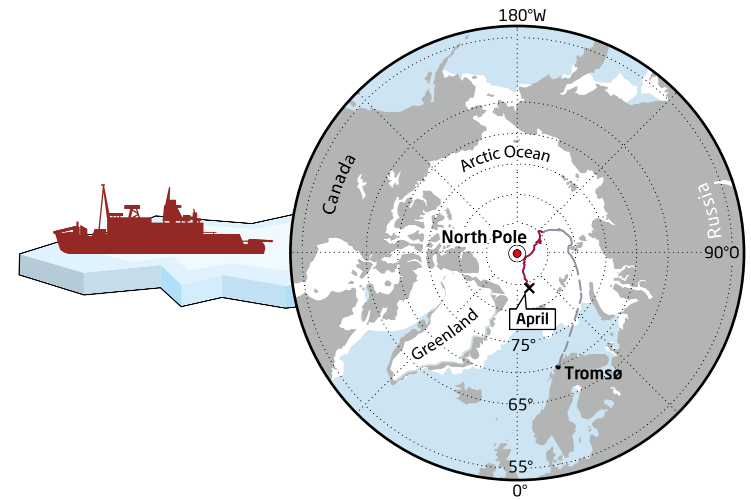
In the Central Arctic, snowfall is comparatively rare. The snow that does fall is often blown by the wind, chiefly accumulating on the lee side of obstacles like pressure ridges.



DriftStory 06

Snow, the great unknown

The number of winter days on which snow falls in the Central Arctic can be counted on one hand. Nevertheless, the amount of snow on the Arctic sea ice is a key factor influencing how quickly the ice grows, and when it begins melting in the spring. But until recently, little has been known about this enigmatic white substance. AWI sea-ice physicists have developed and implemented a unique snow research programme, the first findings of which have attracted considerable interest.

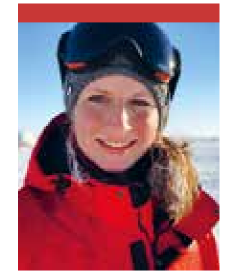
Freshly fallen snow is one of nature’s miracles; no other natural product on our planet reflects as much sunlight as it does. And no other natural covering provides as much insulation against the cold as a blanket made up of millions and millions of tiny snow crystals. When the Arctic is covered in its snow-white winter cloak, it reflects up to 90 percent of the sunlight back into space, keeping the region from warming – an effect known as

albedo. At the same time, the layer of snow on land protects plants and animals from freezing. While air near the ground can, under certain circumstances, reach temperatures as low as minus 40 degrees Celsius, beneath the snow layer it remains tolerably mild. There – depending on how high the snow has piled up – temperatures reach ca. zero degrees Celsius. This difference makes it possible for small animals like ermines to survive.
However, from a sea-ice researcher's perspective, the white snow layer first and foremost raises questions. To date no one knows precisely how much snow falls over the Arctic Ocean, how much of it remains on the sea ice, or how it is distributed on the ice. This is all the more important because snow is a decisive factor in determining the fate of the sea ice. In winter, the insulating layer prevents the ice from cooling to any great extent and growing more quickly. In spring, on the other hand, it reflects sunlight and delays the onset of melting – but only until the snow itself melts. When meltwater collects on the ice, puddles are formed, known as meltwater pools. These pools absorb heat from the sun, accelerating sea-ice melting. As such, the relationship between ice and snow is extremely complex and variable.
However, the extent to which the amount and depth of snow make a difference in that relationship, and which physical and chemical processes are at work in the snow layer over the course of the year, has remained unchartered scientific territory. Which is why the AWI's sea-ice physicists have made snow a major focus of their MOSAiC research and developed an extensive measuring programme. Since October 2019 they have been investigating sea-ice cover at all temporal and spatial scales, on a daily to weekly basis.
This fieldwork is fundamental research in its purest form – from the tiny snow crystals and their metamorphosis into snow grains; to the formation of different snow layers and their density, microstructure, thermal conductivity, temperature, and water and salt content; and finally to the distribution of snow over the entire MOSAiC floe. This has resulted in one of the most valuable MOSAiC datasets, the preliminary results of which are already attracting considerable interest. Actually, it snows far more rarely in the northern polar region than you might think. According to simulations, between 10 and 40 litres of precipitation per square metre of sea ice fall in the Central Arctic, more than 60 percent of it in the form of snow. That means the monthly average precipitation in the North Pole region is exactly the same as that in the Sahara Desert.

The researchers have placed a SnowMicroPen on the snow (l.) in order to obtain a high-definition density profile of the snow cover. The measuring rod is inserted vertically into the snow, where a small sensor on its tip measures the resistance. When storms blow, they all ask themselves: is it really snowing, or is the wind just kicking up loose crystals? (top).

GONE WITH THE WIND

"On our leg of the expedition, we could have counted the days on which we were consciously aware of snowfall on one hand," reports AWI sea-ice physicist Dr Stefanie Arndt, who led the snow programme on the third leg of MOSAiC (from March to May). If



DR STEFANIE ARNDT

is a sea-ice physicist at the Alfred Wegener Institute in Bremerhaven, where for the past several years, she has been investigating the role of snow in polar regions. Her work has led her to explore the remote past, especially of the Antarctic.
But for MOSAiC, the 31-year-old headed back to the High North.

DR MARCEL NICOLAUS
coordinates the AWI Sea Ice Physics Section's Arctic snow buoy programme. In the course of several expeditions to the Arctic and Antarctic, he has especially investigated the transfer of heat, light and energy through the sea ice and the snow cover atop it.

snowflakes are swirling through the air, there's usually a strong wind blowing. "At times like this, it was hard to tell whether fresh snow was actually falling, or whether the wind was just stirring up snow crystals that had already fallen," Arndt explains.

That's why, at the end of her stay at the MOSAiC Ice Camp, the researcher drew the same initial conclusions as her AWI colleagues Daniela Krampe and Dr Marcel Nicolaus had before her on the first two legs: when it comes to local snow accumulation on the Arctic sea ice, snow drifts appear to play a far more important role than total precipitation. "Because of the strong winds, fresh snow doesn't simply stay where it fell. It is transported and accumulates in large mounds on the ice surface, for example in the lee of pressure ridges," says Daniela Krampe.

The AWI researchers' observations have since been confirmed by data from the 14 snow buoys that the team had installed on level ice at the beginning of the expedition. While the snow layer on the level ice increased only gradually, and was still nowhere near the 30-centimetre mark by the end of the winter, behind the ridges the researchers soon found themselves hip-deep in snow.

"Observing the distribution of the snow throughout the winter and being able to measure it to within a centimetre was a unique opportunity," says AWI sea-ice physicist Marcel Nicolaus. Prior to MOSAiC, he had taken part in several past Polarstern expeditions to the Arctic. On these summer voyages, the ship usually didn't reach the Central Arctic until late May or early June. "By then, the snow drifts that had been formed by the wind had largely melted, so that we had little idea what sizes they reached in winter," the 44-year-old explains.

NEW COMPONENTS FOR SEA-ICE MODELS

The wealth of new data gathered on the snow depth and distribution is now being evaluated. The next task for the AWI researchers will be to integrate the new information into current ice models. "Up to now, in our models the snow has mostly been evenly spread over the ice surface. That means they lack a vital component that we need in order to correctly calculate the energy flows and energy balance, so that we can more accurately predict the future development of Arctic sea ice," says Marcel Nicolaus. A few years ago, he conducted a study investigating the influence of snow on the energy balance in the sea ice / ocean system. What he found: if the snow cover melts just 14 days earlier in the year, the sea ice melts so rapidly that, over the summer, the ocean absorbs up to 50 per-cent more energy than if the snow had melted later. A real eye-opener, and one that led the AWI sea-ice researchers to closely follow the spring snow melt.

The drifts on the lee side of pressure ridges are the only parts of the floe where the researchers find themselves up to their thighs in snow; everywhere else, the snow cover is less than 30 centimetres by the end of the winter.

In the summer, all the snow melts away. The resulting meltwater creates pools on the ice, with dark surfaces that reflect far less sunlight. Instead, they largely absorb the solar radiation, causing the water to grow warmer and accelerate the melting of the ice.

DANIELA KRAMPE
a doctoral candidate, is researching the carbon particle content of snow cover on Arctic sea ice. The second leg of the MOSAiC expedition offered her a unique opportunity to collect snow in the immediate vicinity of the North Pole.

The temporary shutdown of the MOSAiC Ice Camp due to the corona pandemic meant that, from mid-May to mid-June, observations were only possible via satellite. Thankfully, the snow buoys on the ice floe continued to faithfully transmit data on the snow thickness. The data showed, among other things, that in May, just four days with an air temperature of less than one degree Celsius above zero were enough to cut the snow depth in half – from 20 to 10 centimetres. In the future, sea-ice and climate models with snow components will have to measure up to this and various other types of new snow data gathered during MOSAiC. Until now, no one else has succeeded in gathering data – especially not such consistent and reliable data – on the snow on Arctic sea ice over an entire winter and beyond.

LITTLE SNOW IS LOST IN ICE LEADS

Based on what was learned during the MOSAiC winter, we also need to rethink our answer to the question of how much snow is lost when leads form in the ice, or when ice floes drift apart and the snow falls into the sea. "Previously, we assumed that ice leads contributed substantially to snow loss. But at the MOSAiC Ice Camp, time and time again we saw newly formed ice leads freeze over within a matter of hours, due to the frigid air temperatures," reports Stefanie Arndt. That means that the snow didn't disappear into the sea for long, but instead soon began collecting on the new ice, where it was then potentially redistributed by the wind.

PAW PRINTS IN THE SNOW

While working on the ice, Stefanie Arndt also observed a second phenomenon: since relatively little snow fell during the winter months, tracks made in the snow were often preserved for several months – including those left by four-legged visitors. "In April 2020, during one of our measurement campaigns, we could still clearly see the tracks of a polar bear that had most likely visited the MOSAiC Ice Camp in December 2019, since there hadn't been any new polar bear sightings during our expedition leg since January," the 31-year-old sea ice physicist explains.
Together with her AWI sea-ice colleagues, Arndt is now eagerly awaiting the end of the expedition and Polarstern's return to Bremerhaven, because the ship's refrigerated cargo hold contains countless snow samples collected at regular intervals and at various sites throughout the Ice Camp. These samples will provide insights into e.g. the number of carbon particles deposited on the snow, or how much microplastic from the Arctic air the snow contains. In addition, investigations of the water isotopes are planned.
The findings of these investigations will shed new light on where the precipitation originated before falling on the Arctic sea ice as snow, and on how the snow itself has changed during its time on the ice. Furthermore, based on the water isotopes from the snow and ice, the sea-ice physicists can identify precisely which portions of the ice were formed from snow rather than from seawater. In this regard it's important to know that the snow layer on the sea ice can, under certain circumstances, become so thick that its weight forces the sea ice under the water's surface. When this happens, water permeates the ice – e.g. by rising up through pores or cracks. When the water subsequently refreezes, snow-ice is formed, and the ice floe grows from above.
Snow is a topic that the AWI's sea-ice experts will be investigating long after the MOSAiC expedition comes to an end. Given the vast number of snow samples and the wealth of new datasets collected, we can expect to see exciting new findings. ■

Throughout the expedition, polar bears frequently approached the ship. Fortunately, there were no encounters between humans and bears that were remotely dangerous.