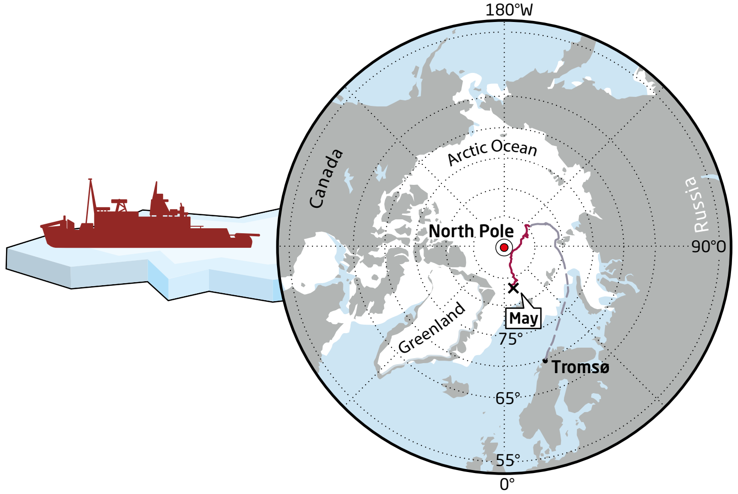
On 30 June 2020, meltwater ponds nearly as long as the research vessel Polarstern covered the MOSAiC ice floe – though the snow began melting weeks earlier.



DriftStory 07

The importance of the first snowball

In spring, along with the sun, warmer temperatures return to the Central Arctic. However, precisely how this changes the snow layer and how it ultimately affects the sea ice are still not completely understood. Accordingly, throughout the MOSAiC expedition, AWI sea-ice physicists have closely observed the changes in the snow cover, and used a surprisingly simple trick to do so.

Satellites, robots, high-tech cameras: on no other polar expedition has the Arctic sea ice been monitored using so much modern technology as on MOSAiC. However, sometimes the sea-ice physicists still use quite simple tricks – like the snowball test. "Trying to make a snowball gives us a fairly good indication of whether or not the snow has started to melt and the percentage of liquid water has increased. Under normal winter conditions, the snow on the Arctic sea ice is far too cold and dry to be made into a ball," explains AWI sea-ice physicist and snow expert Dr Stefanie Arndt.
That's why she regularly used the snowball test as part of her research at the MOSAiC Ice Camp. Arndt took part in the 3rd leg of the expedition, and arrived at the floe at precisely

the point when, for the first time after the long Polar Night, there was once again twilight and the sun announced its return. Spring was just around the corner, bringing with it crucial research questions: when, and above all how would the sunlight and rising air temperatures alter the snow cover on the Arctic sea ice?
But each time, before trying the test, the researcher first let two handfuls of snow run through her fingers – even in the first two weeks of April, when the sun shone round the clock. "An undisturbed area of snow is highly reflective – or has what we call high albedo. It reflects up to 90 percent of the sun's rays. If at the same time the air temperature is below freezing, the solar energy can't melt either the snow or the sea ice below it. That means the physical properties of the snow barely change and it doesn't stick together," Arndt explains.

June 2020: a sheet of wood offers the researchers a makeshift bridge over a stream of meltwater running between the ship and camp.

A FIRST TASTE OF SPRING

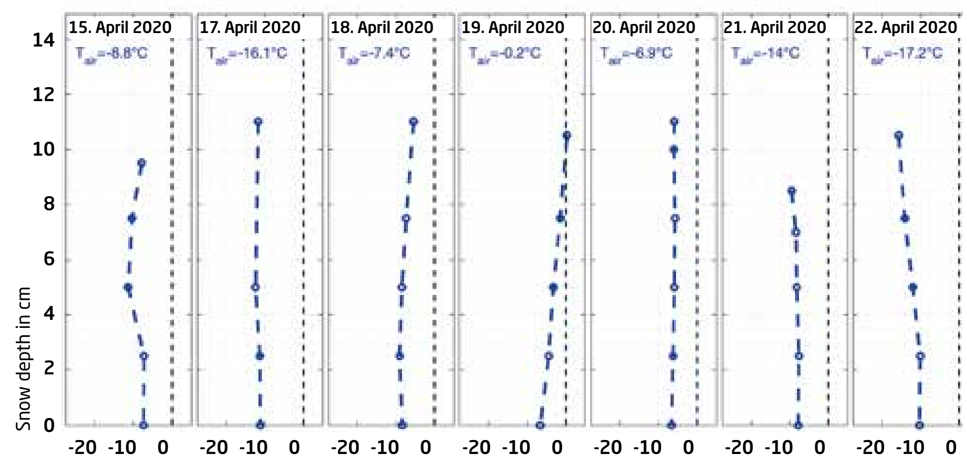
The turning point came on 19 April in the form of a brief but massive inflow of warm air into the Central Arctic. Within the space of a day, the air temperature at the snow's surface in the Ice Camp rose from minus 7.4 degrees to minus 0.2 degrees Celsius. The warm spell only lasted 24 hours, but it was enough to make a lasting change in the snow layer. "The warm air at the snow's surface immediately brought the top third of the snow layer up to the melting point," reports the scientist. Afterwards the entire snow layer froze again. But by that point, the warmth had already left its mark on the snow. "We assume that, in this brief warm phase, the first of many large snow crystals began to melt, changing their shape and becoming smaller, even though we couldn't yet see these changes in detail in the overall snow cover," says Arndt. The only thing that could be seen with the naked eye was a clearly recognisable glazed layer. "From above, the snow looked as if the entire area was starting to melt. But in fact, following the inflow of warm air, the surface refroze and became reflective like a mirror," the researcher reports.
The opportunity to personally experience such a warm spell in the Central Arctic was the highlight of the spring for Stefanie Arndt and the other researchers. All the research groups intensified their measurements in order to document the effects of this event at all levels – from the atmosphere to the ocean. But it soon became clear: it would take more than just a brief influx of warmth to set off the melting season in the Central Arctic. It would take a special event – which occurred almost four weeks later, on 12 May.

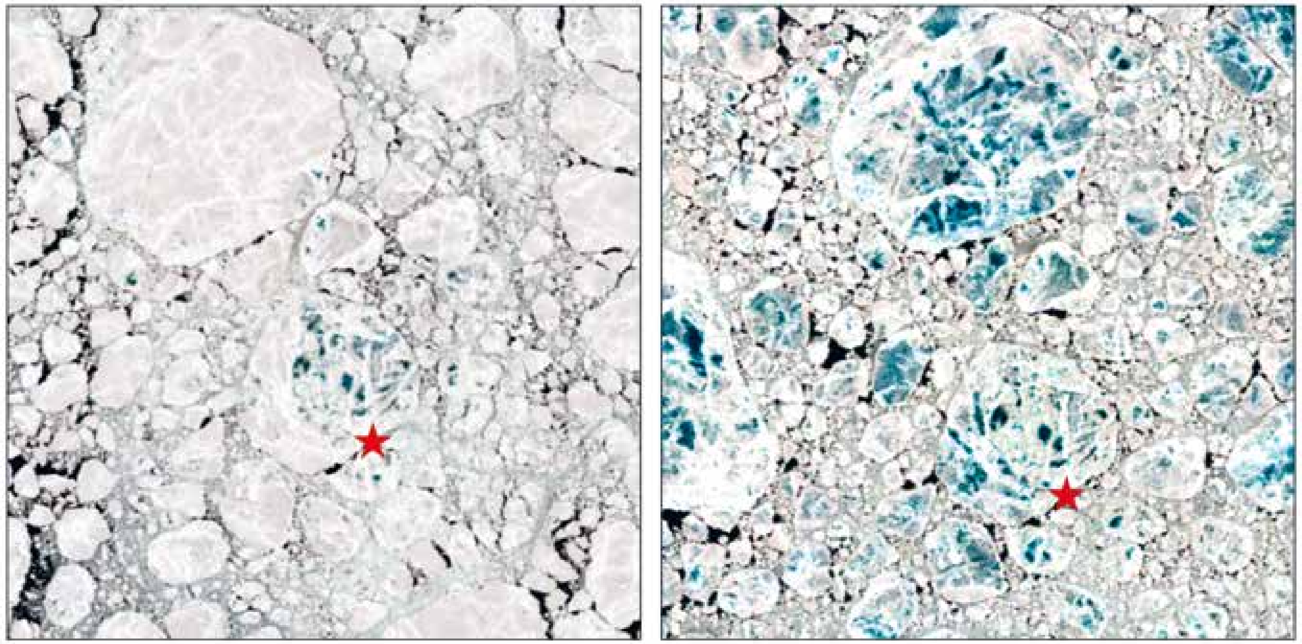
DR STEFANIE ARNDT

In the course of the MOSAiC expedition, Dr Stefanie Arndt frequently made snowballs for research purposes – provided the snow had the right qualities for doing so.

When the atmosphere warms the snow

When the air masses over the MOSAiC floe suddenly warmed between 18 April and 19 April 2020, the temperature profile of the snow layer on the ice rapidly changed, as this data clearly shows. Above all, the upper third of the snow layer nearly reached the melting point. Afterwards, however, the snow cooled again just as quickly.





These two satellite images of the ice near the MOSAiC floe (red star) were taken nine days apart. On 21 June 2020 the first meltwater pond formed (l.); by 30 June 2020 they covered large expanses of the ice (r.).

The North Cape is a promontory extending into the Arctic Ocean from the island of Magerøya, which lies off the northern coast of Norway. Since 1999 it has been dubbed the northernmost point in Europe that can be reached by road from the mainland.

On that day a storm front from the North Cape with wind speeds of 7 to 10 on the Beaufort scale swept through the Central Arctic and replaced the cold winter air at the MOSAiC Ice Camp with warmer air from the south. Once again, the air temperature at the snow's surface soared – from minus 10.9 to minus 0.2 degrees Celsius. But this time the warmth was here to stay, and finished what it had started in April.

WHEN THE FLOES TURN GREY

Freshly fallen snow crystals possess a multitude of tiny surfaces and edges. These reflect the sunlight so that to observers the snow layer appears white. But when the snow becomes warmer, the heat causes the various microstructures to melt into each other. The edges become rounder and the crystals clump together, creating sticky snow that can be formed into snowballs.

"If this process continues for two to three days, the previously white snow turns grey, since the altered optical properties mean that it no longer reflects the entire spectrum of the sun's rays. Instead, it absorbs more and more sunlight, causing the snow to become warmer and to melt further from within. It collapses and becomes wetter, turning into grey slush, and forming the first puddles of meltwater in depressions on the sea ice," explains Stefanie Arndt.

The onset of melting on the sea ice in spring also marks the end of the AWI ice-thickness measurements using the CryoSat satellite. When the snow is wet, the satellite's radar signal is no longer reflected clearly enough. The researchers then have difficulty determining on the basis of the measurement data whether the signal has been reflected by a snow-and-ice layer, or by open water. They therefore discontinue the measurements during the summer.

Unfortunately, in the third and fourth weeks of May, Stefanie Arndt was only able to observe the beginning of the snow melting from on board Polarstern. Due to the coronavirus pandemic, during this key phase for the sea-ice physicists the ship was on her way to Svalbard for a personnel rotation. By the time the ship returned to the MOSAiC floe, it was already mid-June.

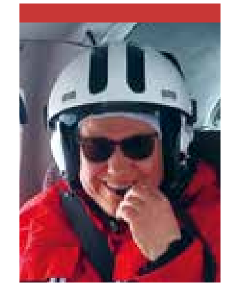
A PATCHWORK OF MELTWATER PONDS

AWI climate researcher Dr Gerit Birnbaum was one of the first participants in the fourth leg of the expedition to actually see the floe. During her laser measurements of the ice with Polarstern's on-board helicopter, she flew over it and its neighbouring floes, and documented the condition of the ice surface: "On our first flyover, on 16 June, the first ponds had already formed on the ice floes in the vicinity of the MOSAiC floe, mainly along the pressure ridges. Meltwater ponds in the flatter, undeformed areas of the floes were still relatively rare. Instead, here we saw regular grey patterns or areas that indicated melting snow, while the pressure ridges looked like white bands stretching across the floes," she reports from on board Polarstern.

Two weeks later, there was water in many areas of the floes. "By the end of June, the area covered by ponds had increased rapidly; the snow melting was in full swing. But as temperatures varied, there were several cycles of melting and refreezing in the top layer of water in the ponds. We could clearly see newly formed, thin layers of ice on their surfaces," Birnbaum recalls. On the young ice, which was just one winter old, the grey slush had disappeared and the resulting meltwater had formed a patchwork of interconnected ponds and puddles. The pressure ridges could still be seen as lighter bands crisscrossing the floes.

The effects of changes on the surface of the ice reach down to the ocean, as the AWI sea-ice physicists' radiation measurements show. In those areas where meltwater ponds form on the ice, less sunlight is reflected. The light warms the water in the ponds and increasingly penetrates the thinning ice into the upper layers of the ocean, where it signals algae to start growing.

Astonishingly, this transparency doesn't decrease again until the meltwater ponds penetrate the ice from above, allowing most of their water to flow into the ocean. At this point the areas of exposed ice at the edges of the former ponds start reflecting more sunlight, and the AWI's MOSAiC sensors beneath the ice record a substantial reduction in light intensity – an important finding in terms of the energy balance and heat fluxes in the sea ice / ocean system.



DR GERIT BIRNBAUM

is a meteorologist in the Sea Ice Physics Section at the Alfred Wegener Institute in Bremerhaven. The role of meltwater ponds in interactions between the sea ice and atmosphere is one of her main research topics.

Radiation sensors measure the amount of incoming or reflected light, and were used both on the ice and below it during the MOSAiC expedition. The underwater measurements focused e.g. on the question of at what point the algae within and below the ice receive enough light to start reproducing.

ACCURATE TO THE NEAREST SQUARE METRE

"By the first few days of July, above all the water in the large, deep ponds on the two-year-old ice had drained out – that means, their water surface or extent had shrunk again. On the one-year-old ice, the melting was so far advanced that in some parts, the area covered by shimmering blue ponds was larger than that still covered by snow, which could only be found at points that were topographically elevated," says Gerit Birnbaum. In technical jargon, these patches of grey and white are also known as the 'scattering layer', since what remains can't really be considered snow.

Gerit Birnbaum and her team were able to document the waxing and waning of the meltwater ponds down to the nearest square metre, since during the helicopter survey flights over the ice, cameras recorded the size and shape of the individual ponds. Furthermore, based on the camera data, the researchers were able to determine the size distribution of the meltwater ponds, whether the ponds were interconnected, and how deep each one was. The average albedo of the sea ice was also measured, while a laser scanner mapped its surface topography.

Knowing how early in the year the first ponds form, how large they become, and when they drain is essential in terms of predicting when in the summer the Arctic is likely to be ice-free for the first time. As a dark, sunlight-absorbing area, the network of meltwater ponds is a major factor in the Arctic sea ice melting more rapidly and extensively in summer than it has in the past.

The heat's handiwork: the areas of grey snow tell the researchers in which parts of the ice floe the snow has already started to melt. This aerial shot was taken on 24 May 2020.

Consequently, Birnbaum's meltwater pond data gathered during MOSAiC will be used to support numerous scientific analyses. Some researchers are investigating whether the ponds on the MOSAiC floe and in its immediate vicinity are representative of the sea ice in the Central Arctic. At the same time, others are using data from the helicopter flyovers to assess how accurately the various satellite-based measuring systems capture the Arctic's meltwater ponds.

One of these systems is MODIS, the Moderate Resolution Imaging Spectroradiometer, aboard the United States' Terra and Aqua satellites. This summer, AWI sea-ice physicists plan to use MODIS data to painstakingly monitor sea-ice melting across the Arctic. To do so, they will use the satellite system to record where and when sea ice was present, in which areas it was covered with meltwater ponds, and where areas of open water formed. So in the end, Gerit Birnbaum's countless helicopter flights over the slowly melting MOSAiC floe will pay off in a variety of ways.

Just over eight weeks later, on 29 June 2020, the experts dismantled their research camp. At this point, much of the floe was already covered with water, and just one day later, it broke into several pieces.