex interplay of wind, seafloor topography and the warm Atlantic water nearby. Combined with modelling, the N-ICE2015 observations gave scientists insight into the transport and fate of warm Atlantic water and how it enters the deep Arctic Basin across the underwater Yermak Plateau.

Sea ice drifting over shallow, warm Atlantic water was found to receive heat fluxes of several hundred watts per square metre from below during storms, which is over 100 times more than what is typical in the interior Arctic Ocean. The seawater in the upper ocean also became saltier during storms. Ordinarily, a layer of colder, not-so-salty Arctic Ocean water lies atop more saline, and heavier, Atlantic water. Storms mix up these layers.

One of the most unexpected findings was that a phytoplankton bloom had already developed below the ice before snow melt. Usually, under-ice phytoplankton in the Arctic only blooms later in the summer, when the snow has melted away and

The ice floes with which the *Lance* drifted originated east of Svalbard, closer to Siberia.

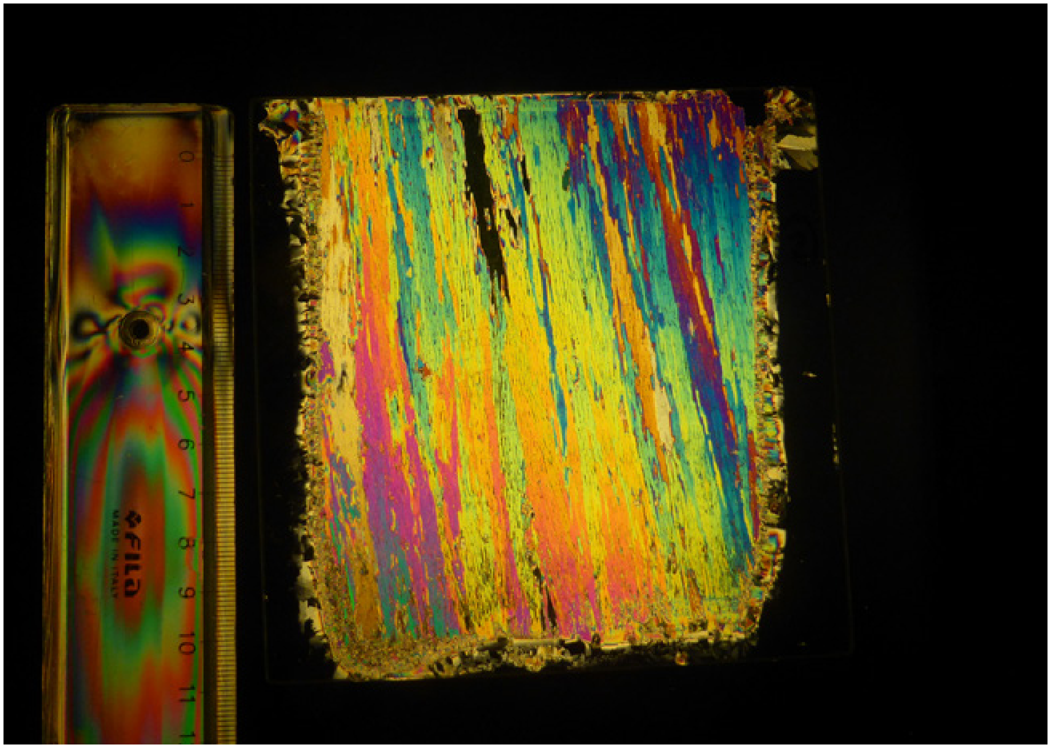


transparent melt ponds on the ice are like windows that let sunlight reach the seawater. But N-ICE2015 biologists discovered that the patches of open water that were created as the now thinner sea ice moved around fostered a phytoplankton bloom quite early in the season.

Snow and sea ice

The N-ICE2015 scientific campaign confirmed the belief that the researchers had from the outset: the ice was thinner than what was known from historical records and most earlier expeditions. During N-ICE2015 the scientists worked on an ice pack less than 1.5 metres thick. Thick snow blanketed the first-year and older ice – nobody expected to find that much snow on the ice in January, on the basis of previous knowledge of the region. There had also been reports from the western Arctic that the snow on the sea ice there had been thinning in recent decades. But the N-ICE2015 scientists found half a metre of snow on the sea ice during the first month of the year, and the same was observed on the other floes that were used for the ice camps later on, confirming that this was a typical situation in the area in 2015.

Snow is a good insulator, which is why Inuit build igloos that protect them from the cold. A thick layer of snow on sea ice keeps the cooling effect of the cold atmosphere at bay, slowing down the growth of the ice. Despite temperatures down to -40°C, the sea ice in the area barely thickened during winter and spring on account of the thick snow. However, snow can contribute to sea ice mass through the formation of so-called snow-ice, when snow gets flooded by seawater and freezes. This can



In the freezer lab, crossed-polaroid photography of a thin slice of a sea ice core yields boldly coloured ice crystals. The columnar crystals grew downward from the granular ice that formed when the water initially iced over.
Photo: S. Gerland

happen when the weight of the snow is so heavy that that the top of the sea ice is submerged below sea level and seawater soaks the bottom of the snow pack. As a rule of thumb, it happens when the snow depth reaches about one third of the ice thickness.

There were two mechanisms that contributed to flooding of the sea ice and formation of snow-ice. These mechanisms were the break-up of the ice floes during storms and bottom ice melt when the sea ice drifted into the main pathways of the warmer Atlantic waters north of Svalbard. When the latter happened, the ice melted at the bottom even in mid-winter, becoming so thin at some point that the weight of the snow pushed the surface of the ice floes below sea level.

Reports from the N-ICE2015 research were among the first to document widespread flooding and snow-ice formation in pack ice in the central Arctic. These phenomena may be a consequence of the amount of snow falling in the region combined with thinning of the sea ice in the Transpolar Drift, a surface current that crosses the North Pole and the central Arctic Ocean from Siberia to the western Fram Strait. These were the first comprehensive seasonal studies of snow and sea ice in this sector of the Arctic Ocean.

The scientists deployed as many as 40 autonomous buoys or drifters beyond the ice camp, the first set in winter and then more during spring. These revealed that the now younger and thinner sea ice showed more deformation – what happens when slabs of ice ram into one another. Ice that had been bashed by winter storms broke up more easily later in the season.

Using the ship's radar, scientists from the Finnish Meteorological Institute observed sea ice movement and dynamics around the ship. They found that the ice would usually break up along faults that had been weakened earlier, often by storms. Other scientists studied the sea ice before and after a passing storm, using high-resolution airborne data. The results were clear: a storm moves the ice mass around and fosters new ice growth in leads. Without the storms the growth of new ice would have been inhibited by the thick snow.

The N-ICE2015 ice camp was a valuable platform for validating the remote sensing carried out from satellites and the air. Since the satellite radar data could be compared with data gathered on the ground simultaneously, the expedition fine-tuned the use of imagery to detect open water and thin ice and to classify sea ice. Ground-truthing snow and ice, the scientists found that the conventional way that data from the European Space Agency (ESA) satellite CryoSat-2 and an airborne radar

Researchers return to the ship from "The end of the world", avoiding the sastrugi – wind-carved sculptures of snow. Photo: P. A. Dodd

Scientists prepare the release of a weather balloon to observe the atmosphere. The balloons were launched twice a day from the ship or the ice. Photo: P. Leopold

instrument flown on a NASA IceBridge mission above the N-ICE2015 site systematically overestimated sea ice thickness in spring, which was likely to do with the type of snow found in the area.

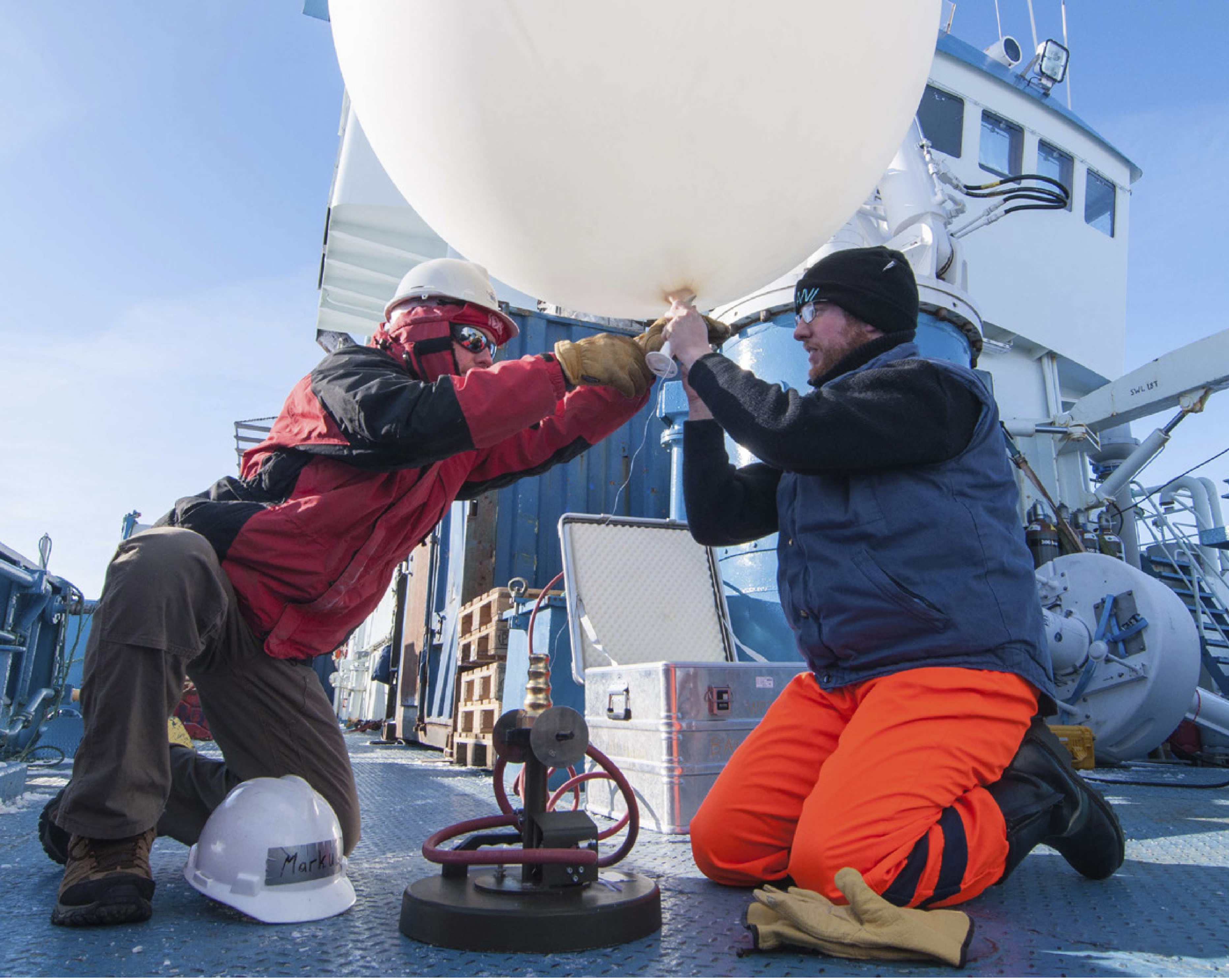
The thick snow cover also had an impact on the build-up of biomass in the ice. The biomass was rather low in older ice with thick snow on top, and the biomass of ice algae in the thinner young ice that formed in refrozen leads quickly approached similar levels as in the older ice. On the other hand, the algae under the new ice were exposed to more sunlight and therefore produced more "sunscreens" to protect themselves from harmful doses of ultraviolet radiation; the scientists discovered the highest levels of these "sunscreens" observed in sea ice algae to date. The older ice is a safe haven, where ice algae can survive through summer and the following winter to seed the algal growth next spring. This points to one of the consequences of the loss of older ice on the Arctic marine ecosystem.

Weather forecasting and dust particles

Crucial for models that accurately predict Arctic weather, observations from these remote areas are sparse. During N-ICE2015, weather balloons were operated in cooperation by scientists from the Norwegian Polar Institute, the Alfred Wegener Institute (Germany) and the Korea Polar Research Institute (South Korea). The weather balloon data was relayed in real-time to the global forecasting network and it was later shown to have improved weather forecasts in North America and in East Asia in the winter of 2015.

Scientists from the Norwegian Polar Institute and several other institutions studied different aspects of the atmospheric conditions in the High Arctic. The winter storms were a recurring theme of interest to all the science groups of the expedition, no matter what subject they were studying. Measurements of winter Arctic storms – especially direct observations – are rare. These were among the most striking outcomes of N-ICE2015.

Atmospheric scientists and oceanographers from the UPMC, now Sorbonne University / CNRS (Équipex IAOOS), in France, provided several ice-tethered buoys to study not only the ice and ocean but also the atmosphere, including aerosols. Winter dusty-type aerosol – dusty marine particles, desert dust and polluted dust – seemed to be overrepresented in satellite data.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Suspended from a helicopter, an EM Bird emits and receives electromagnetic signals, allowing researchers to calculate sea ice thickness. Combining this data with photographs taken from the aircraft, a better idea of the nature of the sea ice in the larger area around the *Lance* emerges. The tent used for operating the ROV can be seen to the right. Photo: S. Gerland

An Arctic without ice?

Amassing novel, interdisciplinary data and new knowledge from the High Arctic, the N-ICE2015 expedition exceeded the high expectations that had built up before the *Lance* set off on her last major mission for the Norwegian Polar Institute.

> *Having so many excellent scientists in on the N-ICE2015 expedition boosted the scientific quality, increased the number of scientific questions and for certain made the ship into a continuous seminar – a researchers' heaven!*
>
> **Harald Steen**

Scientists around the world are still making use of this data to shed light on the ongoing changes in the Arctic and how they are affecting the rest of the planet.

> *In essence, the real work of the scientists started after all the data had been collected in the field. It was a pleasure to coordinate the activity of all the scientists after the expedition. Everyone was in high spirits and worked as a true team. All the interesting research findings that were published in the years after the expedition gave this expedition a legacy that will last for decades to come.*
>
> **Mats Granskog**

A researcher puts his back into retrieving an ice core below a melt pond. Different types of ice were sampled regularly throughout the expedition to understand how the ice changes with seasons.
Photo: M. Fernández-Méndez

In 2017, the Norwegian Polar Institute sold the *Lance*. The cake in honour of the old lady read "Thank you for your long and faithful service!" Latest news is that she is enjoying the warm waters off the island Tristan da Cunha in the southern Atlantic Ocean, where she transports passengers, crayfish and lobster. Photo: A. K. Balto

Regardless of the high quality of the N-ICE2015 research, the findings cannot be taken as representative of the whole Arctic. More observations from different parts of the Arctic are needed. The German MOSAiC and the Norwegian Nansen Legacy projects have taken this into account, building on the N-ICE2015 work. Through these three projects alone, the research effort in the Arctic has greatly intensified over the last decade.

> *The Arctic is now – in 2022 – warming three times as fast as the rest of the world. At the time of N-ICE2015 we suspected it was warming twice as fast. An Arctic with or without ice makes a dramatical difference, to ocean and air temperatures alike. The conditions for living creatures are changing at a frightening speed, and many cannot adapt to the new climate regime quickly enough. In the circumpolar Arctic, the archipelagos of Svalbard (Norway) and Franz Josef Land (Russia) are warming the most. Since the warm branch of the North Atlantic Current, known as the Gulf Stream, passes close by, it comes as no surprise that Svalbard tops the list of warming areas on Earth.*
>
> **Kim Holmén**

As challenging as it was to piece together funding, N-ICE2015 proved to be the right move in a time of rapidly changing climate. Hands-on investigations of the Arctic Ocean and its dynamic sea ice cover were – as NPI Director Jan-Gunnar Winther had put it – "overdue".

> *The N-ICE2015 expedition provided data that no one really had made an effort to get hold of before. Many ships and scientists had been to the North Pole, but hardly any had been in the ice the way the* Lance *was. It was a costly and complicated operation, but it really was necessary.*
>
> **Kim Holmén**

Highlights of the N-ICE2015 findings

- The ice pack had already accumulated nearly half a metre of snow in January. This is much more than the scientists expected.
- The thick blanket of snow inhibited sea ice growth but also contributed positively to the ice mass balance because some of the snow turned into ice.
- There were many storms, especially in winter. These brought with them warm and moist air, even in the middle of the polar night, also slowing ice growth.
- New ice mainly formed in leads created by winter storms.
- The storms also affected ocean mixing. Heat, nutrients and CO_2 were mixed throughout the upper water column during storms. Storms doubled the movement of ocean heat to the atmosphere.
- The thinner ice pack was more fragile and deformed more easily and was also irreversibly damaged and weaker after powerful winter storms.
- Leads in the sea ice caused by storms allowed enough light to reach the water to initiate and maintain an early phyto-plankton bloom that would otherwise have been inhibited by the thick cover of snow and ice.
- Because of the heavy snow load, seawater seeped into the interface between the snow and the ice. The resulting habitat supported ample algal growth, resembling conditions known from the sea ice around Antarctica.

Photo: J. Wallenschus

Current affiliation of authors and persons quoted

All individuals who are quoted in this book are referred to by the affiliation and job title they had at the time of the N-ICE2015 expedition. See below for current position/affiliation.

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More information

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Fram Museum website: www.frammuseum.no

Into the Ice. Norwegian Polar Institute's international exhibition about the N-ICE2015 expedition

Nansen Environmental and Remote Sensing Center, Norway: www.nersc.no

Norsk Polarhistorie website: www.polarhistorie.no

Norwegian Polar Institute social media: #NICE2015Arctic

Norwegian Young Sea ICE Cruise (N-ICE2015) website (including links to stories in *National Geographic,* the BBC etc.): www.npolar.no/nice2015

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Following the long, sunless months of polar night, March sunshine brightens the work of researchers as they measure and flag a test-field for NASA's Operation Ice Bridge campaign. Photo: A. Rösel

This book is published by the Norwegian Polar Institute, with financial support from the Ministry of Foreign Affairs. The institute is a directorate of the Ministry of Climate and Environment and acts as an advisory agency on environmental management and administration of the polar regions. The institute is Norway's executive environmental authority in Antarctica.

The N-ICE2015 expedition could not have been carried out had it not been for the tremendous effort by our research and logistics partners. The Norwegian Polar Institute is especially grateful for the support from the ministries that made it possible to allocate the *Lance* to the expedition. The *KV Svalbard* and the Coast Guard broke the ice and placed us where we wanted to be in the ice, and with their helicopters the Governor of Svalbard and Lufttransport ensured safe crew shifts.

The *Lance* safely anchored to a floe, the scientists could do what they like best – conduct great science in collaboration.

NORWEGIAN POLAR INSTITUTE

For centuries, ships that became trapped in the Arctic sea ice faced almost certain destruction. This book tells the story of when the *Lance*, the Norwegian Polar Institute's research vessel, was deliberately frozen into the sea ice at 83° northern latitude. She served as a platform for scientists investigating conditions in one of the regions of the planet most dramatically impacted by climate change.

The N-ICE2015 expedition provided a wealth of valuable data during the months the *Lance* spent in the ice. New insights into the now younger Arctic sea ice pack were among the highlights of the findings, raising questions about how the loss of older ice will affect the Arctic ecosystem and the climate system as a whole. Unique observations during the cold and dark polar night revealed the powerful role of winter storms, and data from weather balloons improved weather forecasts in North America and East Asia. New knowledge continues to emerge from this special field campaign, advancing our understanding of these remote areas, which play a crucial role in the Earth system.

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