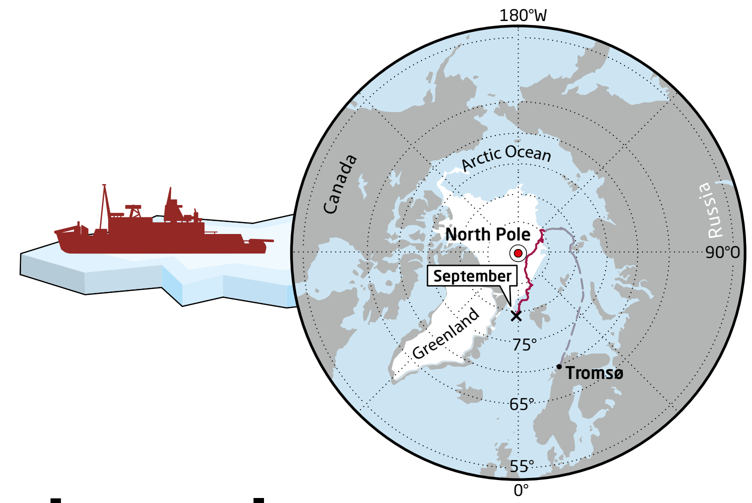
The two research aeroplanes POLAR 5 and POLAR 6 on standby at Svalbard Airport near Longyearbyen, ready to support MOSAiC. POLAR 6, in the background, has the sea-ice thickness sensor EM-Bird mounted in a cradle on its underside.



DriftStory 10

A reunion at the outlet of the Arctic

The AWI sea-ice physicists Thomas Krumpen and Jakob Belter were two of the first researchers to scout the vicinity of the MOSAiC floe in late autumn 2019. Back then, the floe was just beginning its journey through the Central Arctic. Eleven months later, the experts returned to survey the floe again – but this time from an aeroplane and off the coast of northern Greenland, at the other end of the transpolar drift.

How alike the two pictures are: as AWI sea-ice physicist Dr Thomas Krumpen flies over the scattered remains of what was once the MOSAiC floe and many of its neighbouring floes on 2 September 2020, he can't help but recall his first encounter with this particular stretch of sea ice, back in October 2019. Once again, the first cold autumn nights have frozen the ocean's surface; once again, a layer of new ice covers the countless meltwater ponds. And once again, those areas characterised by instable ice, weakened by the summer sun, are covered in a blanket of snow, making the ice look much more intact than it truly is.

STORIES FROM MEEREISPORTAL.DE

POLAR 6 is one of two Basler BT-67 aeroplanes used for German polar research. The turboprop plane is used in the Arctic and Antarctic alike, and is equipped with special-purpose research instruments for each mission.

If Thomas Krumpen didn't know exactly in what part of the Arctic he and his colleague Jakob Belter were, he might think the MOSAiC floe had survived after all. But the location alone dispels any such notion. Today the research aeroplane **POLAR 6** is flying over Fram Strait, an area of ocean between Svalbard and eastern Greenland, and one widely considered to be the largest outlet for the Arctic Ocean. In the winter months (October to April), year after year ca. 1,600 cubic kilometres of Arctic sea ice pass through Fram Strait to the North Atlantic and their certain doom. Just for the sake of comparison: the meltwater produced by this quantity of sea ice would be enough to fill Lake Constance 35 times over.

As such, Fram Strait also marks the end of the transpolar drift: the name given to the wind and ocean-current-powered drift of sea ice from Russia's marginal seas of the Arctic Ocean across the North Pole and ending off of Greenland's eastern coast. It took the MOSAiC floe roughly 610 days to complete its lifecycle, covering more than 5,200 kilometres. On the second-to-last day of July 2020, it finally broke up into several fragments. Ever since, the remains of the ice that once formed the extended vicinity of MOSAiC have

On ice-measuring survey flights the aircraft makes low flyovers, offering the pilot and crew an optimal view of the sea ice. While in the cockpit there's still enough time for a quick glance at the ocean (l.), researchers Thomas Krumpen, Jakob Belter and Cristina Sans i Coll (top, l. to r.) watch closely via camera to ensure that the EM-Bird properly separated from its mounting bracket and is now floating freely over the sea ice.

been trapped off the eastern coast of Greenland – wedged in a hodgepodge of icebergs and markedly thick floes that most likely hail from the extreme north of Greenland.

A PROGRAMME CALLED ICEBIRD

Yet the majority of the ice in Fram Strait hails from the Laptev Sea and East Siberian Sea, offering researchers valuable insights into the climate system in the Arctic. Accordingly, Thomas Krumpen and his colleagues at the AWI's Sea Ice Physics section have returned to the northern Fram Strait at regular intervals for nearly 20 years, to measure the thickness of the sea ice between the 80th and 86th N parallels, and to document its surface characteristics.

The ice-thickness measurements are taken with an electromagnetic sensor called the EM-Bird, which works a bit like a metal detector: the device generates an electromagnetic field, and can distinguish between various layers below it on the basis of their electrical conductivity. For example, saltwater is highly conductive, while sea ice is barely conductive at all. The sea-ice physicists use this contrast to determine how high above the underside of the ice the EM-Bird is.

The sea-ice thickness sensor EM-Bird resembles a torpedo and is towed behind aircraft on a long cable (20 metres for helicopters, 80 metres for planes), at a height of ca. 15 metres above the surface.

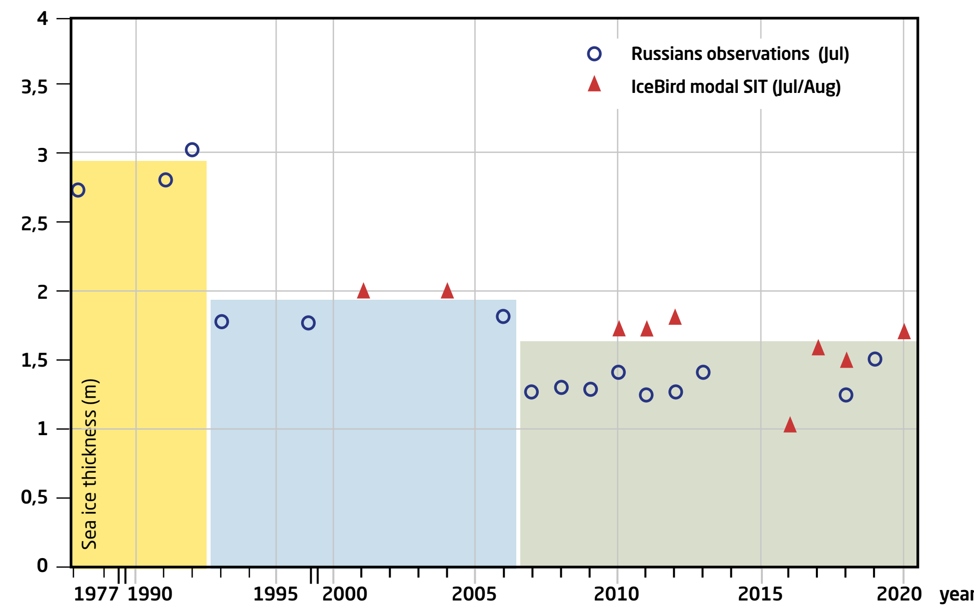
For the first measurements, taken nearly 20 years ago, the scientists had to drag the sensor over the sea ice on a sledge. Consequently, the measured distance from the underside of the ice offered a fairly direct indication of how thick the sea ice and the snow cover atop it were. Since this approach only allowed them to cover very small distances, however, since 2004 the AWI sea-ice physicists have instead used helicopters or research aeroplanes, suspending the torpedo-like sensor on a long cable, ca. 15 metres above the ice – which explains why they call it a 'bird'. A laser range finder measures the exact distance between the sensor and the ice's surface. Afterwards, all it takes to determine the sea-ice thickness is some basic maths: the experts note the distance between the sensor and ice underside, and subtract the EM-Bird's height above the ice.
In honour of this unique measuring method, the AWI's sea-ice physicists named their entire aerial sea-ice measuring programme in the Arctic after the sensor. IceBird has since gathered data from several key regions of the Arctic Ocean and is widely considered one of the most important reference datasets on the development of Arctic sea-ice cover in the world.

TWO MAJOR LEAPS CHARACTERISE THE TRANSFORMATION

The IceBird data on the northern Fram Strait show one aspect particularly clearly – the steady decline of all parameters. For example, where the mean ice thickness was still 2.6 metres in 2001, now it's only 2 metres – a loss of 24 percent. At the same time, the most frequently measured ice thickness value (modal ice thickness) has dropped from 2 metres (2001) to 1.5 metres (2018).
"Today, every single floe has much less time to grow, because the sea ice drifts faster than it used to. Compared to 2000, today's thinner floes complete the transpolar drift in virtually half the time," explains Jakob Belter. Whereas, back at the beginning of IceBird, the sea ice was nearly three years old before being exported to the North Atlantic, today much of the ice hasn't even turned two yet when it enters the northern Fram Strait.
Interestingly, the thickness of the Arctic sea ice hasn't declined uniformly over the last five decades; rather, there were two major 'leaps', as a comparison of the IceBird data with a longer time series prepared by Russian polar researchers reveals. The first leap came in 1992/1993: back then, the mean ice thickness in the Central Arctic suddenly dropped from 3 metres to less than 2 metres. Twelve years later (2005-2007), sea-ice experts from various countries recorded the second leap, in which the ice thickness sank by

The not-so-steady decline in ice thickness

Over the past 45 years the thickness of the Arctic sea ice hasn't declined steadily, but rather in 'leaps', as this comparison of Russian and German observations shows. The three colours indicate the three phases, over the course of which the respective sea-ice thickness has remained virtually constant.



another 50 centimetres. Ever since, it has remained at a relatively constant level, between 1.3 and 1.5 metres.

“We believe both leaps were sparked by fundamental and above all lasting changes in the Arctic climate system. In the meantime, we’ve come to view the first event as a type of early warning, because since 2007 at the latest, it’s been clear that a massive change took place in the Arctic, one that produced lasting changes to sea-ice formation, sea-ice transport and the age structure of the ice. Ever since, the ice has formed later in the year, shown less growth in winter, drifted faster and now leaves the Arctic at an average age of less than two years. There is now much less older, several-metre-thick sea ice in the Arctic than in the past,” says Jakob Belter.

The aeroplane-supported ice-thickness measurements complemented the thickness measurements taken at regular intervals on the floe or in its vicinity throughout the MOSAiC expedition. For the latter, researchers dragged the sensor across the ice on a sledge (top) or suspended it on a cable for helicopter flyovers (l.).

DEADLY HEAT FROM THE DEEP

To make matters worse, there are already indications of a next leap in the ice-thickness curve: in the summer of 2016, during their aerial survey flights over the northern Fram Strait, the AWI sea-ice physicists chiefly documented ice that was barely 1 metre thick (excluding pressure ridges and deformations) – an absolute record low. In order to determine why the ice was up to 50 centimetres thinner than in previous years, the experts used a three-stage plan. In the first stage they analysed satellite data, which allowed them to retrace the ice’s route back to its point of origin in the Laptev Sea. They then checked what the weather conditions had been like along the route. Could a summer heat wave have melted the ice from above? But no, the atmospheric data didn’t reveal any major irregularities from 2014 to 2016.

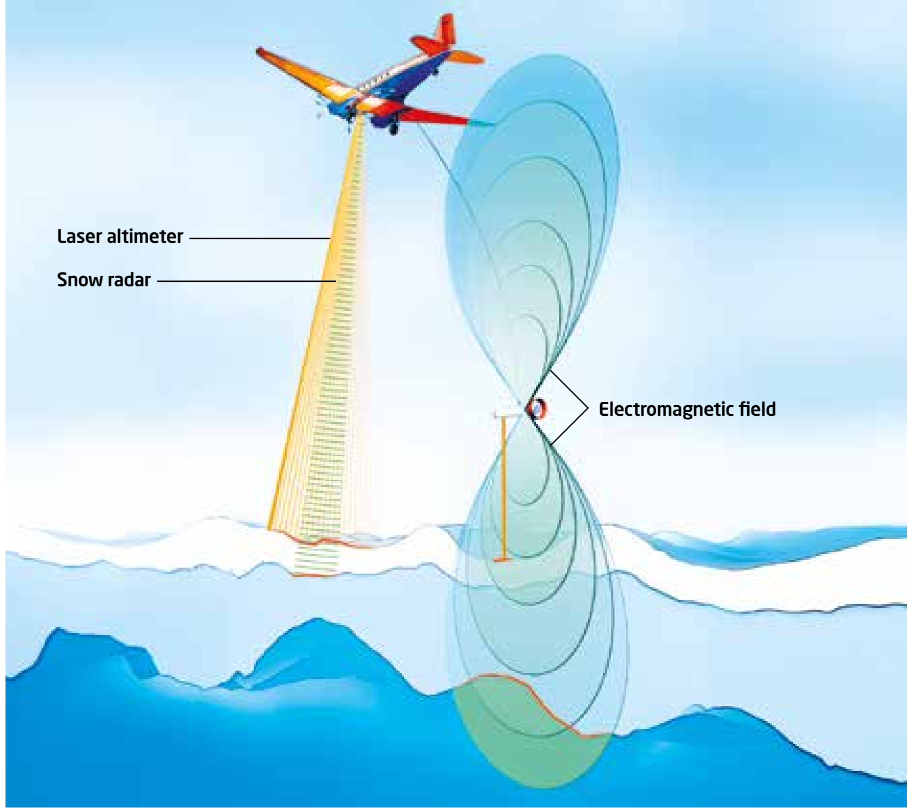
That meant the answer had to lie in the ocean – and sure enough: from January to May 2015, researchers from the University of Fairbanks, Alaska recorded unusually high temperatures in the waters north of the Laptev Sea. This was due, as we know today, to heat rising from the depths with Atlantic water masses and slowed the young sea ice’s growth in winter.

At Svalbard Airport near Longyearbyen, AWI sea-ice physicist Jakob Belter performs routine maintenance on the electromagnetic sea-ice-thickness sensor EM-Bird. Here the sensor can be seen in its specially designed cradle for take-offs and landings, which is mounted on the underside of the research aeroplane POLAR 6.

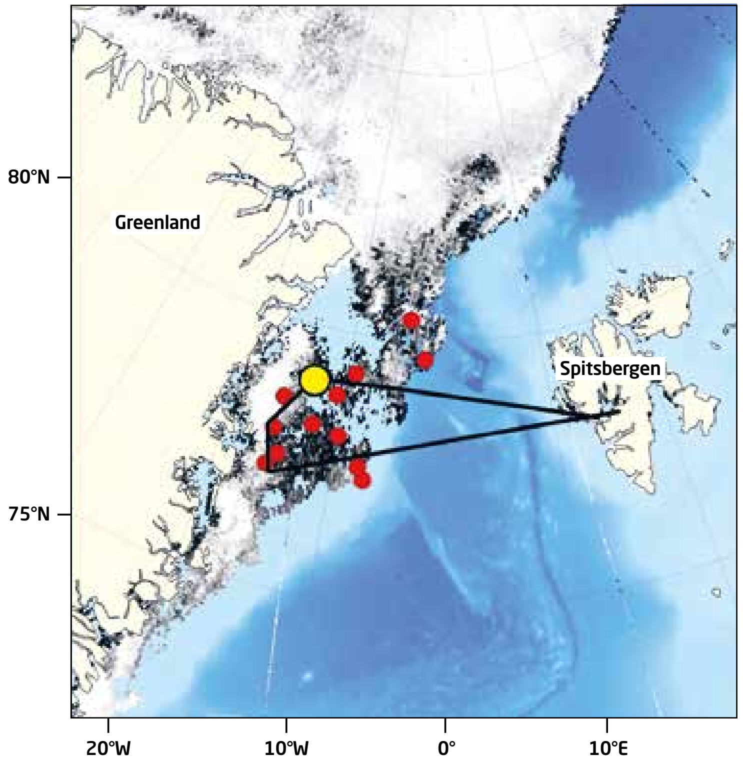
"Using the satellite data, we can prove that the ice we measured in Fram Strait in July 2016 had previously passed through exactly these unusually warm waters off the edge of Russia's continental shelf," Jakob Belter explains.
But does this finding automatically mean that the low ice thickness at the end of the transpolar drift was solely due to the warm ocean water at the drift's beginning? Couldn't the effects of the heat have faded with time? To find answers to these questions, the young researcher simulated the growth of the ice in a simple sea-ice model. The computer calculated how thick the ice should theoretically be, based on the ocean and atmospheric data supplied to it.
"In this model-based simulation we worked under the assumption that the heat from below, that is, from the ocean, remained constant, and that the ice only grew because of the cold atmosphere," says Belter. "But when we looked at the results, we soon realised that our model couldn't reflect the extraordinarily low ice thickness in 2016 – in other words, that the constant we'd used for the heat from below was wrong. Accordingly, the ocean must have contributed far more heat, especially at the beginning of the drift, than we initially assumed."
Just how much more heat is extremely hard to say. "In our first calculations we assumed a heat input of 2 watts per square metre of ice. We later boosted the number to 8 watts, increasing the estimated heat input more than fourfold. The results are now moving in the right direction, though they still don't match the ice-thickness values measured in the northern Fram Strait. Accordingly, we believe that the 'ocean heat wave' in the winter of 2014/2015 must have been a fairly substantial event, and that its effects on sea-ice thickness growth were too great to be fully compensated for," Belter explains.
Further, this wasn't the only extreme-heat event, as the latest research findings show. In the winter of 2017/2018, the instruments of the US oceanographers in Fairbanks

Four at a go

Using its snow radar, altimeter and the EM-Bird, the research plane can combine four key parameters to determine the exact sea-ice thickness: the height of the snow cover, how high the aircraft is above the surface, and the distance between the EM-Bird and the ice's surface and underside, respectively.



Nearly at the finish line



By early September 2020 the MOSAiC floe had already broken up into several fragments and the ice from its vicinity had scattered across the Fram Strait. The red dots indicate sea-ice buoys that were deployed near the floe at the start of the expedition. The yellow dot marks the position of the Norwegian research icebreaker Kronprins Haakon, which the AWI sea-ice physicists flew over during their aerial survey flight in Fram Strait. The black line indicates POLAR 6's route during the aerial survey flight.

once again recorded rising warm-water masses in the eastern Arctic Ocean. It has since been confirmed that Atlantic water, which can be as warm as 1.5 degrees Celsius and previously circulated at depths of between 150 and 900 metres, rose to a depth of just 80 metres. Under these conditions, the thermal transfer between Arctic water masses is altered. When that happens, like it did in 2014/2015, heat rises from the depths to the ocean's surface, even in winter, and either melts the ice from below or slows its growth. The effects can still be seen a year later, as the IceBird measurements from 2016 impressively demonstrate.

Does the IceBird data from the past several years point to any further 'heat attacks' from the deep? According to Jakob Belter: "No, so far there's no indication of that. But that doesn't mean the sea ice wasn't affected by heat. Thanks to our colleagues from Alaska, we know that there were other ocean heat waves in the eastern Arctic Ocean in the past few years. But they apparently didn't affect the ice that we observed downstream in Fram Strait a year later. So far, we've only managed to capture it in 2016."

In September 2020, sea ice from the former vicinity of the MOSAiC floe drifts through the northern Fram Strait and heads to the south, where it will melt in a just a few weeks' time

THE MOSAiC FLOE: A REPRESENTATIVE ICE SHEET, RIGHT UP TO THE END

It would appear that the ice from MOSAiC's extended vicinity has also been spared contact with extreme heat from the depths of the Arctic Ocean. "Until it collapsed on 30 July 2020, the MOSAiC floe had a modal thickness of 1.7 metres. And even on our flyover in September, the remains of the great ice field were still 0.9 to 1 metre thick, which was even a bit surprising, given how late in the year it was," says Thomas Krumpen.

After learning this, everyone who participated in the MOSAiC expedition could breathe a sigh of relief. "We can now say with certainty that, up until its disintegration, the MOSAiC floe was a representative example of the sea ice in this region," say Thomas Krumpen. "In turn, this gives us confidence that the countless experiments conducted in the course of the expedition will yield representative outcomes and reflect the environmental conditions in the Central Arctic as accurately as possible. Rounding out this unparalleled expedition, that's a truly good piece of news." ■