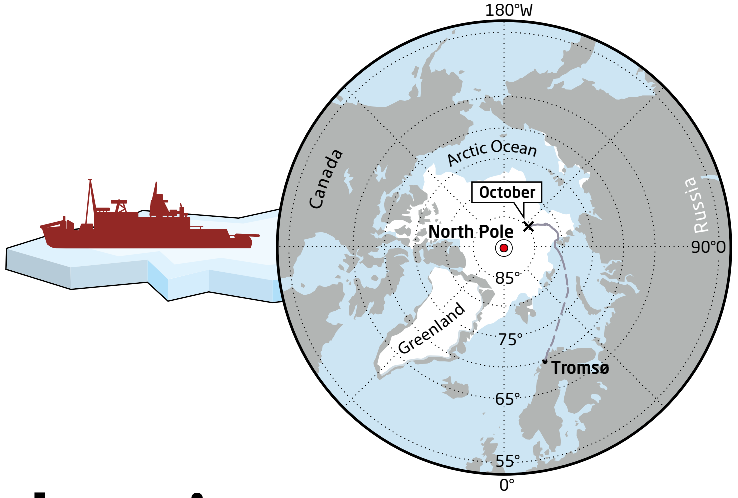
Early in the MOSAiC expedition, an international team of experts on board the Russian research icebreaker Akademik Fedorov (r.) supported RV Polarstern (l.) in her search for the ideal floe.



DriftStory 01

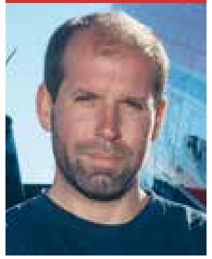
Detective work on ice that's far too thin

Whoever hopes to unlock the mysteries of the sea ice has to first know its past. Accordingly, sea-ice physicist Thomas Krumpen started looking for clues, and traced the history of the MOSAiC floe back to the beginning – even to the exact day it was formed.

AWI sea-ice physicist Dr Thomas Krumpen is the 'profiler' in the MOSAiC Sea-Ice Group. Even if the largest-scale Arctic expedition in history isn't a whodunit, where the goal is to bring the wrongdoer to justice, nevertheless most of the researchers on board the icebreaker RV Polarstern, which serves as the base of operations for the expedition, are preoccupied with two fundamental questions: where did the sea ice that we're living and working on actually come from? And just what type of ice is it composed of? Finding the answers as early in the expedition as possible is a key priority, since this information is essential for nearly all model-based studies and satellite validations, not to mention the investigations into the material flows and food webs that will be carried out in the course of the year-long drift experiment.

Accordingly, in September 2019 Krumpen was one of the first members of the AWI's Sea-Ice Group to depart for the Central Arctic, and was tasked with profiling the 'scene of the crime' – in other words: describing the sea ice in MOSAiC's starting region in painstaking detail, and determining its origins. The 41-year-old conducted his detective work on

The MOSAiC drift experiment began on 4 October 2019, when the research icebreaker Polarstern moored at the selected ice floe. The starting coordinates: 85° 04.582' North / 134° 25.769' East.



DR THOMAS KRUMPEN
is a sea-ice physicist at the Alfred Wegener Institute in Bremerhaven. The 41-year-old is an expert on ice formation in shelf seas and has developed a method for reliably retracing the routes of drifting ice.

board the Russian research icebreaker Akademik Federow, as it was engaged together with RV Polarstern scouting of the region, located ca. 950 kilometres north of the New Siberian Islands.To gain a first impression both ships went to coordinated search regions and followed the same procedure. From Akademik Federow Thomas Krumpen and two other sea-ice observers began by documenting from the ship's bridge how many ice floes were in the target region, roughly how old and thick the ice was, at which points channels were forming in the pack ice, and whether the ice was covered with meltwater pools, or whether the floes had collided, forming pack ice hummocks. In the next step, the researchers used the ship's on-board helicopter to fly to five larger floes within a 40-km radius, surveying the ice thickness and amount of snow cover on each. Krumpen compared the team's on-site readings with extensive weather satellite and ice satellite data on the Russian Arctic, which he had gathered from a variety of sources prior to the expedition. In this regard, the weather data came from a meteorological monitoring station on Kotelny Island, the largest of the New Siberian Islands.

A HISTORY OF EXTREMES

The results of the initial analysis in both search regions were sobering: the ice in the starting region was less than a year old, had a mean thickness of only 30 centimetres, and had undergone substantial melting during the summer, as a result of which it showed heavy weathering and was littered with meltwater pools. The ice's life story read like a string of negative records. "The summer of 2019 was the warmest in the Russian Arctic since the beginning of weather observations on Kotelny Island, back in 1935. Air temperatures over the Laptev Sea and East Siberian Sea beat the previous record high by two to four degrees Celsius," Krumpen reports.

Since the previous winter had been one to three degrees Celsius warmer than the average in the reference period 1981 to 2010, the ice that formed in the 'nursery' for Arctic sea ice – the Laptev Sea and adjacent East Siberian Sea – was far thinner than in the past. Strong offshore winds then rapidly blew it out to the open sea. As Krumpen recalls, "When the air temperature quickly rose in the spring of 2019, this extremely thin ice melted so rapidly and extensively that we not only saw the earliest break-up of the ice cover since 1992, but also the rapid and unexpected northward retreat of the ice edge."Consequently, in the autumn of 2019 it took longer than ever before for the surface water, warmed by the summer sun, to grow cold enough for new ice to form. According to the sea-ice physicist: "At the beginning of the expedition, roughly 80 percent of the sea ice in MOSAiC's starting region was only a few days old. Floes that had survived the summer, and were therefore thick enough for us to work on, were definitely the exception, and hard to come by." Finally, the scientists were successful in the RV Polarstern's search region. The expedition leader chose one of the most stable floes in this sector of the Arctic as home for the expedition.

Once these initial conditions had been established, Thomas Krumpen's real detective work began. The goal was to trace the course of the pack ice in the starting region back to its point of origin. To do so, the remote-sensing expert used a time series of high-resolution

satellite data, which allowed him to identify the MOSAiC floes and therefore reconstruct their journey from the **marginal seas** of the Arctic Ocean to the Central Arctic – down to the exact day. "The ice floes that we set up the MOSAiC monitoring network on were formed off the northern coast of the New Siberian Islands on 5 December 2018, and in a shallow region with a depth of less than ten metres. When RV Polarstern dropped anchor at one of the floes, on 4 October 2019, the ice was exactly 318 days old and had travelled a total distance of 2240 kilometres, on a zigzagging course determined by the wind," says Krumpen.

These new insights into the ice's provenance are supported e.g. by sediment and particle deposits that the researchers found in the sea ice. These trapped deposits, referred to as inclusions, can only be found in sea ice that forms in coastal waters less than 30 metres deep: in shallow waters, the intense winter winds stir up large amounts of sediment from the seafloor, which are subsequently locked into the newly formed ice. Alternatively, the particles can be acquired when the young ice comes into contact with the seafloor in the surf zone. Chemical tests, which will likely tell us exactly which section of coastline the deposits hail from, aren't yet complete.

The following shallow bodies of water in the eastern part of the Arctic Ocean are considered to be marginal or shelf seas: the Barents Sea, Kara Sea, Laptev Sea and East Siberian Sea.

Finding the right floe: a Russian transport helicopter drops off researchers for scouting work on the sea ice.

ONE LAST LOOK AT THE OLD ARCTIC

The unexpectedly high number of inclusions has given the participants the chance to thoroughly analyse the role of Arctic sea ice as a means of transport for sediments, nutrients, climate-relevant gases and toxins – and an opportunity that, in Krumpen's opinion, is very unlikely to come around again in the future: "Due to climate change, the majority of the sea ice formed in the marginal seas now melts before it can reach the Central Arctic. As a result, essential transport processes are now faltering, producing changes in the material flows of the Arctic Ocean. In MOSAiC we're now taking one last look at the Arctic as we know it, and as we've investigated it over the past several decades. At the same time, we're getting a first impression of what things will look like in the future." For the sea-ice profiler, one thing is certain: the old Arctic's days are numbered. ■

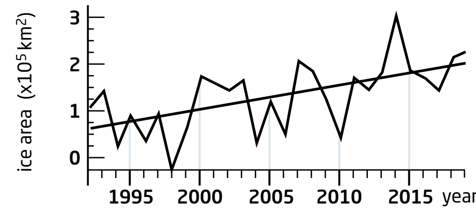
For safety reasons, the experts always worked in teams: they needed to be alert in case any polar bears approached.

The MOSAiC floe: Its first year was far too warm

The following environmental processes are part of the reason the MOSAiC floe, at the age of one year, was far thinner and much more unstable than the experts had expected.

Wind-driven ice export (March-April, 1992-2019)

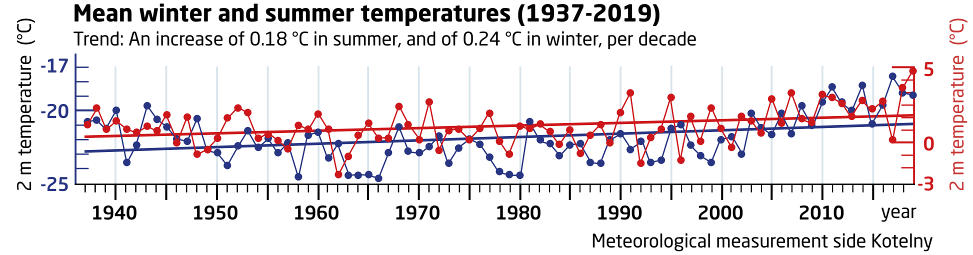
Trend: Increase of 53,000 km² per decade



At the end of winter 2018/2019, intense offshore winds rapidly moved large quantities of ice from Russia's marginal seas toward the Central Arctic (ice export). As a result, new patches of open water – called polynyas – appeared near the coast, and new ice formed within them.

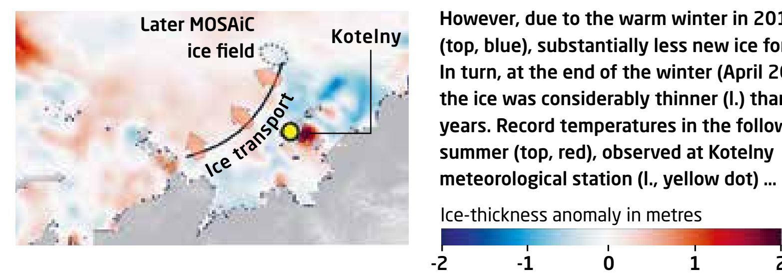
Mean winter and summer temperatures (1937-2019)

Trend: An increase of 0.18 °C in summer, and of 0.24 °C in winter, per decade



Differences in ice thickness

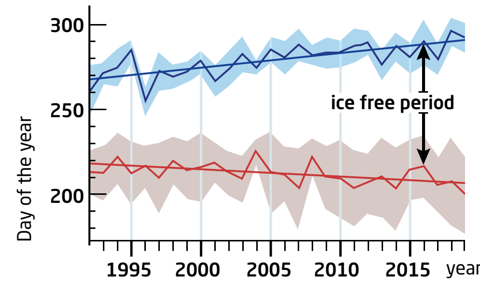
(CryoSat/SMOS data: Difference between April 2019 and April 2010-2018)



However, due to the warm winter in 2018/2019 (top, blue), substantially less new ice formed. In turn, at the end of the winter (April 2019), the ice was considerably thinner (l.) than in past years. Record temperatures in the following summer (top, red), observed at Kotelny meteorological station (l., yellow dot) ...

Start of break-up and freezing in the marginal seas

Trend: Start of freezing (blue) 8.5 days later, and start of break-up (red) 3.8 days earlier, per decade



... soon melted the remaining, thin ice. In 2019 satellites captured the earliest ice break-up in the Laptev Sea since the beginning of recordkeeping. Due to the prolonged high summer temperatures, researchers also documented record high water temperatures. In September 2019, this heat delayed new ice formation in the marginal seas.