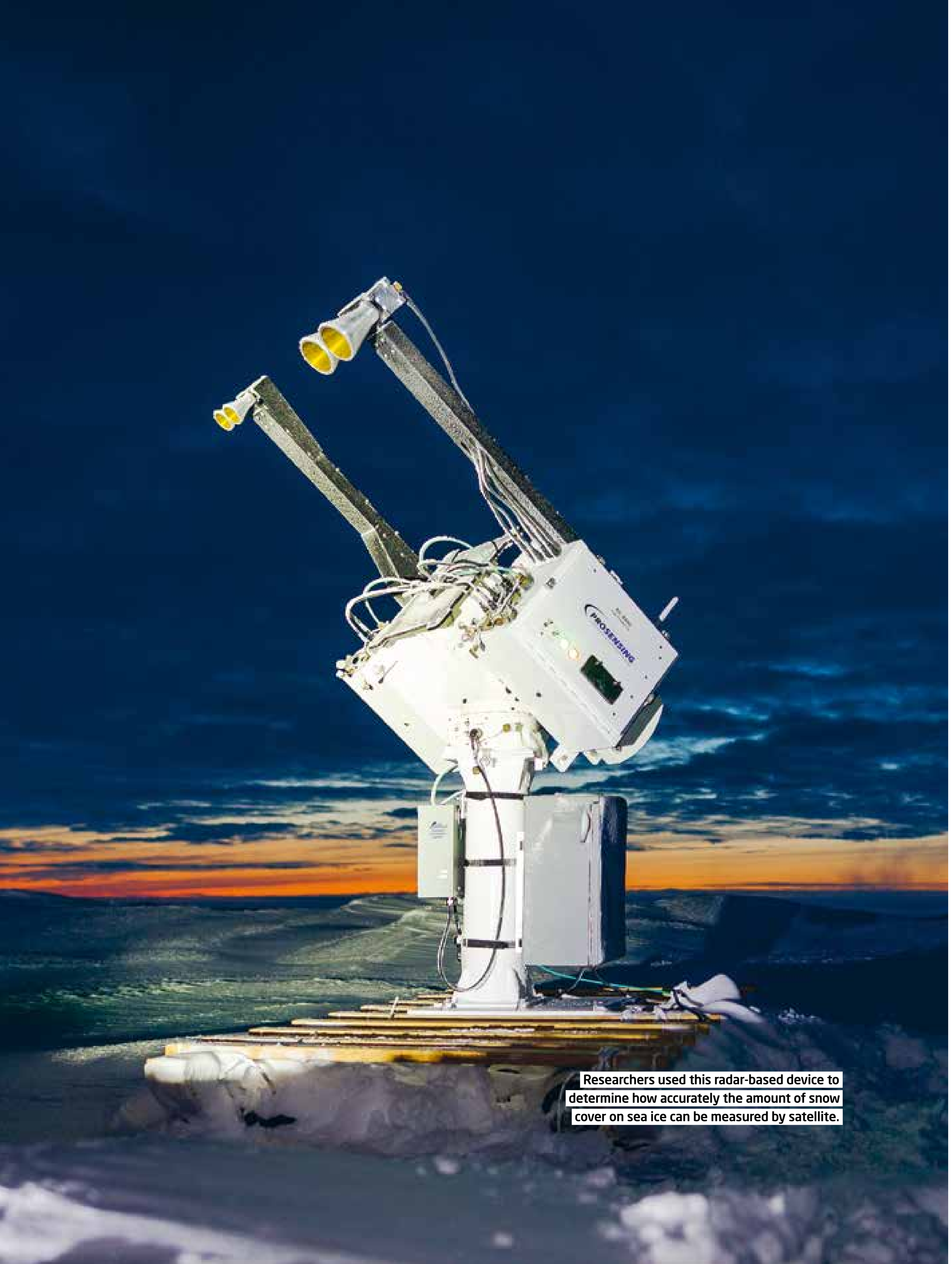
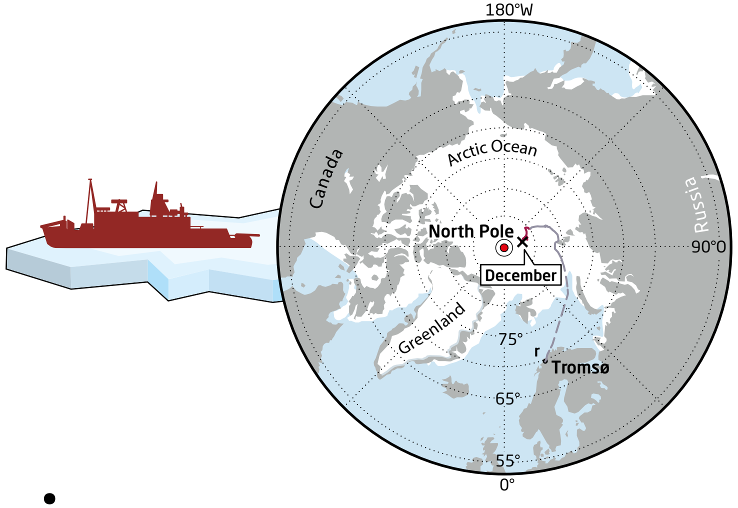


Researchers used this radar-based device to determine how accurately the amount of snow cover on sea ice can be measured by satellite.



DriftStory 02

For a clearer view from space

Satellite observation is the only way to effectively monitor the Arctic sea ice on a broad scale. Yet this approach still has its fair share of weaknesses. Unparalleled control measurements gathered during the MOSAiC expedition will now help to overcome them.

As Dr Gunnar Spreen stood on the bridge of the research icebreaker Polarstern on the evening of 19 November 2019, in the ship's spotlights he suddenly saw the section of the MOSAiC floe where his remote sensing group's measuring instruments normally stood – drifting right past the ship! Thankfully, the ice movement along a long lead stopped after ca. 500 metres. Nevertheless, the physicist from the University of Bremen (Institute for Environmental Physics – IUP) knew that his group would now be forced to look for a new location; the ice where the instruments had been installed was now crisscrossed with small cracks, and seeping seawater had turned the snow on the ice into a briny mush.
As a result, the snow cover that the researchers had planned to use as the basis for a range of tests and experiments over the next several months was now useless. Today, snow remains one of the greatest sources of uncertainty in the remote sensing of sea ice, and one of the reasons why satellite experts joined the largest-scale marine expedition to the Central Arctic in history.

THE IDEAL TOOL

Satellites have been used in sea-ice research for over 40 years. Some of the most important findings on climate change, e.g. regarding the wide-scale retreat of Arctic sea ice, were made with the help of satellite data. Satellite-based ice charts are now used in polar shipping, and are available to everyone, quasi in real-time, at online portals like meereisportal.de.

Today, more than 20 satellites provide constant sea-ice coverage for the polar regions. The majority of them orbit at altitudes of 600 to 800 kilometres and reach speeds of up to seven kilometres per second (25,000 km/h), allowing them to circle the planet roughly 14 times a day. Some satellites use optical sensors to monitor the Arctic and Antarctic; in other words, they produce images similar to those from a camera. But they can only be used in the spring, summer and autumn, when the sun is above the horizon, illuminating the polar landscapes. Moreover, clouds can block their view.

Instead, Gunnar Spreen and his team use microwave sensors to observe the sea ice. These sensors can deliver essential data, even in the long Polar Night and through cloudy skies. In this regard, two fundamentally different measuring techniques are used – one with active microwave sensors (radar measuring) and one with passive sensors (radiometer measuring).

On the bridge of the Polarstern, physicist Gunnar Spreen uses its ice radar to check the ice movements near the ship (l.). He and his team have already been forced to relocate the ten remote monitoring stations once, after a large lead formed in the ice nearby.

If a given satellite is equipped with active microwave sensors, they emit long-wave (millimetre to decimetre), invisible electromagnetic radiation toward the Earth and measure either how much of the signal is reflected back by the sea ice, or how much time it takes for the signal to reach the ice and be bounced back to its source. The amount of energy reflected allows the experts to draw conclusions regarding the ice's age and surface structure; in turn, they can use the signal's travel time to deduce how far the sea ice extends above the surface. Based on its height, they can then determine how thick the ice is.

In contrast, passive microwave sensors don't emit any signals; instead, these radiometers measure how much long-wave radiation the sea ice emits on its own, simply because of its temperature: every body with a temperature above absolute zero (minus 273.15 degrees Celsius) emits both infrared and microwave radiation. Snow and sea ice have a base temperature of between minus 1.8 degrees Celsius on the underside of the ice and minus 30 degrees Celsius on the surface, and accordingly emit radiation. Though the amount of microwave radiation produced is only a fraction of the infrared radiation, the microwaves can pass through clouds and the atmosphere with virtually no interference.

As a result, satellites can measure them very precisely from space – around the clock, 365 days a year. "Satellites are the only tool that allows us to observe sea ice in the polar regions on a broad scale, and at any time," says Gunnar Spreen. "Yet the great challenge is that we can never use them to directly measure important ice properties like the area, thickness, age or concentration. Instead, the satellites record physical parameters like the microwave brightness temperature, which we have to convert in order to draw conclusions about the sea ice," the physicist adds.

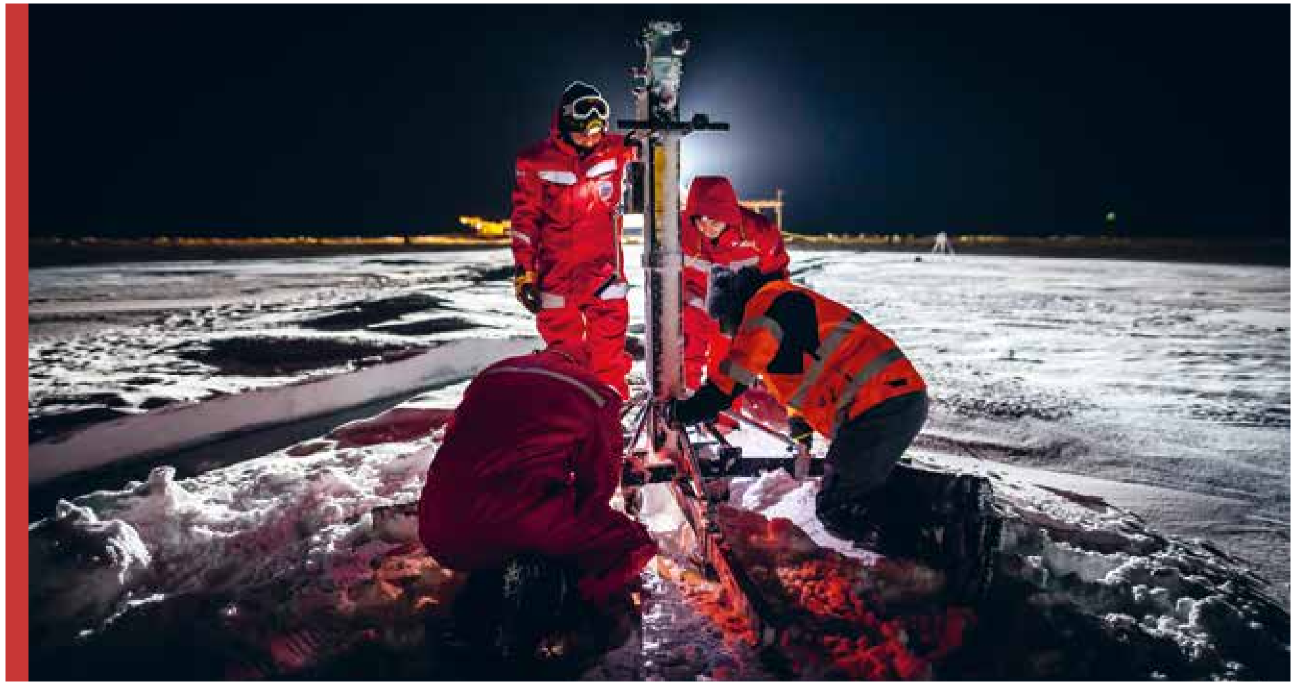
CryoSat-2 is the name of a satellite from the European Space Agency, which solely focuses on monitoring our planet's ice masses. It is equipped with a radar altimeter, which can measure both the thickness of the sea ice and height differences in the Greenland and Antarctic Ice Sheets.

NOT ALL SNOW IS THE SAME

To make these conversions, the experts use special algorithms that include equations on e.g. which physical processes are triggered when microwaves hit snow and penetrate it, or are scattered and reflected by it. Unfortunately, these methods are lacking in accuracy, because snow isn't a reliable constant; on the contrary, it changes continually, and so do its backscatter properties.

"For instance, freshly fallen snow consists of light, fluffy flakes, which makes it virtually transparent for microwave radiation, so we only see the ice below it," Spreen explains. But as snow grows older, the flakes clump together into larger grains, which can definitely reflect back microwave signals. Similar effects can be produced when the wind, as it did in the first few weeks of MOSAiC, whips over the snow cover, compressing its surface. "Then the backscatter properties undergo a fundamental change. Not all snow is the same."

In turn, Spreen gives an example of the errors that a compacted snow surface can produce: "When we use the CryoSat radar altimeter to measure the ice thickness, we work under the assumption that the satellite signal is reflected at the snow/ice interface. But we now know that that's not always true. If the snow's surface layer is compressed by wind, or if ice lenses form in the snow, our signal might no longer be reflected back at the snow/ice interface, but instead higher up in the snow. If we then base our ice-thickness calculations on this distance measurement, it automatically introduces a source of error."



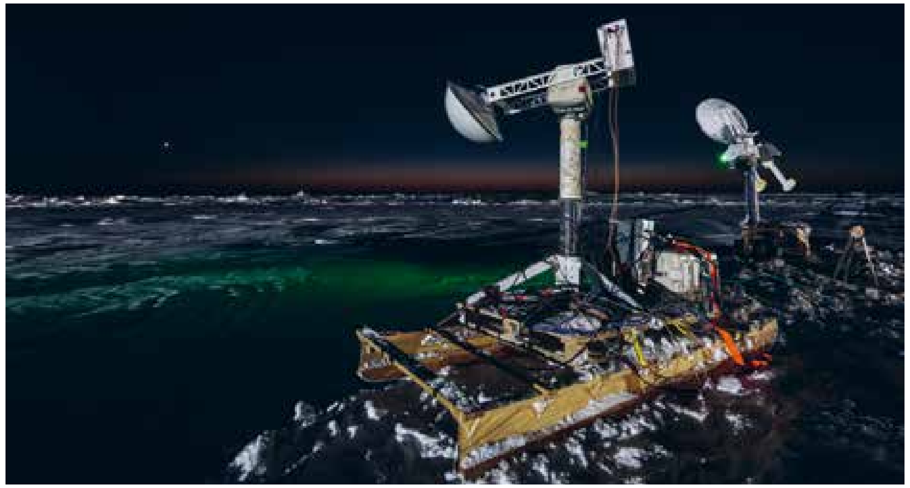
Relocating the equipment: While one of the instruments was being dismantled, the lead in the ice was less than two metres away. The instruments are mounted on sledges, which means moving them across the ice is strenuous but not impossible.

BRINGING SATELLITE TECHNOLOGY DOWN TO EARTH

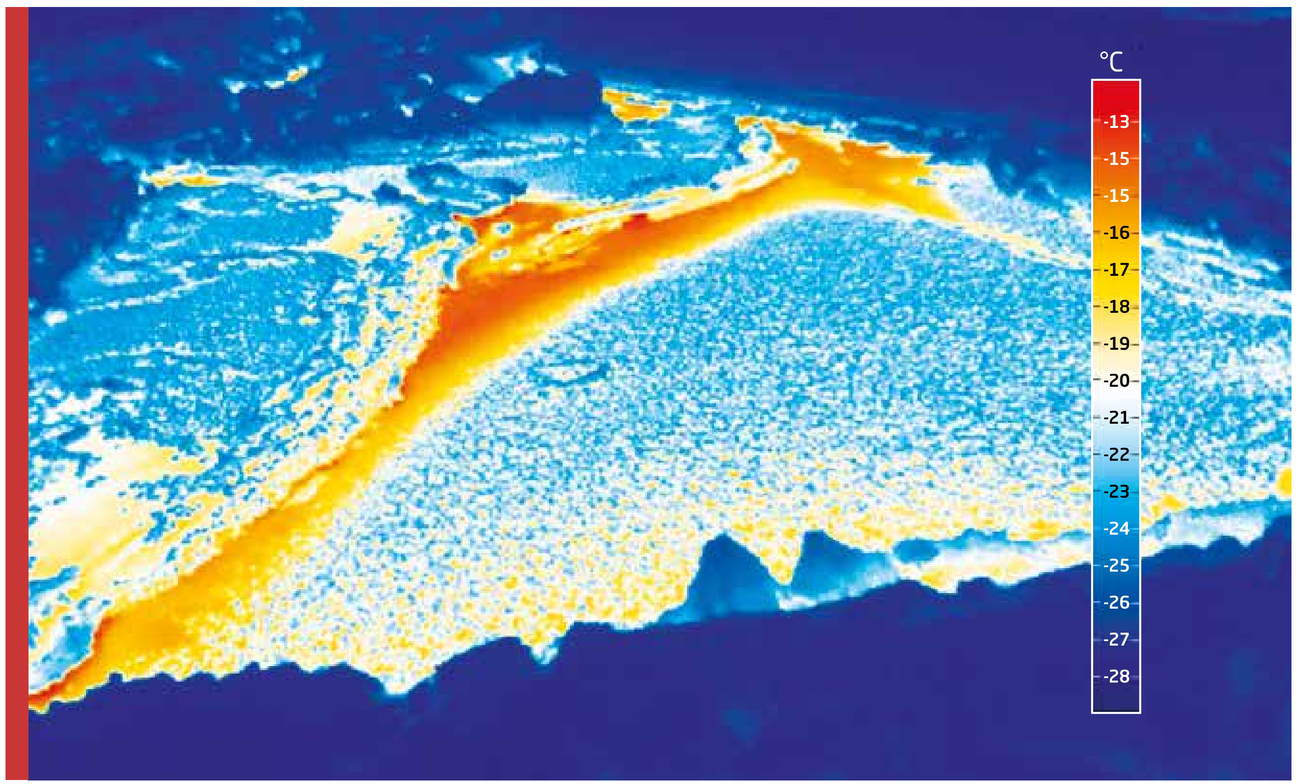
In order to identify this and other sources of error, for the MOSAiC expedition the experts had to bring their satellite technology "down to earth". The Remote Sensing Site is home to ten high-precision instruments, which use the same sensors as satellites. All ten are aimed at the same patch of ice and snow, allowing the researchers to gather a range of different readings simultaneously, and to scan the ice and snow using microwave signals at various frequencies. In addition, the sea-ice physicists use conventional methods to record ice parameters like the floe's thickness, salinity and snow cover, and subsequently compare the results with the parameters derived from the microwave data.

In the Arctic, the Polar Night refers to the phase of the year in which the sun never rises above the horizon. Though there is still a bit of twilight south of the 78th parallel, to the north of it, it remains pitch black nearly 24 hours a day.

"Our goal is to understand exactly what happens to our satellite signals in snow and ice, and how backscatter and radiation change with the seasons," says Gunnar Spreen. This hasn't been possible to date because essential data was lacking, especially from the Polar Night. Thanks to MOSAiC, for the first time the experts will be able to observe the processes at work in the ice and snow on a sea-ice floe for an entire year: from winter, with snowstorms and bone-chilling air temperatures down to minus 30 degrees Celsius; to spring, when the snow will grow warmer and contain more liquid water; and lastly to summer, when meltwater pools will form, and the ice will have more holes than Swiss cheese. Given the unprecedented opportunities that the expedition offers, 13 research centres have contributed satellite equipment, making the MOSAiC satellite validation programme



the largest coordinated international endeavour to improve the accuracy of remote sensing methods for sea ice in history. But the participating researchers have a great deal of hard work to do before they can announce any major gains – and not just because sudden ice movements in November made it necessary to relocate the entire Remote Sensing Site. "Once we've gathered all the on-site data on the interactions between microwaves, snow and ice, we will analyse it in an effort to better grasp the physical processes. Then the next step will be to integrate the processes in our data analysis algorithms, in the form of improved equations. Once that's complete, we can apply the algorithms to the same satellite data and check whether there is now less uncertainty," Spreen explains.
Nevertheless, the snow and ice readings taken during MOSAiC have already yielded one concrete finding: a new dual-frequency technique for measuring the snow cover height on sea ice has proved its value during fieldwork on the MOSAiC floe. As Spreen relates, "The dual-frequency radar altimeter will soon be used in the new European satellite CRISTAL. The signal in the higher frequency is reflected near the snow's surface, while the waves in the lower frequency are reflected at the snow/ice interface." The difference between the two values represents the snowcover height, with a minor degree of uncertainty. "In



This infrared image shows newly formed, thin ice. Seawater, which is much warmer, is rising up through a lead in the ice.

our test runs on the ice, we could see precisely how the two signals were reflected. We can now transfer these insights to the algorithms, so as to reduce the uncertainty before the satellite is ever launched."
Besides CRISTAL, MOSAiC's Remote Sensing Group will provide on-site ice data for a second future ESA satellite mission. The Copernicus Imaging Microwave Radiometer – CIMR for short – will measure ice and snow properties at five different microwave frequencies, helping scientists to monitor the ice area and thickness, snow cover height, and ice movements.
In the meantime, Gunnar Spreen can even see a positive side to the fact that a runaway slab of ice almost made off with all his monitoring equipment back in November: "Just a few days earlier, a two to three-metre-wide channel had appeared at our site. Since the air temperature was minus 30 degrees Celsius, the uppermost water layer quickly refroze, which gave us a unique opportunity to investigate this extremely thin ice and its ice flowers. Working on the Arctic sea ice during the Polar Night and getting to see and hear how quickly conditions can be changed by the wind and ocean was a truly fascinating experience!" ■

How satellites measure sea ice

Passive Remote Sensing

Measure energy that is naturally avaibable

- Emitted energy (a): Visible wavelength (day only)
- Reflected energy (b): Infrared, Microwave wavelength (day or night)

Active Remote Sensing

Satellite sensor emits radiation und records backscattered an reflected radiacion

- Independent of sun, day and night
- Often higher resolution than passive systems