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Key Points:
- Here we present extensive observations of platelet ice formation under Arctic winter sea ice
- The subice platelet layer appears to form locally due to seed crystals in ocean surface supercooling

Supporting Information:
- Supporting Information S1

Correspondence to:
C. Katlein,
ckatlein@awi.de

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Platelet Ice Under Arctic Pack Ice in Winter

Christian Katlein[1], Volker Mohrholz[2], Igor Sheikin[3], Polona Itkin[4], Dmitry V. Divine[5], Julienne Stroeve[6,7], Arttu Jutila[1], Daniela Krampe[1], Egor Shimanchuk[3], Ian Raphael[8], Benjamin Rabe[1], Ivan Kuznetov[1], Maria Mallet[1], Hailong Liu[9], Mario Hoppmann[1], Ying-Chih Fang[1], Adela Dumitrascu[10], Stefanie Arndt[1], Philipp Anhaus[1], Marcel Nicolaus[1], Ilkka Matero[1], Marc Oggier[11], Hajo Eicken[11], and Christian Haas[1]

[1]Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung, Bremerhaven, Germany, [2]Leibniz Institute for Baltic Sea Research, Rostock, Germany, [3]Arctic and Antarctic Research Institute, St. Petersburg, Russia, [4]UiT University of Tromsø, Tromsø, Norway, [5]Norwegian Polar Institute, Tromsø, Norway, [6]University College of London, London, UK, [7]Center for Earth Observation Science, Department of Environment and Geography, University of Manitoba, Winnipeg, Manitoba, Canada, [8]Thayer School of Engineering, Dartmouth College, Hanover, NH, USA, [9]Shanghai Jiao Tong University, Shanghai, China, [10]University of Gothenburg, Gothenburg, Sweden, [11]International Arctic Research Center, University of Alaska Fairbanks, Fairbanks, AK, USA

Abstract The formation of platelet ice is well known to occur under Antarctic sea ice, where subice platelet layers form from supercooled ice shelf water. In the Arctic, however, platelet ice formation has not been extensively observed, and its formation and morphology currently remain enigmatic. Here, we present the first comprehensive, long-term in situ observations of a decimeter thick subice platelet layer under free-drifting pack ice of the Central Arctic in winter. Observations carried out with a remotely operated underwater vehicle (ROV) during the midwinter leg of the MOSAiC drift expedition provide clear evidence of the growth of platelet ice layers from supercooled water present in the ocean mixed layer. This platelet formation takes place under all ice types present during the surveys. Oceanographic data from autonomous observing platforms lead us to the conclusion that platelet ice formation is a widespread but yet overlooked feature of Arctic winter sea ice growth.

Plain Language Summary Platelet ice is a particular type of ice that consists of decimeter sized thin ice plates that grow and collect on the underside of sea ice. It is most often related to Antarctic ice shelves and forms from supercooled water with a temperature below the local freezing point. Here we present the first comprehensive observation of platelet ice formation in freely drifting pack ice in the Arctic in winter during the international drift expedition MOSAiC. We investigate its occurrence under the ice with a remotely controlled underice diving robot. Measurements of water temperature from automatic measurement devices distributed around the central MOSAiC ice floe show that supercooled water and thus platelet ice occur widely in the winter Arctic. This way of ice formation in the Arctic has been overlooked during the last century, as direct observations under winter sea ice were not available and contrary to typical Antarctic observations; manifestation of platelet ice in Arctic ice core stratigraphy has been more challenging to identify.

1. Introduction

Platelet ice is a characteristic feature of Antarctic landfast sea ice, where supercooled ice shelf waters lead to the advection and growth of subice platelet layers (Hoppmann et al., 2020). They consist of loosely attached decimeter sized plate-shaped ice crystals (Hoppmann et al., 2017; Langhorne et al., 2015; Smith et al., 2001) and can be up to several meters thick. These ice platelets form by nucleation in supercooled layers of seawater either at depth (Dieckmann et al., 1986) or directly at the ice underside (Leonard et al., 2006; Mahoney et al., 2011) in the vicinity of large ice shelves, which provide supercooled water due to basal ice shelf melt in the water circulation of ice shelf cavities. The porous structure provides shelter for a particular ice associated ecosystem (Arrigo et al., 2010; Günther & Dieckmann, 2004; Vacchi et al., 2012) and is thus important for biogeochemical cycles (Thomas & Dieckmann, 2002).

As ice shelves are much less common in the Arctic (Dowdeswell & Jeffries, 2017), observations of platelet ice in the Arctic are rare, and the processes causing its formation are poorly understood. The availability of

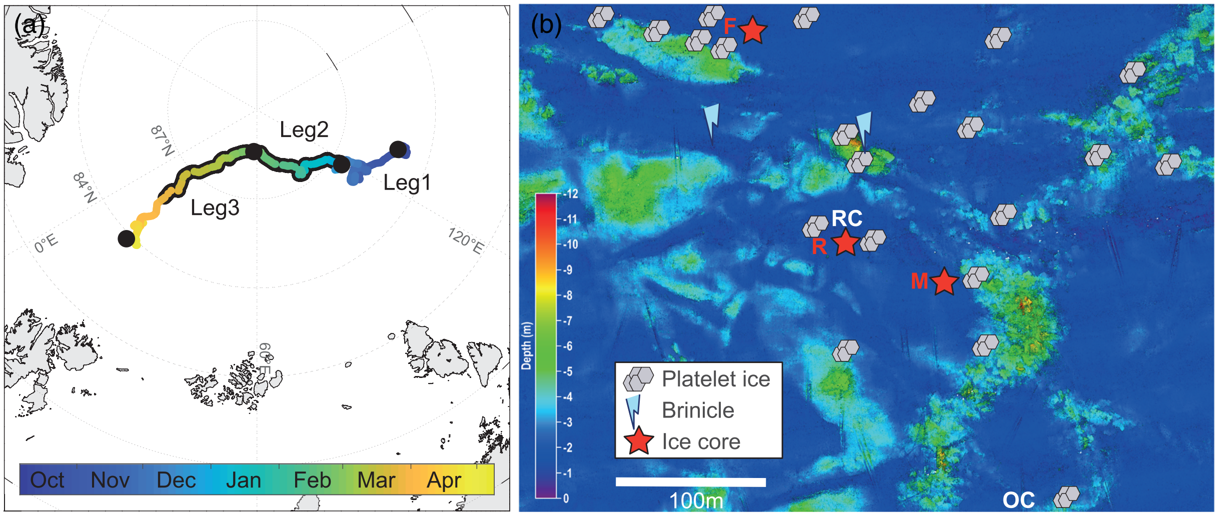

Figure 1. (a) Drift track of MOSAiC floe in the Central Arctic Ocean from October 2019 to mid-May 2020. Black dots denote start and end of Drift Legs 1, 2, and 3, respectively. Platelet ice was observed between 30 December 2019 and 28 March 2020 (black highlighted track). (b) Map of ice draft derived from multibeam sonar survey on 21 January 2020 with most prominent locations of the ubiquitous platelet ice observations (gray symbols), brinicles (light blue symbols), and ice core samples (red stars). White letters indicate the position of the ROV access hole (RC) and the MSS deployment hole (OC). Red letters refer to ice cores taken at the ROV site (R), the ice mechanics site (M), and the ridge site (F).

supercooled water plays a central role for the growth of decimeter scale ice platelets (Lewis & Perkin, 1983, 1986; Weeks & Ackley, 1986). Jeffries et al. (1995) presented one of the few descriptions of platelet ice in the Arctic Ocean. Their study identified platelet ice crystals in 22 out of 57 ice cores collected in the Beaufort Sea during August and September 1992 and 1993. They suggest four different sources for supercooled water, two of which require the presence of ice shelves and coastal interactions and are therefore not relevant for the central Arctic Ocean. The other two include small scale "ice pump" mechanisms (Lewis & Perkin, 1983, 1986) and the interaction of summer meltwater with the underlying colder seawater, leading to the formation of false bottoms in underice melt ponds and platelet ice crystals (Eicken, 1994; Martin & Kauffman, 2006; Notz et al., 2003). They describe platelet ice as a widespread feature in the Beaufort Sea based on their ice core analysis. Carnat et al. (2017) describe two cores with platelet ice signature. Early observations from Lewis and Lake (1971) stay vague in the description but show that the phenomenon is not new. The Russian drifting Station NP-2015 also detected platelet formation caused by meltwater percolation through the ice cover (personal communication I. Sheikin), and an indirect observation under fast ice in summer was described by Kirillov et al. (2018).

Subice platelet layers can be separated from frazil ice in such way that the geometric size of the platelet ice crystals is on the order of 1–10 cm. Frazil ice describes the crystal habit resulting from the initial stages of sea ice growth, when small disk and needle-like crystals smaller than 1 cm appear suspended in the upper water column or at the ocean surface (Hoppmann et al., 2020; Weeks & Ackley, 1986; Zubov, 1963). Subice platelet layers exhibit a rather random orientation of crystal axes. This is significantly different from the skeletal layer at the bottom of growing sea ice, where parallel oriented ice lamellae are growing into a microscale layer of constitutionally supercooled water caused by the brine expulsion during sea water freezing (Lofgren & Weeks, 2017; Rutter & Chalmers, 1953; Shokr & Sinha, 2015).

No extensive direct in situ observations of platelet ice under Arctic sea ice particularly during winter are available. Anecdotal reports from divers, such as during the Tara expedition (Ragobert & Roblin, 2008) or the "Under the Pole" diving expedition (Bardout et al., 2011), allude that this feature has been mostly overlooked in the Central Arctic. Figure S1 and Table S1 in the supporting information provide an overview of previous observations.

Here, we present the first extensive, more systematic in situ observations of growing subice platelet layers under Arctic sea ice in winter. Dives with a remotely operated vehicle (ROV) during the international Arctic drift expedition "Multidisciplinary Observatory for the Study of Arctic Climate" (MOSAiC) from

January to March 2020 around 88°N (Figure 1) revealed a widespread coverage of decimeter scale platelet ice crystals growing on and under the bottom of the ice.

2. Materials and Methods

2.1. Study Area

The ice floe of the MOSAiC drift experiment of the German research icebreaker Polarstern (Knust, 2017) consisted of a conglomerate of various ice types, out of which deformed second year ice and relatively level residual ice (first year ice grown into a remaining matrix of very rotten melted ice; WMO, 2014) were the most abundant. Initial ice thicknesses during the mobilization of the drift station in the beginning of October 2019 were as little as 20–30 cm for the residual ice and around 60–80 cm for the undeformed second year ice (Krumpen et al., 2020). By March, ice growth had increased the level ice thickness to about 145 cm for the residual ice and around 200 cm for the second year ice (Figure S2). Pressure ridges with typical keel drafts of 5–7 m and maximum of 11 m characterized the deformed ice. More details about the composition and history of the MOSAiC floe can be found in Krumpen et al. (2020).

2.2. ROV Operations

We carried out ROV dives from a hole through the ice covered by a heated tent. The M500 ROV (Ocean Modules, Atvidaberg, Sweden) was equipped with a comprehensive sensor suite including cameras as well as a 240 kHz multibeam sonar (Katlein et al., 2017) and provided an operating range of 300 m from the access hole. We documented platelet ice occurrences mostly with four cameras: a high-definition zoom video camera (Surveyor HD, Teledyne Bowtech, Aberdeen, UK), two standard definition video cameras (L3C-720, Teledyne Bowtech, Aberdeen, UK), and a 12 megapixel still camera (Tiger Shark, Imenco AS, Haugesund, Norway).

The ROV dives covered many different sites, but several places were revisited (Figure 1b) due to repeating routine dive missions allowing for a temporal assessment of platelet ice evolution. On 15 February 2020, we towed an underice zooplankton net (ROVnet) with the ROV directly along the ice underside (Wollenburg et al., 2020) to brush off platelet ice samples for structural analysis. In the lab, platelets were frozen into a solid block of ice by adding sea water to the sample container, in order to later analyze the platelet ice crystal structure.

2.3. Ice Core Sampling and Analysis

We extracted ice cores in three locations (Figure 1b) where subice platelet coverage had been previously confirmed by ROV imagery. We analyzed them for ice texture by preparing thin sections using the Double Microtoming Technique (Eicken & Salganek, 2010; Shokr & Sinha, 2015) in the lab on board. We photographed the thin sections between crossed polarizers to identify crystal geometric properties. To associate an approximate date of ice formation to each ice sample along the core, we used a simple ice-growth model based on the number of freezing-degree days (Pfirman et al., 2004), forced by air temperatures recorded by the Polarstern weather station.

2.4. Physical Oceanographic Measurements

We measured vertical and horizontal profiles of seawater conductivity, temperature, and pressure (CTD) using three independent different types of platforms. One CTD sensor was mounted on the ROV (GPCTD, SeaBird Scientific, USA), while we performed recurring deployments of a free-falling microstructure sonde (MSS 90LM, Sea and Sun Technologies, Trappenkamp, Germany) through a nearby hole in the ice (Figure 1b). In addition, several autonomous stations with CTD packages at a depth of 10 m (SBE37, SeaBird Scientific, USA) were operational in the MOSAiC distributed network at distances of 10–40 km from the central floe (Figure S3). All devices were calibrated by the manufacturers immediately before the expedition. The respective measurement uncertainties are discussed in Text S1.

3. Results and Discussion

3.1. Subice Platelet Layer Morphology

We observed a 5 to 30 cm-thick subice platelet layer covering the ice bottom as shown in Figure 2. The ice platelets are composed of blade- or disc-shaped single ice crystals with *c*-axis alignment normal to the

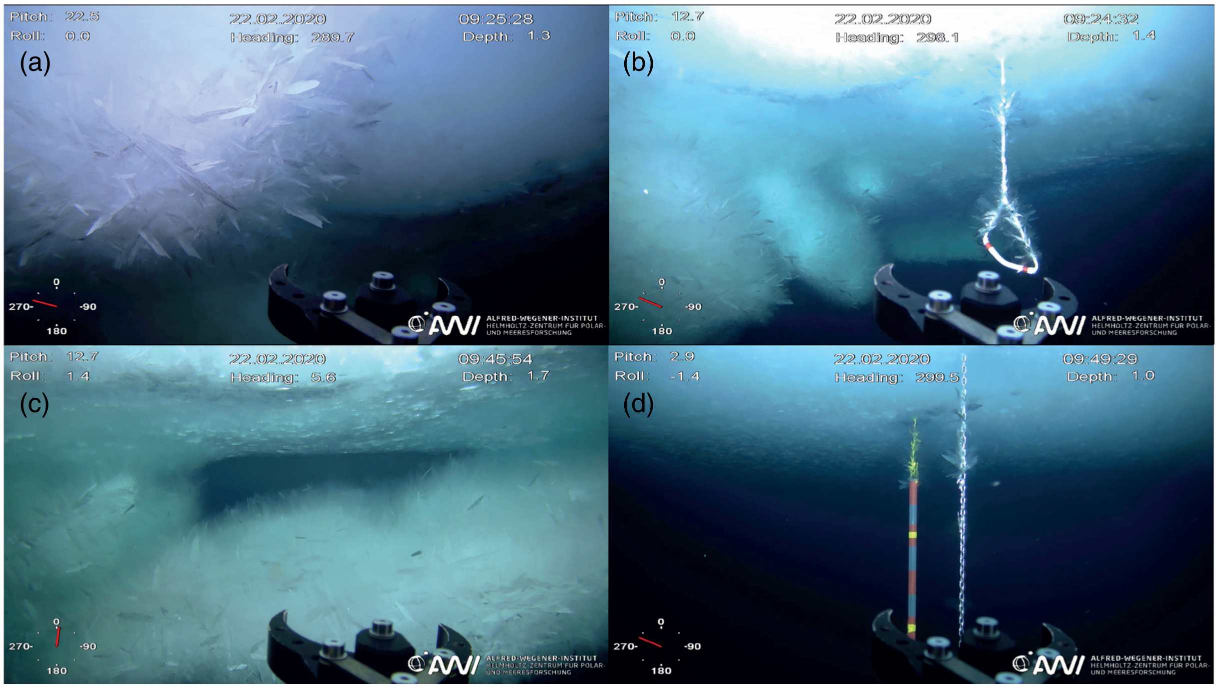

Figure 2. (a) Close-up picture of platelet ice covering a ridge block. The ROV manipulator opening in the foreground is about 9 cm wide. (b) Rope sling next to a pressure ridge: Both the rope and the ridge are vastly covered in ice platelets. (c) Upward growing platelet ice in a ridge cavity. (d) Platelet ice crystals covering the rope and chain of underwater installations. Note the lack of platelet growth on the plastic marker stick and the coverage of small platelet crystals underneath the level ice.

platelet surface. Most platelets were firmly attached to their substrate but fragile to physical impact by the ROV. When observed on ropes or chains, platelet ice crystals were tightly grown through their structure (Figures 2b and S4) and not just loosely attached to the respective surface. This indicates that these platelets grew on site and have not been advected in from deeper waters or horizontally as already suggested by Lewis and Lake (1971). Contrary to Antarctic fast ice, we did not find meter-thick layers of platelet ice accumulation (Hoppmann et al., 2017; Hunkeler et al., 2016), possibly due to slower platelet or faster congelation growth. The freezing front of the congelation ice quickly progressed downward into the subice platelet layer and incorporated it by congelation ice growth in between the platelet crystals (Dempsey et al., 2010). A thickness difference between Arctic and Antarctic subice platelet layers was already proposed by Lewis and Perkin (1986) based on different driving depths in the ice pump mechanism.

We identified crystal sizes up to approximately 15 cm from the ROV camera footage. Maximum crystal size retrieved with the towed zooplankton net was 9 cm, while the thicknesses of platelet crystals ranged from 0.8–2.5 mm. However, due to the limited size of the sampling bottle with a diameter of 10 cm and the physical interaction of the ROVnet (0.4 by 0.6 m opening) and platelet ice structures, platelets may well have been broken during the sampling process.

Platelet ice growth depends on available crystallization nuclei or seed crystals for secondary nucleation. Probably due to this reason, we did not observe platelet growth on the polymer-covered thermistor strings hanging in the water column. The complex structure of core-mantle polyamide rope or metal parts provided sufficient crystallization nuclei for platelet formation (Figures 2d and S4). Another explanation could be material-dependent adhesion of seed crystals as described in Robinson et al. (2020). This was particularly obvious on 15 February 2020, when the ROV had been hanging for 3 days in 2 m water depth and was covered in up to 30 mm large platelet crystals on edges and corners, while particularly smooth plastic surfaces were unaffected by platelet growth (Figure S5).

3.2. Spatial Distribution of Platelets

Platelet ice coverage was ubiquitous in the entire observational range of the ROV. However, platelet ice growth was almost exclusively observed in the uppermost part of the water column, above a depth of 2–

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3 m. Deeper lying ridge keels as well as deep hanging ropes and instrument installations were not covered in platelet ice. Few installations exhibited a vertical gradient of platelet ice growth coverage, with the most extensive occurrence at the ice water interface and diminishing platelet cover toward depth (Figure S6). This has been observed similarly in the Antarctic (Dayton et al., 1969; Hoppmann et al., 2020; Mahoney et al., 2011). Platelet crystals were largest (up to 15 cm) and most prominent on blocks, ridges, and edges protruding from the level ice, but at close inspection, we found also smaller-scale platelet ice crystals (1–2 cm) throughout the bottom of level ice. Also, these smaller platelets appeared different from ice lamellae expected in the skeletal layer. We identified no significant spatial difference in underice roughness (and thus platelet coverage) from acoustic backscatter derived from the multibeam sonar measurements (Figure S7).

While sheltered areas between ridge keels with low currents seemed to provide best conditions for platelet growth, we observed significant platelet growth of similar size also at locations that were completely exposed to the ice-relative currents (Figure S4) and more than 100 m away from any significant ice feature. Lewis and Milne (1977) attribute the presence of subice platelet layers to cracks or pressure ridges. While this seems to coincide with the locations of our most prominent observations, we also observed platelet ice far away from such features and can thus neither prove nor rule out the ridge associated ice-pump mechanism of platelet formation as predicted by Lewis and Perkin (1986).

We found no direct link between platelet ice distribution and brine drainage features. Despite the occasional observation of brinicles—ice stalactites forming from the contact of descending, cold brine with seawater (Lewis & Milne, 1977)—we encountered them both with and without intense platelet ice cover (Figure S8).

3.3. Temporal Variability

During MOSAiC, the ROV diving schedule only allowed for a weekly cycle of repeated visits (Figure S9). Therefore, our information on the temporal variability of platelet ice occurrence is limited and less objective. However, we could identify clear differences in the amount of new platelet ice formation between different periods. These periods were characterized either by new crystal growth, the lack of such, or even a perceived reduction in platelet ice cover. They are identified in Figure 3 to investigate a link between oceanographic conditions and platelet ice formation. As the ROV sampling in the described location only started on 31 December 2019, we cannot provide a detailed assessment of the situation before. However, we observed no platelet ice during ROV dives before 6 December 2019 in a different location approximately 1 km away. We observed platelet ice for the last time during an ROV dive on 28 March 2020, after the floe had been affected by deformation and the return of sunlight. This coincides with the time, when water temperatures under the ice climbed above the local freezing point again (Figure 3c).

3.4. Supercooling

We found supercooled water, the basis for platelet ice formation, well below the ice water interface, which we confirmed using three different independent measurement platforms. Temperature and salinity data from the ROV, a free-falling Microstructure Sonde (MSS), and several autonomous CTDs deployed at 10 m depth in 10–40 km distance from the ROV site all revealed water temperatures around 0.01–0.02 K below the respective seawater freezing point in the uppermost mixed layer (Figure 3a). This degree of supercooling is similar to observations from the Antarctic (Mahoney et al., 2011) and larger than the calibration uncertainty and uncertainties in the calculation of the local freezing point of seawater. Hence, we can confirm the existence of supercooled water several meters thick as prerequisite for platelet ice formation (Smith et al., 2001). Measurement uncertainties might however obscure the absolute magnitude and depth of ocean surface supercooling.

Within the mixed layer, the local seawater freezing point is pressure and therefore depth dependent, while temperature and salinity values are approximately constant. Thus, freezing-point departure increases toward the surface with a higher level of supercooling in the uppermost mixed layer right under the ice (Figures 3a and 3b). This can explain the observed decrease in platelet ice abundance below 2 m depth.

A simple hypothesis for platelet ice growth might thus be that water molecules attach to existing crystallization nuclei, for example, at the ice underside as soon as they are in a strong enough state of supercooling. Considering the turbulent nature of the mixed layer, where water particles get mixed up and down through the entire mixed layer at a time scale of 30 min (Denman & Gargett, 1983), they oscillate between supercooled and nonsupercooled states. Thus, we hypothesize that platelet ice formation is only possible as

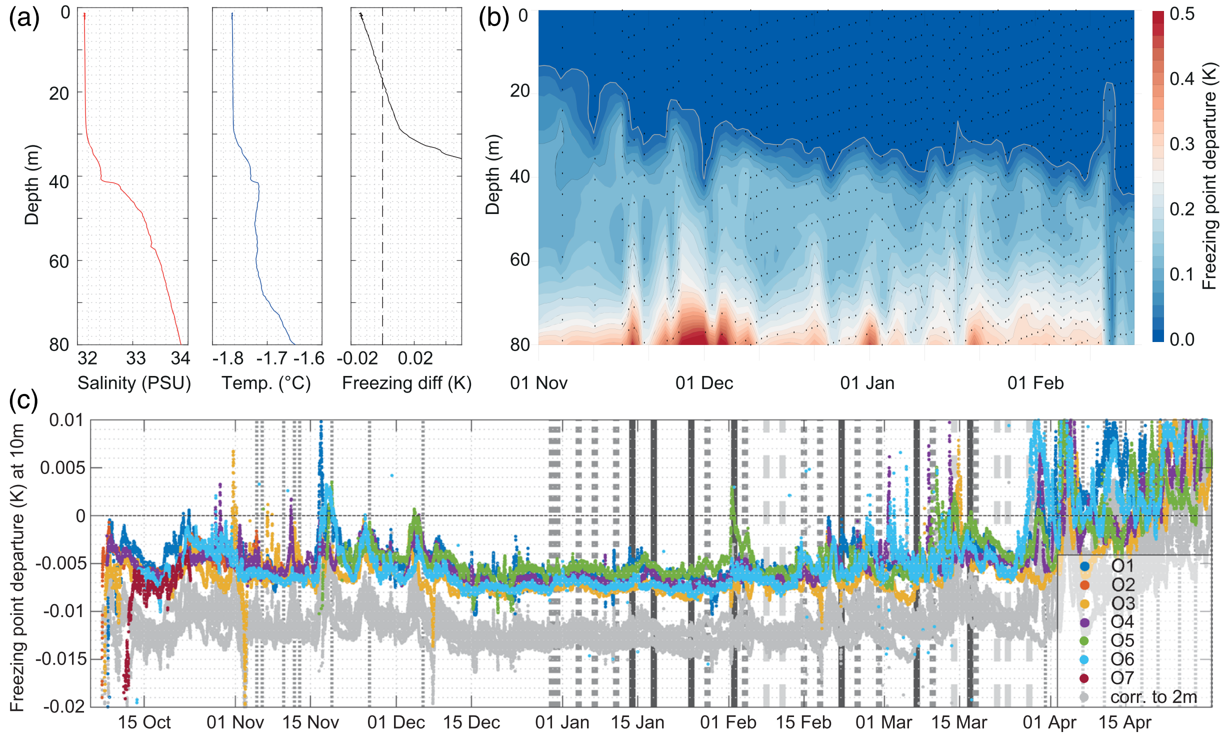

Figure 3. (a) Salinity, temperature, and freezing point departure observed by the ROV on 22 February 2020. (b) MSS time series of water temperature above the surface freezing point. Note the consistent deepening of the supercooled layer indicated in blue color. (c) Time series of freezing-point departure measured in 10 m depth (and adjusted to 2 m depth in gray) from the autonomous observation stations. Vertical lines indicate platelet ice intensity observations classified as high (solid lines), normal (thick dotted lines), and low intensity (dashed lines) based on visual ROV observations. Thin dotted lines indicate ROV surveys without platelet ice observation. See Figure S3 for geometric location of stations relative to the central observatory.

soon as the temperature in the complete mixed layer lies below the vertically averaged seawater freezing point. This can be either achieved by excessive atmospheric cooling during the Arctic winter (Danielson et al., 2006; Skogseth et al., 2017) or due to a sudden shoaling of the mixed layer, cutting off mixing beyond a certain depth, so that suddenly, most of the surface mixed layer has a temperature below the freezing point causing respective formation of platelet ice. Platelet ice could also originate from frazil crystals generated in the water column (Robinson et al., 2020; Skogseth et al., 2017) that rise up and attach to the surface. If present, free-floating frazil ice crystals should have been easily detected in light beams used for ROV surveys or Secchi-disk casts. No such enhanced light scattering by ice crystals was observed, but we might have missed it particularly due to temporal limitations of the sampling schedule. Another plausible explanation for platelet formation lies in the "ice-pump" mechanism (Lewis & Perkin, 1983, 1986): Descending salty brines generated by strong atmospheric cooling in leads or even under a completely closed ice cover can melt deep lying ridge keels and thus supercool the water column and respectively generate platelet ice. Determining the exact nature of the processes involved in the temporally varying strength of platelet ice formation would require more targeted high temporal resolution investigations of platelet growth than could be accomplished during the rigid observational plan for MOSAiC.

Time series of MSS and autonomous observations show that the detected levels of platelet ice were only apparent after a more temporally stable mixed layer with a depth of ~30 m had established in mid-December. Furthermore, the perceived decrease in platelet ice coverage observed in mid-February was likely linked to a passing eddy, decreasing the freezing-point departure in the upper mixed layer (Figure 3b).

Observations of autonomous CTD sensors deployed in the distributed network at 10 to 40 km distance from the central MOSAiC floe (Figure S3) consistently show similar amounts of ocean surface supercooling (Figure 3c). This allows the conclusion that platelet ice formation under Arctic winter sea ice is not a local curiosity, but a widespread, overlooked feature in the Central Arctic Ocean.

3.5. Persistence in Ice Core Analysis

Despite the ubiquitous occurrence of platelet ice shown in our study, there is a general lack of extensive signs of platelet ice formation in the texture of Arctic sea ice cores of the Transpolar Drift (Tucker et al., 1999). To further investigate, we retrieved ice cores at three locations (Figure 1b) where we had documented platelet ice beforehand with the ROV cameras. In contrast to most Antarctic landfast ice cores, all of the investigated ice core bottom thin sections (Figure S10) showed only weak signs of incorporated platelet ice. Rapid congelation ice growth of 5–9 cm per week might have concealed a more obvious signature of platelets (Dempsey et al., 2010; Gough et al., 2012). However, in various places we found a few large, inclined crystals interpreted as originating from platelet crystals. Moreover, during the first leg of MOSAiC at the end of November 2019, an ice core retrieved at the second-year ice site contained more clearly identifiable sections of platelet ice (Figure S11). Thin section analysis indicates substantial microstructural and textural similarities with literature reports of Antarctic platelet ice (Jeffries et al., 1995; Langhorne et al., 2015; Leonard et al., 2006; Smith et al., 2001).

To investigate this more closely, we analyzed the texture of collected platelet crystals refrozen into seawater. The resulting texture (Figure S12) looks significantly different from the one described for freshwater-derived platelet ice by Jeffries et al. (1995). In particular, platelet ice crystals seen from the side have a rectangular rather than triangular shape, and also, many platelet crystals exhibit subgrain boundaries, which are described as absent in the work of Jeffries et al. (1995).

We thus have two hypotheses why these ubiquitous platelet ice crystals under Arctic winter sea ice do not leave a strong record in the texture of ice cores. First, despite their spectacular voluminous appearance, the ice platelets actually only take up a small volume fraction, so that it is unlikely to observe multiple platelet crystals in a submillimeter thick ice core thin section. This has been found also for Antarctic platelet ice incorporated into fast growing congelation ice (Dempsey et al., 2010; Gough et al., 2012). Second, the platelet crystals may serve as primary nucleation surfaces also for the congelation growth in a way that obscures their initial origin. Both hypotheses could explain why such a widespread cover of subice platelet layers in the winter Arctic has been overlooked in the last decades of sea ice texture investigations.

3.6. Physical, Ecological, and Biogeochemical Implications

Considering large-scale energy fluxes and the thermodynamics of sea ice growth, platelet ice formation under Arctic sea ice in winter does likely not affect the thermodynamics of sea ice growth significantly. This is particularly due to Arctic platelet ice being a local seasonal phenomenon maintaining a closed energy budget. In contrast, Antarctic platelet ice is often derived from water masses with spatially different origin and thus disrupting the local energy budget. Even though the impact may be small for ice-ocean physics, the porous, ragged structure of the platelet ice interface does affect small-scale roughness of the ice underside and will in particular affect the entrainment of water constituents, such as sediments, nutrients, or biological assemblages. One sample of subice platelets from the ROVnet showed elevated levels of halocarbons compared to the general ice column, meaning this subice platelet layer could play a role also in different biogeochemical cycles. Despite the assumed inactivity of the underice ecosystem during polar night, platelet ice might still serve as a substrate for algal growth and protection for underice macrofauna, as we observed amphipods maneuvering through the maze of crystal blades (Figure S13).

Platelet ice could also play a significant role in the poorly understood consolidation of voids, for example, in sea ice ridges, where it would be able to close large gaps faster than by pure congelation ice growth. This could explain why voids in ridge keels often appeared slushy when drilled through during MOSAiC (Figure S14).

While platelet ice observations in the Arctic date back to the 1970s (Lewis & Milne, 1977), the thinner (Haas et al., 2008; Kwok & Rothrock, 2009) and more dynamic sea ice (Kwok et al., 2013) of recent years might increase rapid cooling of Arctic surface waters and thus promote platelet ice formation.

4. Summary

During the polar night of the international drift expedition MOSAiC in 2019–2020, we observed a widespread coverage of the ice underside with a subice platelet layer. These up to 15 cm large platelet ice crystals grew in situ from supercooled water of the uppermost mixed layer, both on exposed ice features and level ice.

This is the first comprehensive in situ observation of subice platelet layer formation during Arctic winter in the free-drifting ice of the Central Arctic. As historic observations show, this is not a new phenomenon, but only modern robotic equipment at a winter drift ice station allowed for its detailed observation.

Platelet ice formation has been overlooked so far as a widespread feature of ice growth during Arctic winter. Our study provides the first observational evidence for a link between platelet growth intensity, mixed layer stability, and supercooling, but the detailed processes with respect to their seasonal impacts on ice-ocean interactions are yet to be understood. In particular, we were able to show that this subice platelet layer does not always leave a clear imprint on sea ice texture and was hence easily overlooked in past ice core analyses (Figure S15).

The potential importance of subice platelet layers for the ice-associated ecosystem and biogeochemical fluxes during Arctic winter should be investigated more closely in the future. To improve our understanding of the involved physical processes, we suggest a more targeted investigation during future Arctic winter campaigns with the goal to achieve higher temporal resolution and more objective observations of platelet crystal growth. This could be achieved by fixed underwater cameras in relation to water dynamics, potential ridge keel melting, and thermodynamics in the mixed layer.

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Data Availability Statement

Data used in this manuscript were produced as part of the international Multidisciplinary drifting Observatory for the Study of the Arctic Climate (MOSAiC) with the tag MOSAiC20192020. All data are archived in the MOSAiC Central Storage (MCS) and will be available on PANGAEA after finalization of the respective data sets according to the MOSAiC data policy. Screenshots from ROV video (Katlein, Krampe, & Nicolaus, 2020), acoustic backscatter (Katlein, Anhaus, et al., 2020b), ice core data (Katlein, Itkin, & Divine, 2020), and ROV CTD data (Katlein, Anhaus, et al., 2020a) are already available on PANGAEA. Oceanographic data from autonomous platforms 2019O1–201908 can be accessed online (at seaiceportal.de). Ice and snow thickness data were kindly provided by Stefan Hendricks.

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