Editor Decision: Publish subject to minor revisions (review by editor) (26 May 2020) by Jean-Louis Tison

Comments to the Author:
Hi Stefanie, Mario and co-authors,

I have now read your detailed responses to the two reviewers, but, if I am not mistaken, could not find the file with revised manuscript, highlighted with changes. I guess you were waiting for the changes to the figures, with understandable reasons.

Response: We are sorry for the missing manuscript file. It could have been provided easily, but it was not obvious in the web interface where it should have been uploaded. Even in the documentation about the review process it was mentioned that the revised file was only supposed to be uploaded after the editor gave his/her ok to the responses. Maybe it was a simply oversight on our end, but the journal could consider to make it more obvious where to upload that file.

I believe you have answered most of the comments from the reviewer. I am still a little bit uneased by missing any data on ecosystem and ocean circulation, as these items were underlined both by the two reviewers and by myself initially.

Response: While we still believe that the combination of the unique in-situ drilling dataset with remote sensing and meteorology observations makes a sound story, we also understand your and the reviewer's concerns. We took this issue seriously, and in our present (major) revision, we tried our best to mitigate the unease about the lack of ecosystem data, oceanographic data and also sea ice crystal fabric mentioned in one of your other comments. Please note that there is no ecosystem program running at the station, so there are unfortunately no regular observations available. It has led to such desperation that the authors were doing some biological sampling (in this case, chl-a filtration of a few cores in one season) themselves. Sea ice coring was initially planned to be a regular activity, but was logistically not feasible. Oceanographic data (such as shown in Hoppmann 2015) is in principle available, but needs more analysis and even then might not give a whole picture about circulation patterns etc. We have been trying to push for more oceanographic observations, but, as with coring, is currently not feasible (yet). In short, we just don't have the suitable datasets at hand right now to provide a comprehensive, overarching picture. We understand this (physical) paper as a foundation for further investigations. A point of the paper is to highlight that such data is urgently needed to fully understand this system. We hope for your understanding.

Having said all that, we have decided to add some entirely new figures and paragraphs regarding the above-mentioned aspects to the manuscript, which hopefully help to support the main points and convince you to accept it for publication in your journal.

The following paragraph about sea ice crystal fabric has been added to the discussion:

4.4 Sea-ice growth history

A detailed study of sea ice crystal fabric by means of visual inspection of thick/thin sections or with the help of an automated fabric analyzer can help immensely to determine the dominant growth processes in a given area of interest. At the same time, the growth history of fast ice is to a large degree governed by the timing of the formation of a persistent ice cover, and can only be interpreted accurately by the help of as much auxiliary information as possible, most importantly from regular satellite imagery such as MODIS, Sentinel-1 or Radarsat.

It has been planned since the start of the AFIN monitoring at Atka Bay in 2010 to regularly obtain sea ice cores for crystal fabric analysis. A set of cores from the six main sampling sites (Figure 1) has been obtained in 2011, and again in 2012. Only 4 out of these 12 cores have been processed so far (all from 2012), which is obviously only a very small sample size compared to the decade of measurements shown above. While the limited ice core data thereby is insufficient to make general statements about sea ice growth processes at Atka Bay, we provide this data here to highlight a few major aspects, some of which have already been discussed earlier.

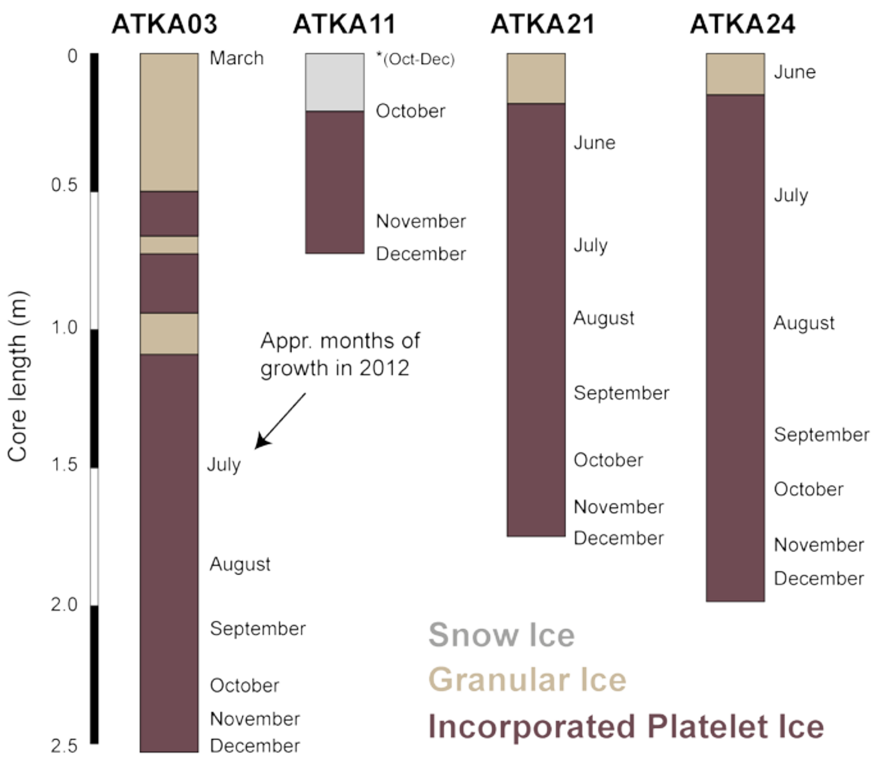

Figure 9: Sea-ice crystal fabric from ice cores obtained at four different fast ice sampling sites in December 2012, derived from vertical and horizontal thin sections (0.1m spacing) along the full core length (see also Hoppmann et al., 2015a; Hoppmann et al., 2015b; Hoppmann, 2015).

From the (limited) data we have from the four 2012 cores (Figure 9), it is evident that 1. there is no columnar texture at all; 2. there is a small fraction of granular ice in the top parts of three cores; 3. there is a small fraction of snow ice in one core and 4. all cores are dominated by incorporated platelet ice. The core from the western part of Atka Bay (ATKA03) exhibits a comparably high fraction of granular ice: a 0.5m long section at the top, and 2 smaller sections a little bit deeper, with some incorporated platelet ice in between. This crystal fabric is a manifestation of the dynamic conditions under which the initial growth takes place, and supports the other datasets shown above. The strong easterly winds (Figure 3) keep pushing the initially forming thin ice towards the western ice shelf edge, which leads to a grinding of the fragile frazil crystals, and subsequently to a rafting of the newly formed ice. This process seems to be still relevant even after the ice has thickened to >0.5 m, probably by very strong winds. In this way, the thickening rate of the sea ice is greatly accelerated initially (Figure 4). The absence of exclusively columnar ice is evidence that there are already platelet crystals emerging from the cavity very early in the season. While it has been suggested in an earlier study that such crystals would be present in the bay from June onwards (Hoppmann et al., 2015b), there is a possibility that they might arrive even earlier, at least in parts of the bay close to the outflow of ISW. While the ice core taken at ATKA11 is not representative at all for sea ice in the bay due to an early breakup event and subsequent late refreezing, the presence of snow ice is an evidence for a process that we would argue plays an underestimated role in this region. However, we currently do not have any more direct evidence for the wide presence of snow ice at Atka Bay (due to the lack of ice core data) other than the observations of negative freeboard in our main dataset (Figure 5), and several observations of extensive surface flooding from summer campaigns. In order to fill this knowledge gap, a dedicated program of obtaining much more core sections from the top of the sea ice at different locations would have to be implemented, with a subsequent crystal fabric and/or oxygen isotope analysis. As indicated above, this is currently not feasible. The other ice cores taken at ATKA21 and ATKA24 are close to the "typical" sea ice thickness at Atka Bay of 2 m, and exhibit the expected granular ice at the top from wind and waves, and incorporated platelet ice throughout the rest of the core. No evidence from dynamic growth processes is found in these cores. This is in line with our knowledge so far, especially since the sea ice in that area of the bay typically forms later in the year and is less influenced by strong winds.

The following paragraph about multi-disciplinary research (including the requested ecosystem data) has been added to the discussion:

4.5 Implications for multi-disciplinary research

Such a multi-layered, thick sea-ice cover not only very efficiently separates the atmosphere from the ocean with respect to ice growth, but it also influences the exchange of any fluxes between the two climate system components. Thereby, it also strongly impacts the ice-associated ecosystem, which is particularly unique in sub-ice platelet layers (Arrigo, 2014). Günther and Dieckmann (1999) concluded from their study that about 99% of the total fast-ice biomass in Atka Bay originates from algae initially growing in the sub-ice platelet layer. The maximum Chl-a concentration in their study was around 490 mg m^{-3} in the bottom of the fast ice, and 240 mg m^{-3} in the platelet layer in summer, at a site that had up to 0.35 m of snow cover. The authors argued that their total observed fast ice biomass was significantly lower compared to the mostly snow-free fast ice of the Ross Sea. However, it was still on the very upper range of biomass usually found in Antarctic fast ice (Meiners et al., 2018). At the same time, more recent results from 2012 reveal that Chl-a concentrations can reach up to 900 mg m^{-3} when there is much less snow present (Fig. 9).

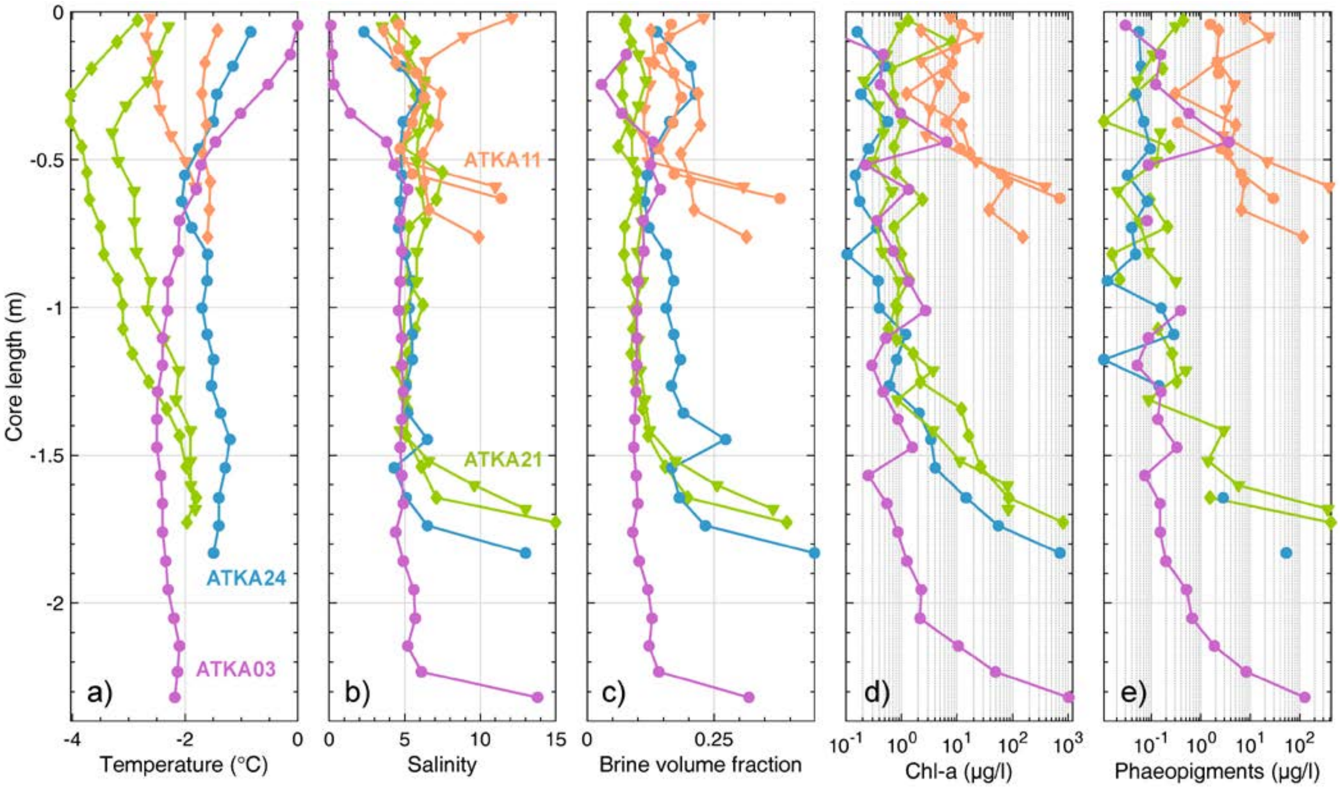

Figure 10: Sea-ice physical and biological properties from cores obtained at different fast ice sampling sites in Nov/Dec 2012 (after Hoppmann et al., 2013).

While a few studies exist that investigate shade-adaptation in algae and link algal growth to snow depth on McMurdo Sound fast ice (e.g. Sullivan et al., 1985; McGrath Grossi et al., 1987; Robinson et al., 1995), so far still comparably little is known about the adaptation of the ecosystem in the upper ocean to perennial fast-ice conditions and sub-ice platelet layers. These and similar knowledge gaps that exist with respect to ice-shelf influenced fast-ice regimes can only be addressed by integrated, multi-disciplinary research in comparably easy to access locations in coastal Antarctica, one of which was introduced in this physical study.

Finally, we added the following paragraph about oceanographic data into the discussion (section 4.2):

Regarding the properties of the ocean in this region with respect to its interaction with the ice shelf and sea ice, Hoppmann et al., 2015b used a subset of oceanographic data collected by the nearby PALAOA hydrographic observatory (Boebel et al., 2006) to link fast ice observations to ocean properties. A more recent study by Smith et al. (2020) helped to constrain the boundary conditions for Ice Shelf Water outflow by mapping in great detail the cavity geometry of the Ekström Ice Shelf. This study also shows data from repeated CTD casts through a borehole in the ice shelf, revealing the buoyant outflow of Ice Shelf Water in a relatively shallow surface layer. While these efforts help to better understand the complex system of ice shelf-ocean-sea ice interaction in this region, we conclude that a more comprehensive, year-round oceanographic study that also implements a dedicated survey program is urgently needed as a complement to the sea ice monitoring in order to investigate in more detail the outflow of Ice Shelf Water and the complex processes involved in the redistribution of platelet crystals that emerge from the ice shelf cavity.

I would therefore like you to consider the following further comments in your response:

a) Comment of reviewer 1 on "contextualizing" the discussion of the results with the observation and modelling work Hughes, Dempsey, Robinson and Cheng: it is good that you have included those refrences, but, not having the new version of the manuscript, I cannot judge on how you adequately used these references to "contextualize". Please be sure this explicitely comes out in your final manuscript version

Response: We hope that the updated manuscript addresses your concerns.

b) If the process of "blocking by underwater topographic features" is invoked, it has to be documented one way or another.

Response: Ice rises have now been mentioned explicitly, and references to Hoppmann, 2015 and Figure 1 have been made, where their presence can be seen in the radar signature.

Also, I can understand that you would like to expand on the oceanographic part in a companion paper, but at least mention it as "work under way" , "in prep", "submitted" or "in press"...

Response: see above. We prefer not to "overpromise", and decided to omit a statement that work is on the way.

c) Fabric and crystal structure: please, at least clearly acknowledge their interest and the unavailibilty for logistic reason, or eventually use infos from Hoppman papers..

Response: See above

d) Reviewer 2 has underlined my comments on the total absence of data on ecosystem and related variables. He asked for delete. I can understand you want to show how your physical data set would be of interest for future multidisciplinary work on this...I would therefore accept your comment, but with two wording changes:
- change "...prevents a significant light input..." to "... should prevent..."

Response: This part has been removed. While we do even have some spectral irradiance data from within the platelet layer available along with the Chl-a measurements above, we consider this far beyond the scope of this paper. Again, the ecosystem part that was majorly criticized especially by reviewer #2 was only meant to highlight a significant gap in the current research at Atka Bay. We hope this has been made clearer now.

- change: "...which was introduced in this study..." to "...which was introduced in this physical study"...

Response: Has been changed as suggested.

-ensure that there is no discussion left on the potential role of leads and cracks on the light regime or other matters that have not been documented...

Response: The discussion has been adjusted and the speculative aspects have been removed or reformulated.

e) My initial comments on "ocean circulation" and "ecosystem" have been adressed above. There is still my comment on "snow ice formation" which is mentioned several time without any data...the same stands for this...did you document it with isotopic measurements (since there is no crystallography)?...If it is just hypothetical, don't mention snow ice formation in the manuscript.

Response: We did not do any isotope analysis. We now show evidence of snow ice in the section about sea ice growth. The following text has been added to the new sea ice growth history part (see above):

While the ice core taken at ATKA11 is not representative at all for sea ice in the bay due to an early breakup event and subsequent late refreezing, the presence of snow ice is an evidence for a process that we would argue plays an underestimated role in this region. However, we currently do not have any more direct evidence for the wide presence of snow ice at Atka Bay (due to the lack of ice core data) other than the observations of negative freeboard in our main dataset (Figure 5), and several observations of extensive surface flooding from summer campaigns. In order to fill this knowledge gap, a dedicated program of obtaining much more core sections from the top of the sea ice at different locations would have to be implemented, with a subsequent crystal fabric and/or oxygen isotope analysis. As indicated above, this is currently not feasible.