Ice Sensing Algorythm
Development for float deployments in the Barents Sea
summer 2018

MOCCA Report

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BSH

Cover: Painting „Argo float ice sensing“ by Jan o. Backhaus

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INTRODUCTION

The need to expand measurements with profiling floats into the seasonally ice-covered northern High Latitudes is illustrated in the strategy plan for the Euro-Argo ERIC. Work carried out in the framework of WP 4 of the MOCCA project aims on supporting this development.
Operating floats in ice covered environments is a challenging task. Minimization of risks of damaging floats in ice and selecting appropriate deployment locations and mission parameters to ensure the maximum lifetime need to be analyzed.
To prevent the crushing of a float between ice floes during the surface phase or the damage to the antenna when hitting the bottom of the ice cover during ascend, floats are equipped with an Ice Sensing Algorithm (ISA) for operation in ice-covered regions. Ice Sensing Algorithms have been used successful in the Southern Ocean during the past, but more complicated hydrographic conditions in the Arctic Ocean make an adaption necessary.

The principal of the ice sensing algorithm is as following:
In order to prevent the float from surfacing in ice, it needs to 'detect' ice by a detection parameter that can be measured on the float during ascent. Water temperatures close to the freezing point are an obvious choice, but the depth range and the threshold need to be carefully selected.
If, on the ascent, the float is measuring critical value the ascent is aborted, because the surface is expected to be ice-covered. The profile data are stored internally and the float descends down to the parking depth and starts to drift again. As long as the float cannot surface profile data are stored internally on the float. When the ice has disappeared after winter and the float is no longer triggering the ice algorithm during ascent it will surface again and transmit not only the most recently measured profile but also all profiles stored on the hard disk during ice coverage.

An ISA was first developed for floats in the Weddell Sea of the Antarctic by Klatt et al. (2007). They found out that for the hydrographic conditions in the Southern Ocean ice at the sea surface can be detected by a median temperature below -1.79 °C in the depth range 50 to 20 meters. In the Arctic however the presence of the inflow of warm Atlantic Water at shallow depth, makes the definition of a critical value and especially the depth range of calculation more complicated.

Principally other criteria can be used to detect ice; for example using salinity or density instead of temperature and calculating the mean or minimum of a certain depth range instead of the median. These have to be incorporated into the float software in cooperation with the manufacturer.

For summer 2018 Euro-Argo float deployments with ice sensing are planned for the northern Barents Sea. This report describes the development of an ISA for this particular region. Future modifications of the ISA are expected with feedback from the floats and for different deployment region.

The ISA was developed in different steps:
1. Hydrographic profile data from the region of interest (Barent Sea) were compiled.
2. They were combined with ice coverage information.
3. Profile data from ice covered regions and regions near to the ice edge were confronted to profiles from open water.
4. Different parameter settings for an ISA were deduced from the profile data and tested on the compiled data set. The ice detection with the ISA was compared to the ice flag given in step 2 and the most appropriate ISA was deduced.
5. It was finally checked if this ISA is compatible with the available ISA parameters of the floats.

The development of an ISA for the Barents Sea along these steps is described in the following sections.

1 COMPILATION OF HYDROGRAPHIC DATA FROM THE BARENTS SEA

For summer 2018 from the Finnish Euro-Argo partners float deployments were planned for the northern Barents Sea (approx. 79.38 °N/28.69 °E and 77.01 °N/29.95 °E) which needed an ISA on the float. To analyze the recent hydrographic conditions in this region profiles from the area 74 °N to 80 °N and 16 °E to 40 °E and from the time span 2006 to 2015 were extracted from the UDASH data set, published in PANGAEA and described in Behrendt et al. (2018).

The UDASH is a unified database for Arctic and Subarctic Hydrography. It brought together data from different sources, instruments and platforms. The main source is the World Ocean Data base, which constitutes almost 78 % of the total. Tests were applied to remove duplicate profiles and to guarantee a uniform data quality. For a detailed description see Behrendt et al. (2018).

Our compiled sub data set from the UDASH for the Barents Sea consists of 2439 profiles. With the exception of a small number of profiles (16) almost all profiles were measured by ship-based CTDs. Details of the data set were summarized in Table 1 and Figure 1. Profiles near the coast and in the fjords of Svalbard showed up with an extreme fresh surface layer, possible due to influence of melt water from glaciers and snow. As this influence is not representative for most parts of the Barents Sea these profiles are excluded from the further analyses; finally given a total of 2022 profiles.
In ANNEX I temporal and spatial distributions of the profiles for all individual years are shown.

Table 1: Information on the UDASH sub data set for the Barents Sea. The number of profiles in ice or with distance to the ice <= 50km was calculated after exclusion of the profiles close to Svalbard (for ice information see next section).

Year	Number of profiles:				
	total	Measured with CTD/bottle	close to Svalbard → excluded	in ice	with distance to the ice edge <= 50 km
2006	329	323/6	44	2	25
2007	419	419	48	-	21
2008	344	344	43	20	63
2009	224	222/2	33	-	25
2010	214	214	40	1	13
2011	187	187	16	2	9
2012	223	223	54	2	8
2013	230	230	72	3	10
2014	247	247	67	7	11
2015	32	32	-	1	1
2006-2015	2439	2423/16	417		
2006-2015 without Svalbard	**2022**			**38 (1.9%)**	**186 (9.2%)**

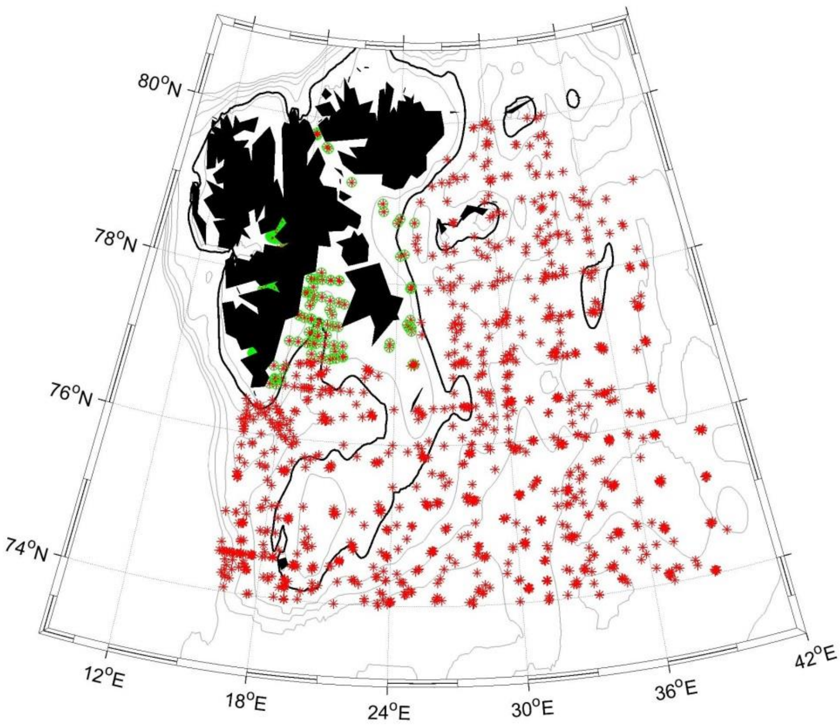


Figure 1: Map of the northern part of Barents Sea with positions of all profiles (red asterisks) from the data set compiled for the time span 2006-2015. Profiles near the coast and in the fjords of Svalbard (green circles) are excluded from the analysis. Depth contours are shown for 50, 100, 200, 300, 400 and 500 m in grey and for 100 m in black.

2 COMBINATION OF THE HYDROGRAPHIC DATA WITH ICE INFORMATION

To find characteristic features of profiles in open water, under ice or close to the ice edge information for the time and position of the ice edge for each hydrographic profile was needed. The Multisensor Analyzed Sea Ice Extent - Northern Hemisphere shapefiles (MASIE-NH), which are available daily from 2006 onward, was used to determine, if the measurements were taken under ice or in open water, and to calculate the shortest distance to the ice edge.
The shapefiles provide the sea ice extent boundaries as polygons. They were constructed using satellite data, but they also draw on information from NIC (National Ice Center, Boulder, Colorado, USA) operational charts and other sources.
For satellite data daily ice edge position can be off by tens of kilometers or more from the ice edge that an analyst would draw. Reasons include known errors in thin ice detection, bias in summertime concentration estimates, and the relative compactness of the marginal ice zone (Partington et al., 2003). As in MASIE satellite data are combined with other ice information we expect the product to perform better near the ice edge, but keep in mind that this area is most problematic.

Only approximately 2 % of the hydrographic profiles were taken in ice-covered regions and 10 % within 50 km distance to the ice edge, but most of the profiles are from open water (see Table 1). Thus, the analysis relies on a relatively small number of profiles (38 ice profiles, 186 profiles with distance to ice smaller than 50 km).
Figure 2 shows the distribution of ice and near-ice profiles spatially (Fig. 2a) and temporally (Fig. 2b). The positions of the profiles are in the vicinity of the deployment positions. The temporal distribution displays gaps in summer and most prominent from October to January, which reflect the large ice coverage of the northern Barents Sea during winter that hampers measurements with non-ice-resilient research vessels. Most measurements are taken during the retreat of the ice coverage in spring (see ANNEX II for spatial distribution per month).
For information on the typical ice cover of the Barents Sea see Inque at al. (2012), Sorteberg and Kvingedal (2006), Kvingedal (2005) and Loeng (1991).

a)

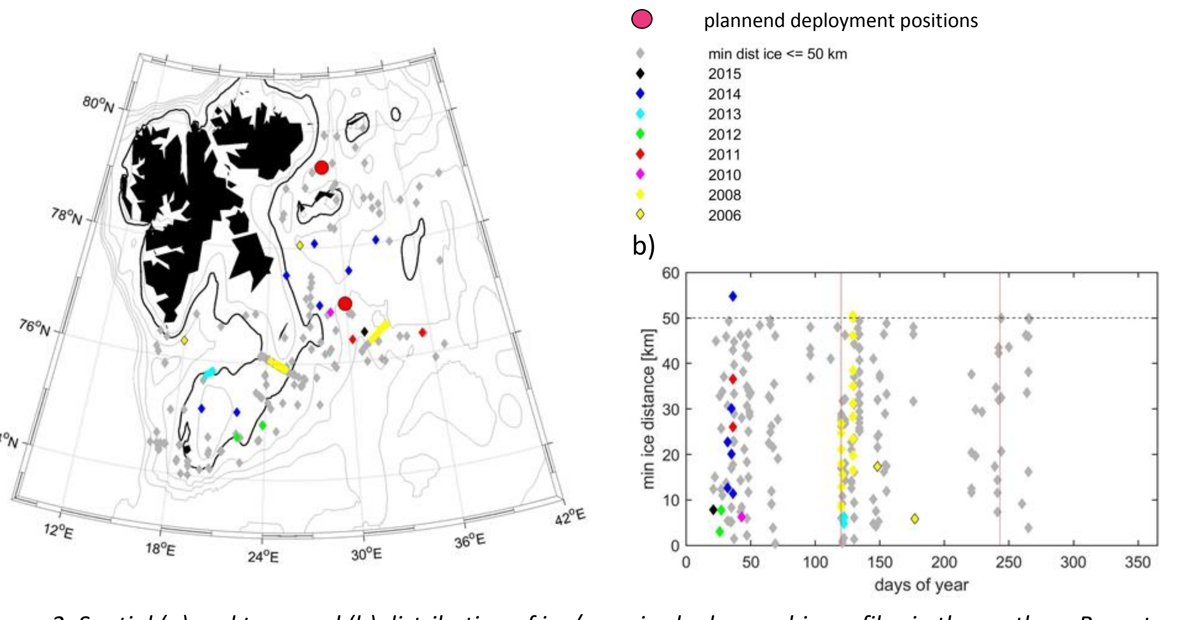


Figure 2: Spatial (a) and temporal (b) distribution of ice/near-ice hydrographic profiles in the northern Barents Sea. Depth contours are shown for 50, 100, 200, 300, 400 and 500 m in grey and for 100 m in black.

MASIE-NH: National Ice Center and National Snow and Ice Data Center. Compiled by F. Fetterer, M. Savoie, S. Helfrich, and P. Clemente-Colón. 2010, updated daily. *Multisensor Analyzed Sea Ice Extent - Northern Hemisphere (MASIE-NH), Version 1, 4km x 4km.*. Boulder, Colorado USA. NSIDC: National Snow and Ice Data Center, doi: 10.7265/N5GT5K3K.

3 COMPARISON OF ICE, NEAR-ICE AND OPEN WATER PROFILES

For the comparison the profiles have been divided into three time spans: January to April, May to September and October to December. As obvious from Figure 3 and Table 2 no profiles were available within the ice from October to December , but during this time also open water and near ice-edge profiles were sparse. This lack of information will be discussed in the next sections. For the analysis only profiles with a measurement depth greater than 100 dbar were used in the following, as the ISA-floats will be deployed at least at that water depth and planned to profile to a maximum depth of 200 dbar if possible.

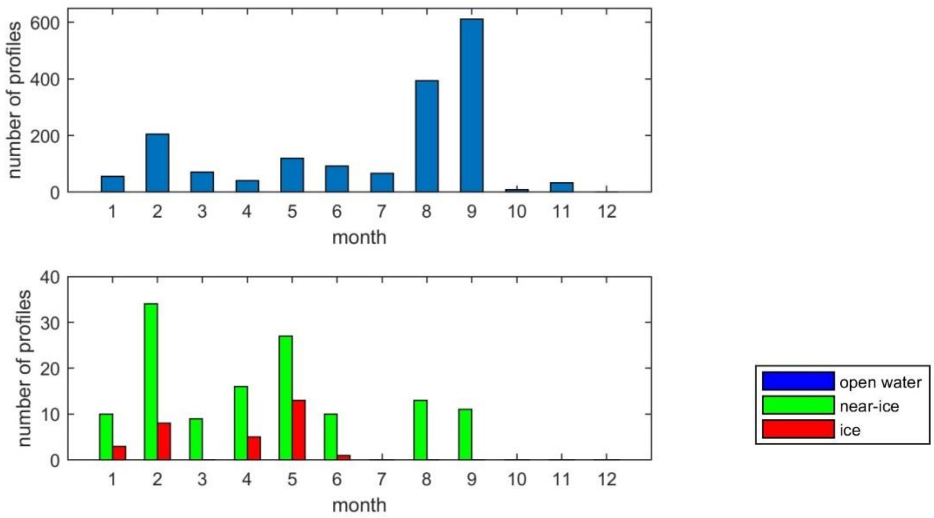


Figure 3: Monthly distribution of total number of profiles (top) and number of profiles in ice (red) or with distance to the ice edge equal or smaller than 50 km (green) (bottom) of the UDASH sub data set for the northern Barents Sea. Only profiles with a measurement depth greater than 100 dbar are considered.

Table 2: Distribution between years and time spans (January to April/May to August/ September to December) of ice/near-ice (distance equal or smaller 50 km) and total number of profiles in the UDASH sub data set for the northern Barents Sea. Only profiles with a measurement depth greater than100 dbar are considered.

Year	**Month 1-4**			**Month 5-8**			**Month 9-12**		
	Number of profiles:								
	Total	Dist <= 50 km	Ice	Total	Dist <= 50 km	Ice	Total	Dist <= 50 km	Ice
2006	43	4		192	20	2	50	1	
2007	68	21		234			69		
2008	53	13	8	144	48	12	102	2	
2009	49	9		75	15		65	1	
2010	43	6	1	25			105	7	
2011	50	8	2	17	1		103		
2012	27	8	2	39			102		
2013	23	9		66	1	3	68		
2014	61	9	7	42			75	2	
2015	20	1	1	9			3		
2006-2015	**437**	**88**	**21**	**843**	**99**	**17**	**742**	**13**	**-**
Depth >= 100 dbar	**371**	**69**	**16**	**671**	**50**	**14**	**654**	**11**	**-**

[Figure 4](#) shows a composition of all temperature, salinity, sigma and sigma-theta profiles, ordered by the three chosen time spans. As background all available profiles are plotted in grey and on top of it in black near-ice profiles and in red ice profiles. Distinct features of ice profiles that stand out from the others, seem to appear only in temperature and possibly salinity.

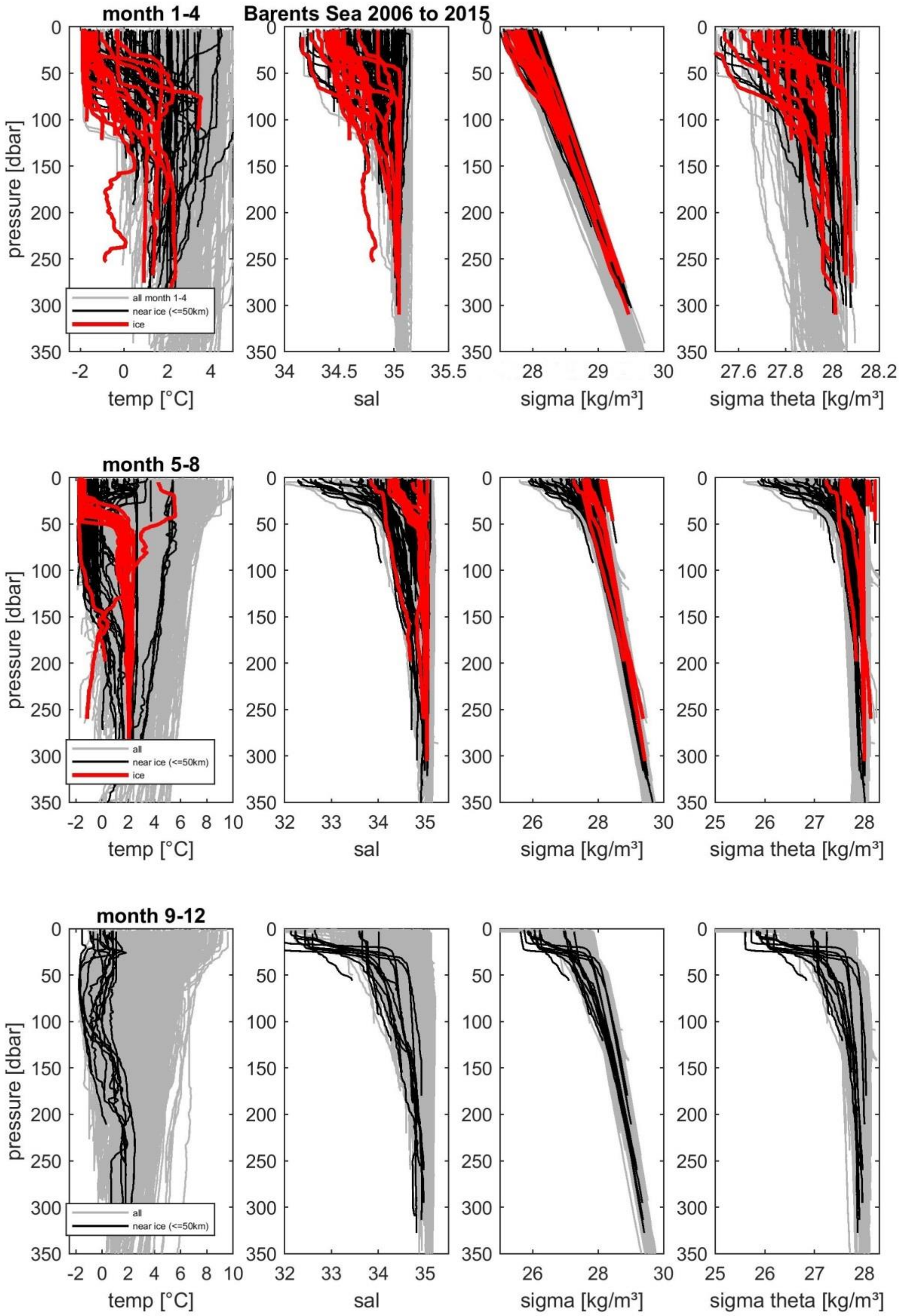


Figure 4: Composition of all profiles of the UDASH sub data set for the northern Barents Sea, ordered by the time spans month 1-4(top), month 5-8 (middle) and month 9-12 (bottom); from left to right: temperature, salinity, sigma and sigma-theta. The range of the x-axes varies for the different time spans!

Figure 5 focuses on the upper 200 m of temperature and salinity profiles from month 1-4 and month 5-8 (month 9-12 is left out because no profiles in ice were measured at that time). For temperature the ice profiles stand out from the remaining with minimum values in the uppermost layer. Below the surface layer a transition to higher temperatures takes place.
Minimum temperatures of ice profiles in the upper layer range between -1 and -2°C in winter in month 1-4 (with 2 exceptions among the total of 21 profiles), but the range became more narrow during the year during month 5-8 (-1.2 to -1.8°C). Low temperatures reach a maximum depth of 80 dbar in month 1-4 but only 50 dbar in month 5-8 (with 1 exception). Also the gradient is much sharper in month 5-8.

For salinity the winter ice profiles in month 1-4 ice showed up with lowest values close to the surface, but this did not hold for month 5-8. In month 5-8 (and month 9-12; see also Figure 4) some near-ice profiles (but not the ice profiles) present the lowest salinities of the total data set. Thus, in the Barents Sea salinity offers no opportunity for ice sensing.

Altogether figure 4 and 5 suggest concentration on temperature in the upper layer as ice sensing threshold.

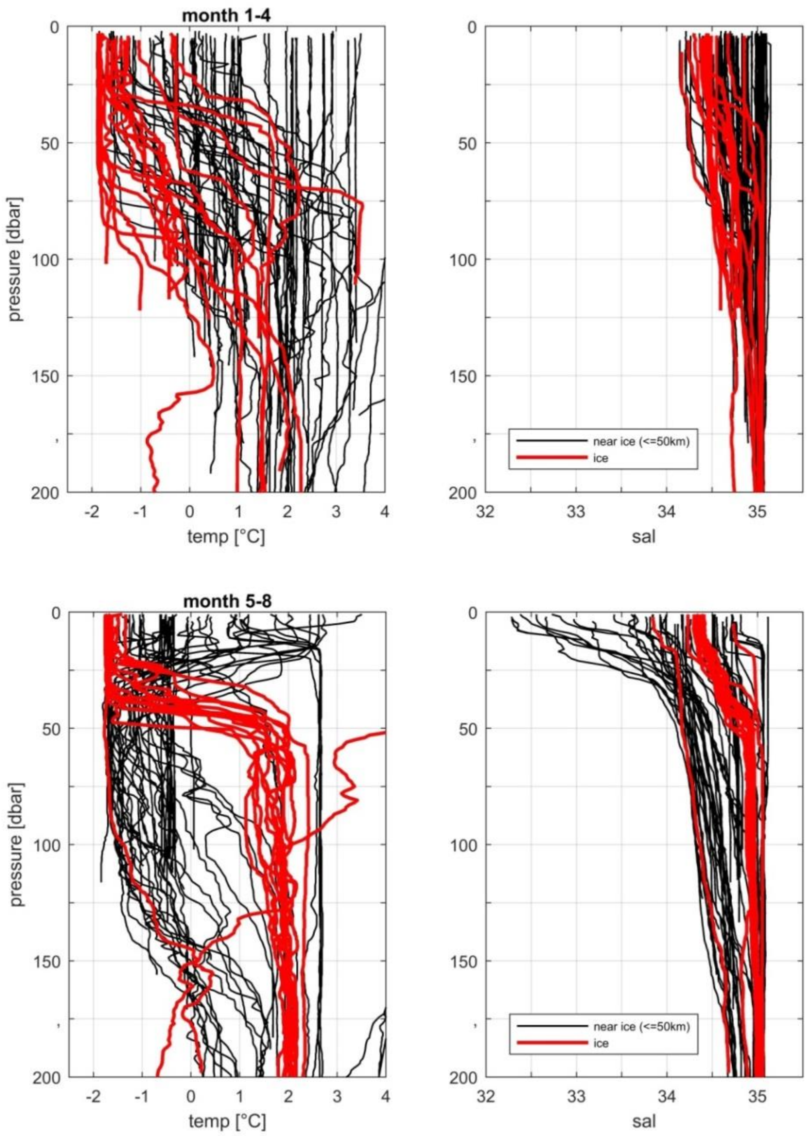


Figure 5: Zoom of temperature and salinity profiles from month 1-4 and 5-8 from figure 4; only the upper 200 dbar of ice and near-ice profiles are shown. Here the range of the x-axes is equal for both time spans!

4 DEVELOPMENT AND TEST OF AN ISA FOR THE BARENTS SEA

In the Weddell Sea a median of -1.75 °C for the depth range 50-20 dbar was successfully operated as threshold in the ISA. For the Barents Sea temperatures close to the freezing point were observed mostly above 50 m depth (see last Section). These facts build the starting point for the ISA development for the Barents Sea.

From every ice and near-ice profile of the Barents Sea data set the median and additionally the minimum of temperature in the depth ranges 50-20 dbar and 20-10 dbar were calculated. The minimum of temperature, in contrast to the median, has the advantage to be independent of the layer thickness of the cold surface water. The results are shown in figure 6.

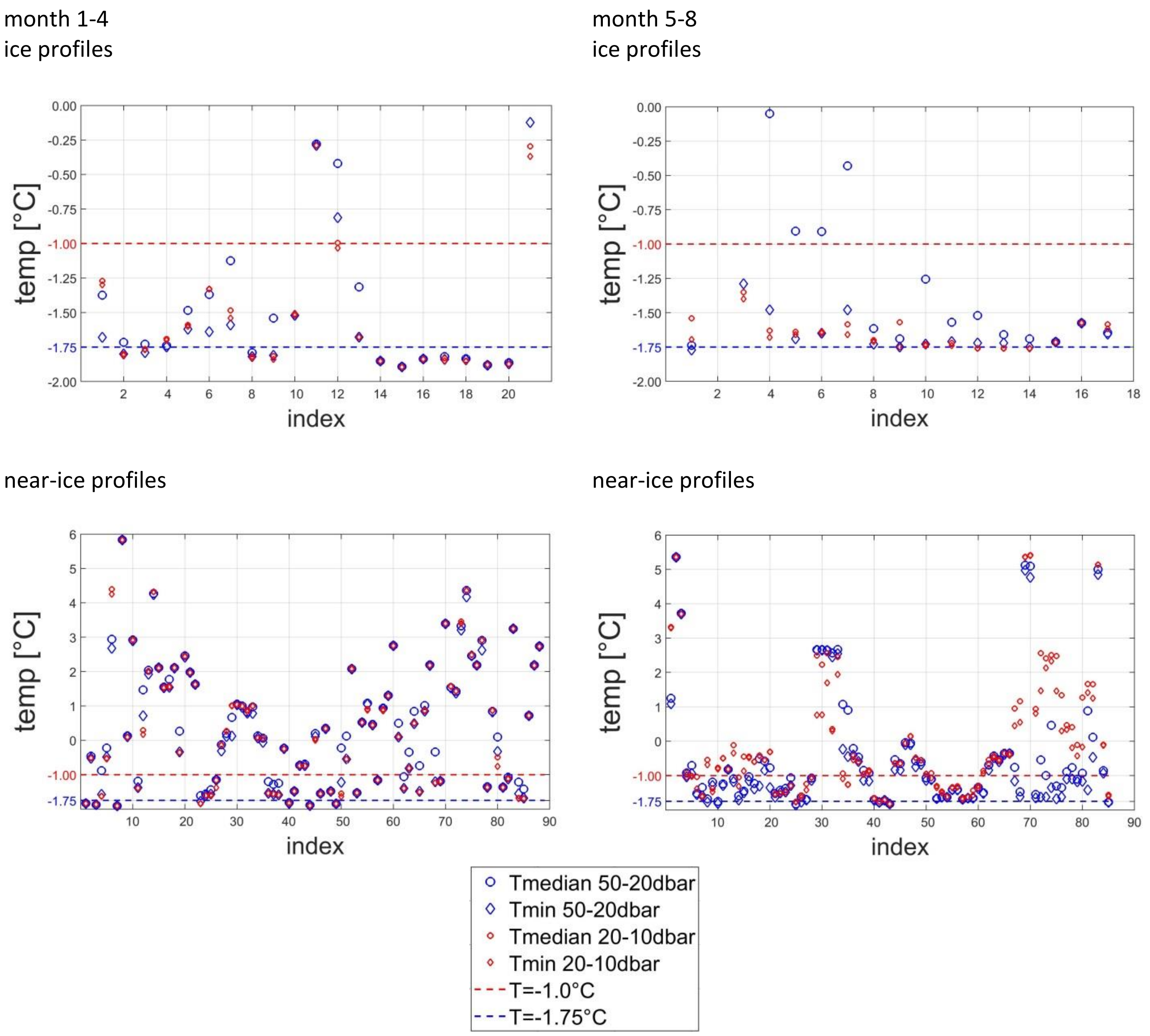


Figure 6: For each individual ice/near-ice profile the temperature median (circle)/minimum (diamond) for the depth ranges 50-20 dbar (blue) and 20-10 dbar (red) are shown; left column: month 1-4, right column: month 5-8, top: ice profiles, bottom: near-ice profiles.-1.75 °C-temperature is marked by the blue dashed line and -1 °C by the red dashed line.
(see also page 15)

Ice profiles (Figure 6, top row)**:**

- Median and minimum temperatures for only few profiles were below -1.75 °C, but for almost all below -1.0 °C, independent of the depth range that was chosen.

- For some profiles of month 1-4 and month 5-8 the median for the depth range 20-10 dbar (red circles) is lower than the one for 50-20 dbar (blue circles), reflecting the observation that low temperatures are observed close to the surface.
- The discrepancy between the two depth ranges is less if the minimum instead of the median was calculated (red/blue diamond), as the minimum calculation is independent of the layer thickness, if the coldest temperatures close to the surface are included at all.
- Only 7 profiles show temperature values above -1 °C for the different calculation methods. But these profiles already show up in Figure 5 as outliners and possibly are wrong detected ice profiles.

Altogether Figure 6 suggests that a threshold of -1.75 °C would not be appropriate for the Barents Sea to select. Instead a median or minimum of -1.0 °C in the depth range 20-10 dbar as ISA threshold seems appropriate.

Near-ice profiles (Figure 6, bottom)**:**

- A considerable among has a median and/or minimum temperature below -1.0 °C and even a few below -1.75 °C for depth range 50-20 dbar and 20-10 dbar, inducing ice detection. There are two explanations possible for this detection: 1. The ice edge information was inaccurate and the profile was instead measured in ice. 2. Hydrographic conditions close to the ice edge are similar to conditions in ice.
- A distinct difference between month 1-4 and month 5-8 is visible. For month 1-4 all four calculated values coincide for a huge among of profiles, but for month 5-8 the calculated median and min values for 20-10 dbar are for most of the profiles higher than the ones for 50-20 dbar. This reflects what was already visible in Figure 5: In month 1-4 the near-ice profiles show typical conditions for ice free regions during the whole year, with higher temperatures than under ice for at least the upper 100 dbar of the water column. In month 5-8 many of the near-ice profiles have comparable low temperatures as the ice profiles around 50 dbar depth, but the values above and especially close to the surface are much higher (up to 3.5°C). This can be explained by progressive ice retreat and warming from the atmosphere during the summer, changing the near surface temperature of the former ice profiles.

Thus, the near-ice profiles support the selected ISA, and especially the selection of a shallow depth range for the calculation.

Test of different ISAs

Finally the functioning of the suggested ISA threshold was tested and compared with the Weddell Sea ISA threshold:

> **ISA-Barents Sea**:
> “ice on top” is expected, if temperature is **below -1.0 °C** in the depth range **20-10 dbar**
> **ISA-Weddell Sea:**
> “ice on top” is expected, if temperature is **below -1.75 °C** in the depth range **50-20 dbar**

The test was done for both temperature values with calculating the median as well asthe minimum for depth range 50-20 dbar and 20-10 dbar, leading to 4 results for every temperature threshold value.

The results are summarized in Table 3.

For every row the pie-charst show how much of the available profiles were detected in a way that is compatible with the MASIE ice information. Starting with the assumption that the MASIE ice information is right, for ice profiles a correct detection (blue segment) means the ISA was able to detect “ice on top” and wrong detection (red segment) means the ISA instead detected “open water”. For the near-ice and open water profiles the meaning of the results is the other way round: right detection means the ISA detected “open water” and wrong detection “ice on top”. To say it simple, we are looking for the ISA (column) with the fewest amount of red. But in reality it is a bit more complicated.

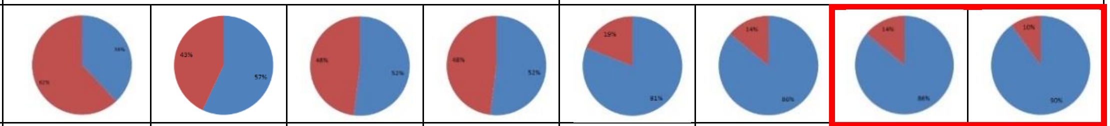
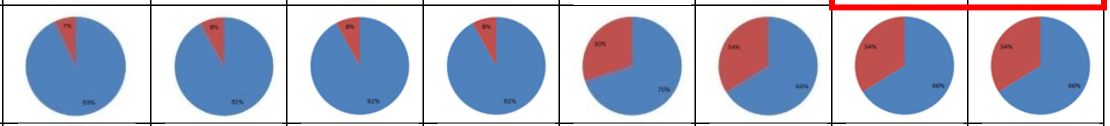
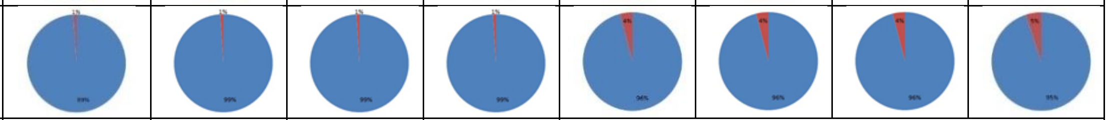
Starting with the first row of Table 3 for month 1-4 and month 5-8 it is obvious that an ISA with threshold temperature -1.0°C for the depth range 20-10 dbar performs best, almost independent of median or min calculation (marked by red boxes). An ISA with threshold temperature of -1.75°C for depth range 50-20 dbar performed worst. This was already obvious graphically from the profiles in Figure 5. Temperatures below -1.75 °C were only very seldom reached in the Barents Sea and the lowest temperatures appeared at least in some ice profiles very close to the surface.

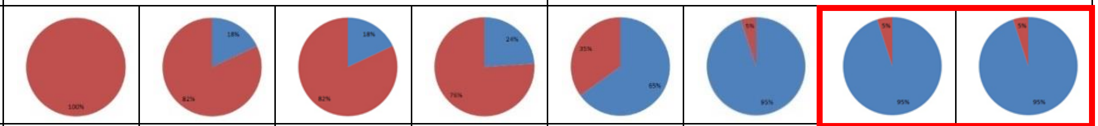
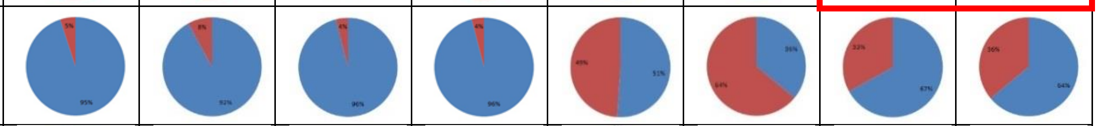
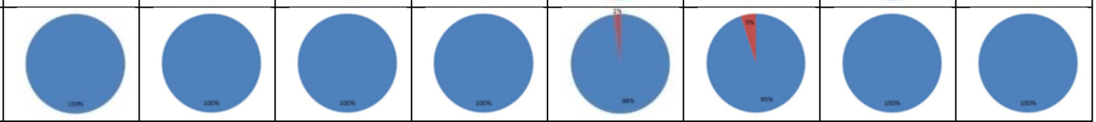
But there are a lot wrong “ice on top” detections for near-ice profiles for suggested ISA-Barents Sea and much less for the ISA-Weddell Sea (second row of Table 3 for month 1-4 and month 5-8). Some of these wrong detections are possibly caused by uncertainty in the exact position of the ice-edge in the MASIE data set (see Section 3). And some of the near-ice profiles may have a characteristic which is that close to the one from the ice profiles that these are unable to separate.
The floats are equipped with an ISA to protect them from becoming trapped or even destroyed in the ice. Thus, to be on the save side, it is suggested to use the ISA-Barents Sea, which detects as much ice profiles as possible in the right way, and accept some wrong ice detections for the near-ice region.

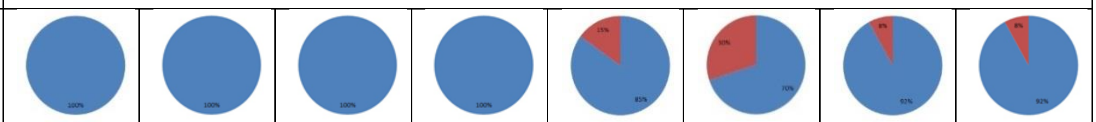
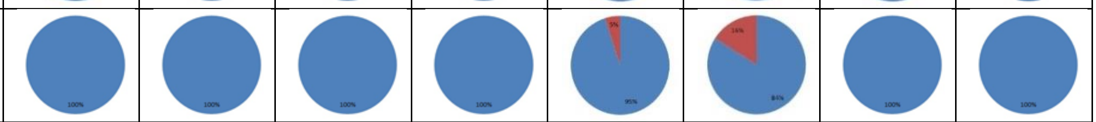
But also different calculation methods were tested. Our results suggest using the minimum calculation. In principal it is the most appropriate way to find the lowest temperature in a given layer. But the analysis presented here was done with quality-controlled profile data and not with raw data, as the ISA will work with in practice. Raw data might include spikes, which can lead to wrong detections. Thus, we suggest using the median calculation, which suppresses individual outliers.

The development of an ISA for the Barents Sea, as presented, based upon a small number of profiles in the ice and near the ice-edge. The ISA will be refined in the future, when hydrographic measurements from Argo floats from the region are available.

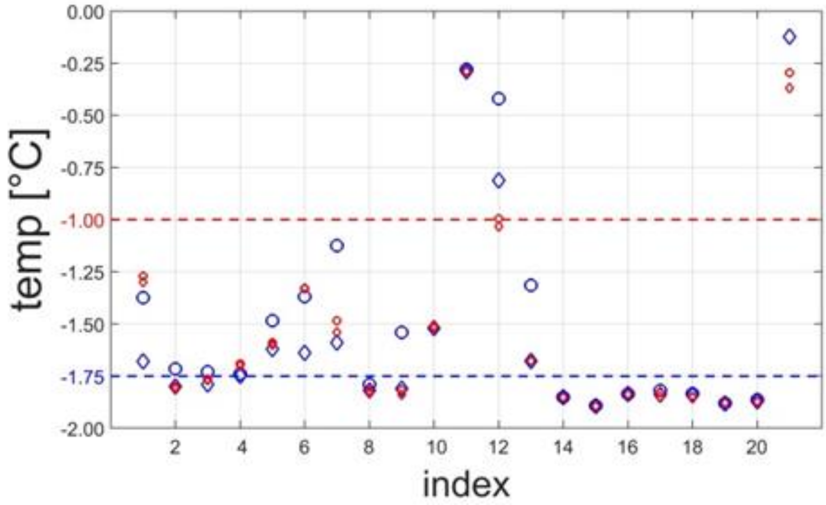
Table 3: Visualization of the results from tests of different ISAs. On the left hand the threshold temperature was -1.75°C, on the right hand -1.0°C. (numbers instead of pie-charts can be found in ANNEX III)

Month 1-4								
Method	Tmedian	Tmin	Tmedian	Tmin	Tmedian	Tmin	Tmedian	Tmin
Depth range [dbar]	50-20		20-10		50-20		20-10	
threshold	<= -1.75°C				<= -1.0°C			
Ice (21 obs)								
Near ice (88)								
Open water (328)								
					detection is right ■ detection is wrong			

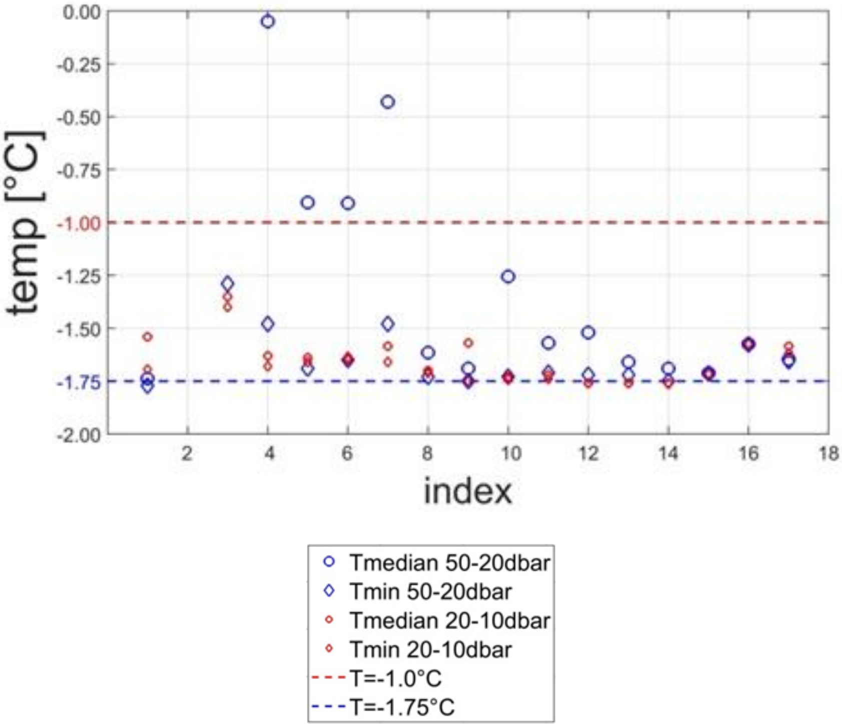
Month 5-8								
Method	Tmedian	Tmin	Tmedian	Tmin	Tmedian	Tmin	Tmedian	Tmin
Depth range [dbar]	50-20		20-10		50-20		20-10	
threshold	<= -1.75°C				<= -1.0°C			
Ice (17)								
Near ice (85)								
Open water (741)								
					detection is right ■ detection is wrong			

Month 9-12								
Method	Tmedian	Tmin	Tmedian	Tmin	Tmedian	Tmin	Tmedian	Tmin
Depth range [dbar]	50-20		20-10		50-20		20-10	
threshold	<= -1.75°C				<= -1.0°C			
Ice (-)	no data							
Near ice (13)								
Open water (729)								
					detection is right ■ detection is wrong			

ice profiles
month 1-4



month 5-8



5 HOW CAN THE DEVELOPED ISA BE INCORPORATED IN EXISTING FIRMWARE OR ARE SOFTWAREE MODIFICATIONS NEEDED?

<u>APEX ice avoidance</u>
The ISA development for the Barents Sea was motivated by the plan of Finland to deploy 2 APEX floats in the area. In the following the parameters for "Ice Avoidance" from the APEX Profiling Float User Manual P/N 301308, Rev. 9 (© Copyright 2014-2017 Teledyne Webb Research, a Business Unit of Teledyne Instruments, Inc.) were compared with the ISA developed in this study.

The first four parameters are:

IceMonths	Determines the months of the year during which ice avoidance is enabled.
IceDetectionP	The pressure in decibars at which temperature data collection begins during the Ascent phase for the purpose of determining **the mixed layer median temperature**.
IceEvsaionP	The pressure in decibars at which the float begins processing the collected temperature data to determine the mixed layer median temperature.
IceCriticalT	The water temperature in Celsius below which ice is determined to be present.

IceDetectionP, IceEvaisionP and IceCriticalT fit into the method for ice detection, which was presented here since they calculate the median temperature in a certain depth range below the surface. At the moment the limitations of the implemented ISA are that the choice of the method to calculate the mixed layer threshold are predefined and cannot be changed (for example e ta minimum or gradient calculation), nor does the ISA offer options to include other parameters (for example salinity).

To optimize the IceEvasionP more discussions with the manufacturer are needed to determine how long the float needs to stop and start descent after detecting that the mixed layer median temperature is below IceCriticalT (equivalent to a distance on the ascent).
The whole Barents Sea is only seasonally ice-covered. Thereupon we expect ice thickness below the surface of around 1 m (but this was not investigated in the present study). If IceCriticalT is reached at 10 dbar we hope that the float will stop and start the descent within 5 dbar, and thus will stay away from the ice. For regions covered with multi-year ice and individual icebergs the information is much more important.

Although our suggested ISA match with the given possibilities for APEX Ice Avoidance, we plan to discuss adaptions with the manufacturer to establish potential options for other deployment areas as well.
IceMonths additionally allows allocating a certain phase in the year for activated ice avoidance. This can be taken as a safety parameter for reappearance of the float as it will try to reach the surface in non-IceMonths, independent of the conditions observed.

Additional parameters are:

IceBreakupDays	The period of days over which the float avoids the surface due to the possible presents of large, crushing icebergs. The period starts with the first determination of the non-presence of ice after having determined the presence of ice over the previous missions.
Ice Cap Detection:	Both parameters are used to define the normal working cycle. Anyway, if communication failed during UpTime and the mixed layer median temperature is

UpTime AscentTimeout	below IceCriticalT, it is possible that ice is preventing the float from surfacing. In this situation an ice cap is determined to be present, and the float will immediately transition to the Park Descent phase of a new mission.

<u>NKE ice detection</u>

In the following the parameters for "ice detection" from the Arvor-I & DO-I Float User Manual (DOC 33-16-033 UTI, version 5, 24.3.2017, © NKE: NKE instrumentation, France) were compared with the ISA developed in this study. NKE is the other large float manufacturer, who offers floats with ice detection. It has 15 mission parameters which are related to ice detection.
The parameters IC3 (start pressure detection), IC4 (stop pressure detection) and IC5 (temperature threshold) allow to build an ISA similar to the APEX ISA. Also for the ARVOR-I-float the detection of ice solely based upon the median of temperature in a certain depth range. No other calculation methods nor parameters are enabled.
IC7 (slowdown pressure threshold) allows to reduce the ascend speed close to the surface. This is an interesting option if ice detection is working close to the surface and heavy ice coverage is expected.

A large number of additionally parameters are given to avoid erroneous detections and enable the try of re-emergence under certain conditions. But these parameters do not affect the ISA itself.

SUMMARY

Two float deployments are planned in the northern Barents Sea within the framework of the Euro-Argo Eric from the Finnish partners for fall 2018. These APEX floats are equipped with an ice sensing algorithm (ISA) to prevent ascent to the surface when ice is present.
In this study we analyzed the most appropriate parameter setting of the ISA in the region.

A hydrographic data set for the northern Barents Sea and time span 2006 to 2015 was compiled on the basis of the UDASH data set. These data were combined with ice information from the MASIE-NH to separate it into profiles measured under ice, near-ice profiles - measured within 50 km distance to the ice, and profiles in open water.
The different groups of profiles were investigated for tree different time spans: January to April, May to September and October to December. Distinct characteristics of ice and near-ice profiles were found although only 2 % of the profiles were taken under the ice and 10 % within 50 km distance to the ice.
On the basis of these characteristics an ISA was suggested for the Barents Sea and compared to the ISA for the Weddell Sea:

ISA-Barents Sea:
"ice on top" is expected, if temperature is **below -1.0 °C** in the depth range **20-10 dbar**
ISA-Weddell Sea:
"ice on top" is expected, if temperature is **below -1.75 °C** in the depth range **50-20 dbar**

To test the functioning of the ISAs for all profiles from the Barents Sea data set the median of 50-20 dbar and 20-10 dbar was calculated and it was checked if the value was below the threshold -1.75 °C respectively -1.0 °C, resulting in a "flag" for ice or open water for each profile, depth range and threshold. The flag was compared with the ice information from Masie-NH. Equal detections was interpreted as right detection with the ISA, different detections as wrong detection with the ISA.
The test result showed (table 3) that with ISA-Barents Sea only very few ice profiles got wrong detection; with ISA-Weddell Sea half or more of the profiles were detected wrong. For both thresholds more profiles are detected right if the depth range close to the surface was taken (20-10 dbar).
On the other hand ISA-Barents Sea detects a large number of near-ice profiles (one-third or more) as ice profiles. This may be due to uncertainties of the Masie ice information close to the ice edge. Anyway we decided to accept these wrong detections as the chosen ISA performs that well for ice-profiles and as we prefer a right-side failure.

Additionally a minimum instead of median calculation was tested and supplied got results even for the 50-20 dbar, when testing it with the UDASH profiles, which are processed data. But we decided to rely on the median as the minimum calculation is vulnerable to wrong detections if the floats raw data contain spikes.

The ISA-Barents Sea can easily be implemented by the given APEX ice avoidance parameter (as well as by the NKE ARVOR-I-float ice detection).

But both ISAs do not support other parameters than temperature nor other calculation methods than median for the threshold. We like to motivate the implementation of more diverse thresholds by the manufacturers!
Both manufacturers gave no information about the time needed to stop the ascent and start the descent if ice is detected. But this information would be very helpful especially if the depth range for threshold calculation is very close to the surface and if the deployment takes place in regions with heavy ice.

Both, WEBB and NKE, include a number of additional features, such as time spans during the year for the use of an ISA, suppression of wrong detections and features to support re-emergence under certain conditions. These are not investigated in the present study.

REFERENCES

Behrendt, A., H. Sumata, B. Rabe and U. Schauer (2018) UDASH – Unified Database for Arctic and Subarctic Hydrography, Earth System Science Data , https://doi.org/10.5194/essd-10-1119-2018.

Inque, J., M.E. Hori and K. Takaya (2012) The role of Barents Sea Ice in the wintertime cycline track and Emergence of a Warm-Arctic Cold-Siberian anomaly. Journal of Climate 25, 2561-2568, doi: 10.1175/JCLI-D-11-00449.1.

Klatt, O., O. Boebel and E. Fahrbach (2001) Notes and Correspondence: A profiling float's sense of Ice. Journal of Atmospheric and Oceanic technology, Vol 24., pp 1301-1308, doi: 10.1175/JTECH2026.1.

Kvingedal, B. (2005) The Nordic Seas, main oceanographic features. In: The Nordic Seas – An integrated perspective. H. Drange, T. Dokken, T. Furevik, R. Gerdes and W. Berger (Eds.). Geophysical Monograph 158, American Geophysical Union, Washington, DC, 39-49.

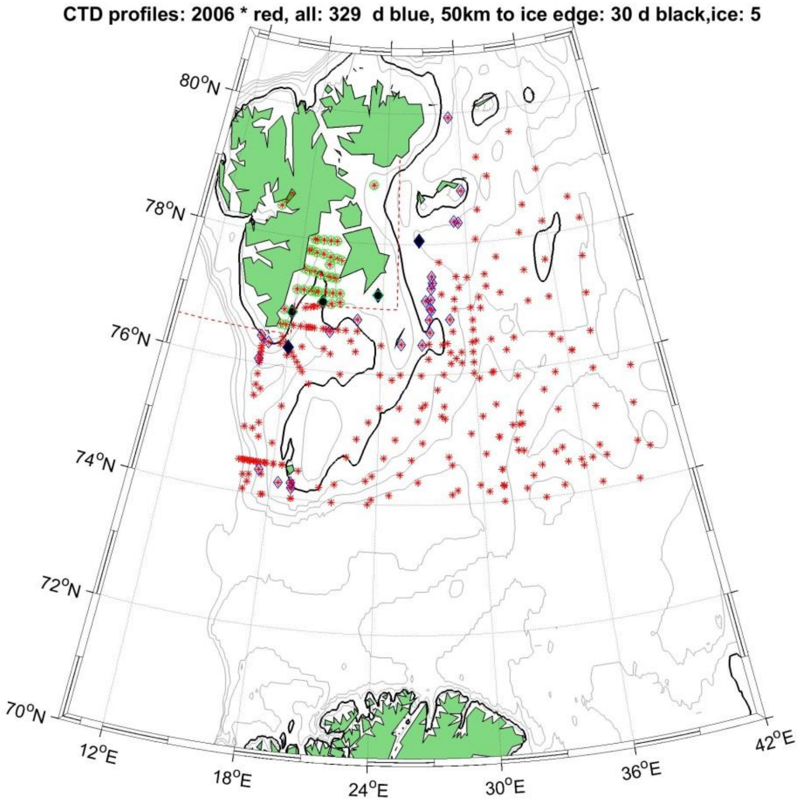
Loeng, H. (1991) Features of the physical oceanographic conditions of the Barents Sea, Polar Research 10:1, 55-18, doi: 10.3402/polar.v10i1.6723.

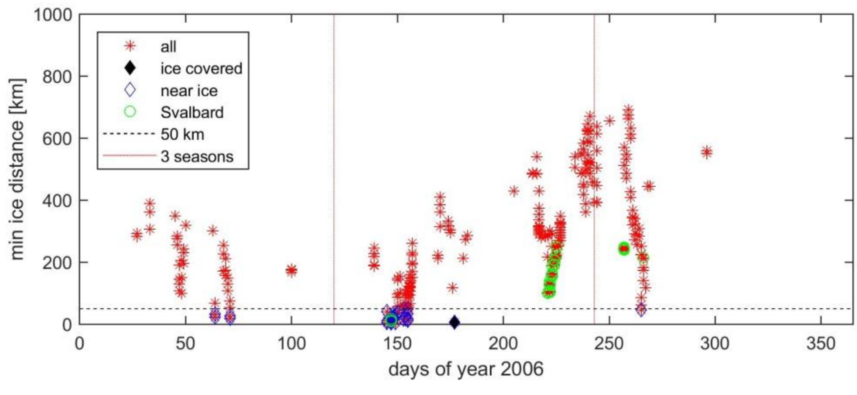
Partington, K., T. Flynn, D. Lamb, C. Bertoia, and K. Dedrick. 2003. Late Twentieth Century Northern Hemisphere Sea-ice Record from U.S. National Ice Center Ice Charts. *Journal of Geophysical Research* 108(C11), doi: 10.1029/2002JC001623.

Sorteberg, A. and B. Kvingedal (2006) Atmospheric forcing on the Barents Sea winter ice extent. Journal of Climate 19, 4772-4784.

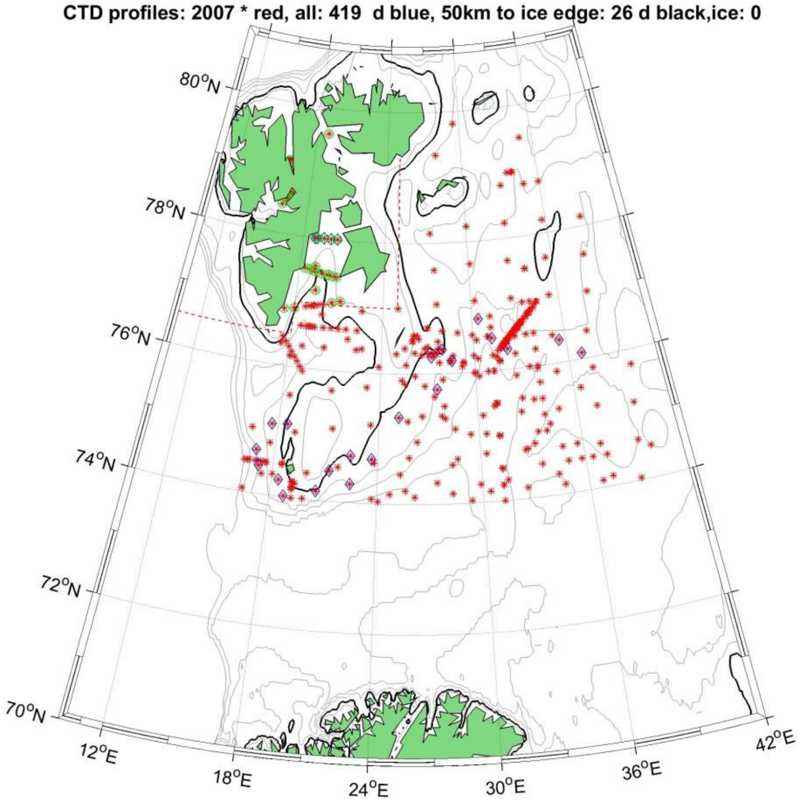
ANNEX I

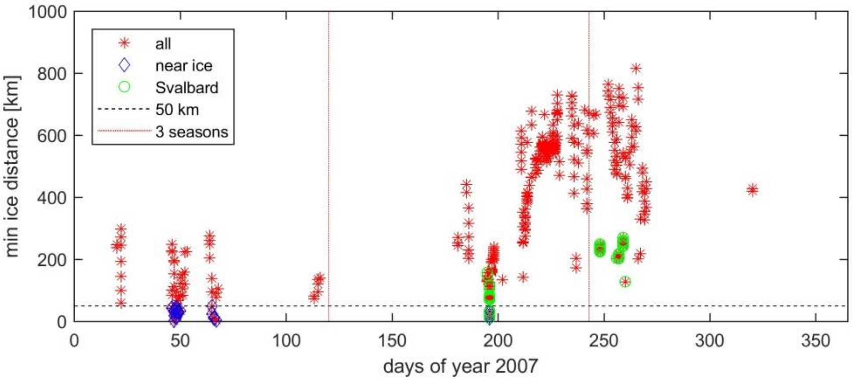
Spatial and temporal distributions for the individual years of the compiled hydrographic data set for the (northern) Barents Sea, 2006-2015. Depth contours are shown for 50, 100, 200, 300, 400 and 500 m in grey and for 100 m in black.

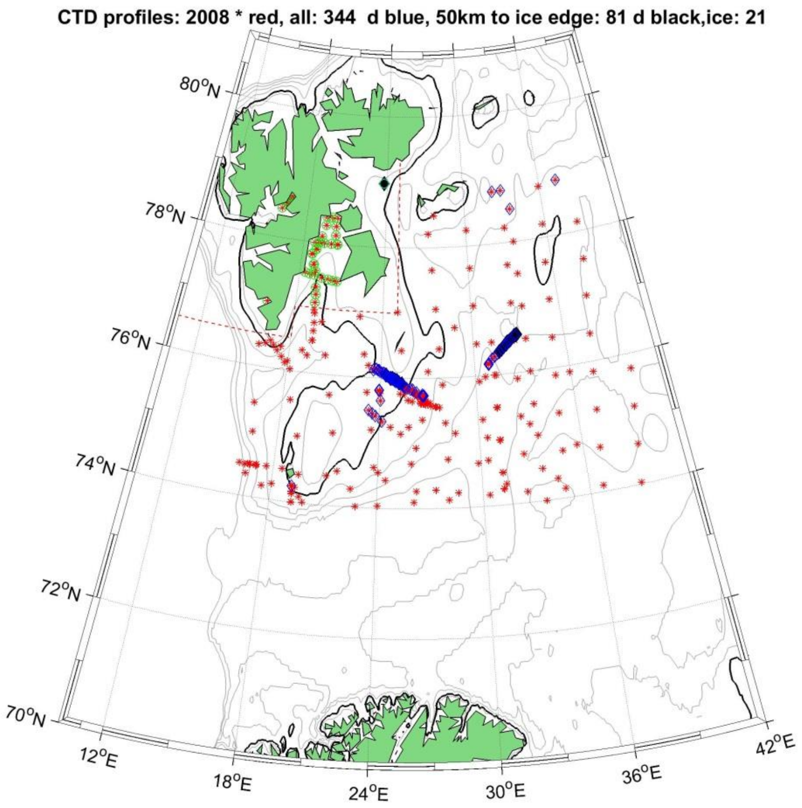


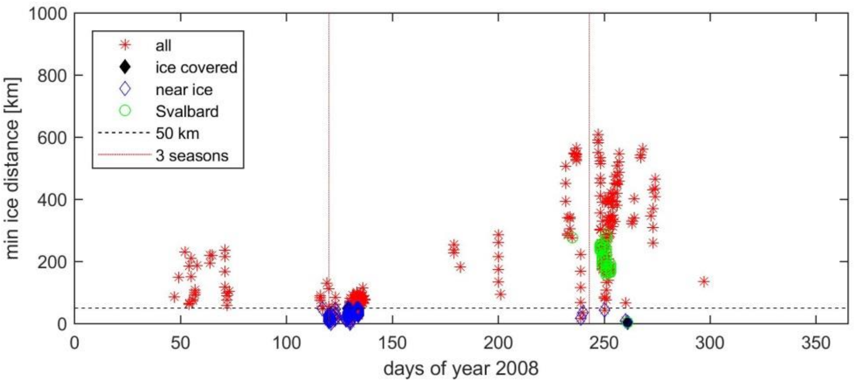


CTD profiles: 2007 * red, all: 419 d blue, 50km to ice edge: 26 d black,ice: 0

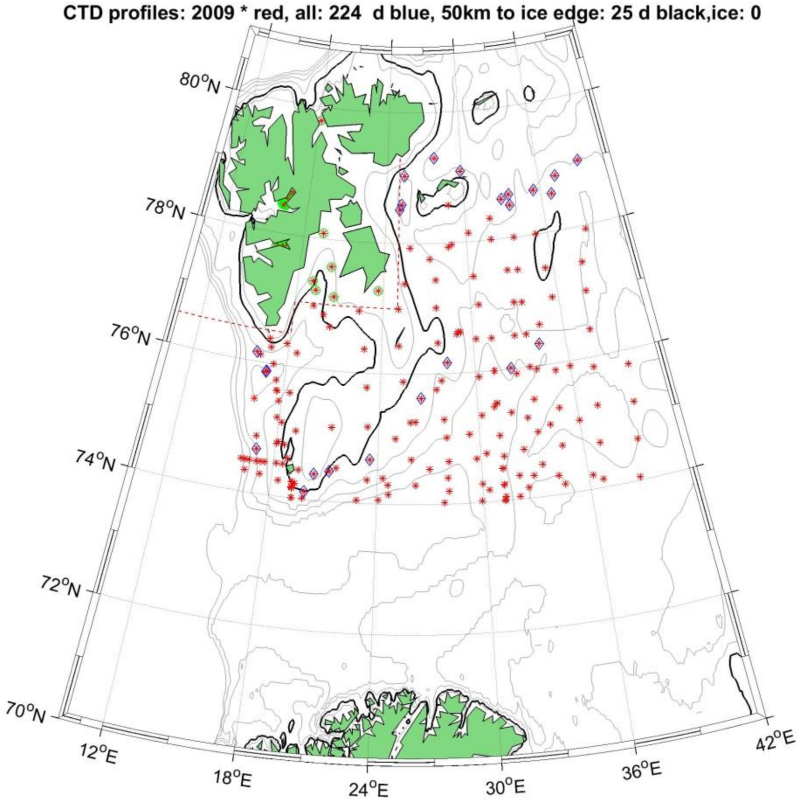


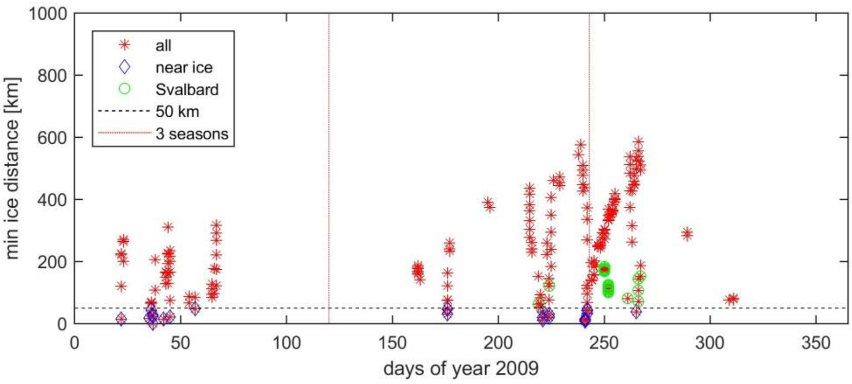


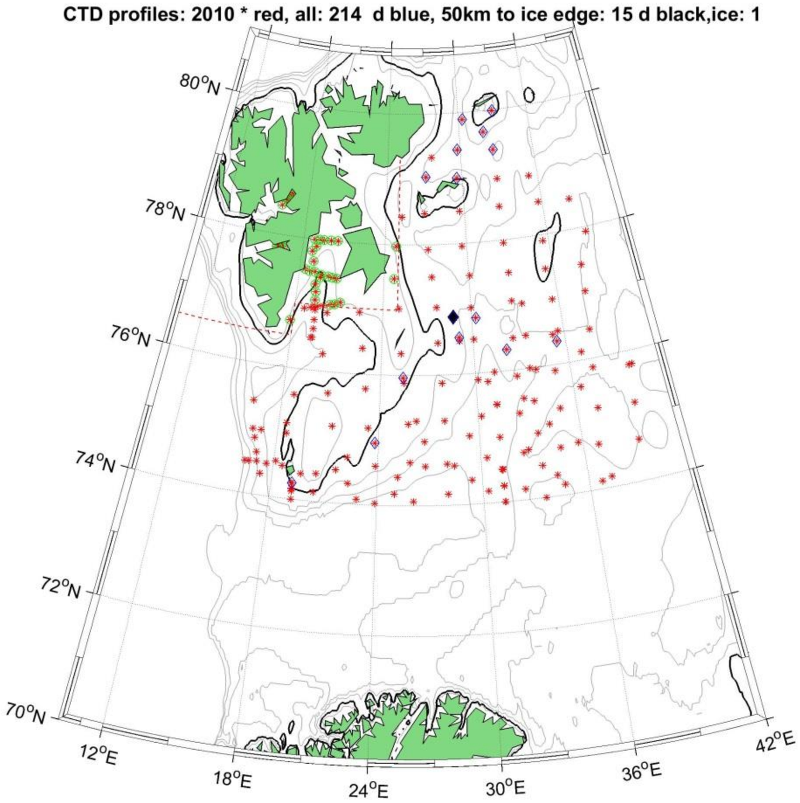

CTD profiles: 2008 * red, all: 344 d blue, 50km to ice edge: 81 d black,ice: 21
80°N
78°N
76°N
74°N
72°N
70°N
12°E
18°E
24°E
30°E
36°E
42°E

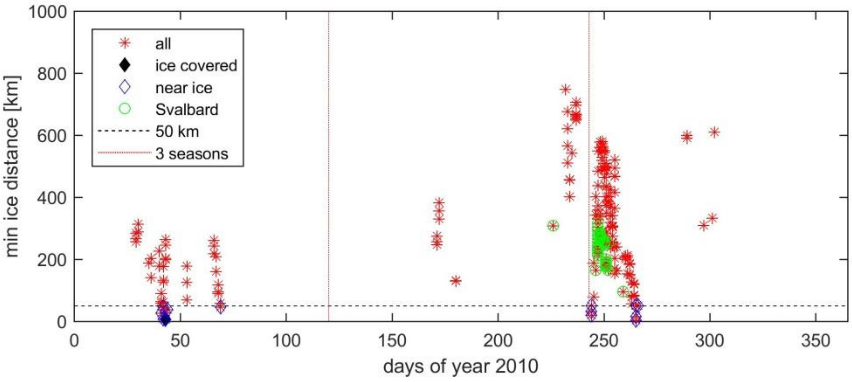

all
ice covered
near ice
Svalbard
50 km
3 seasons
min ice distance [km]
days of year 2008
0
200
400
600
800
1000
50
100
150
250
300
350

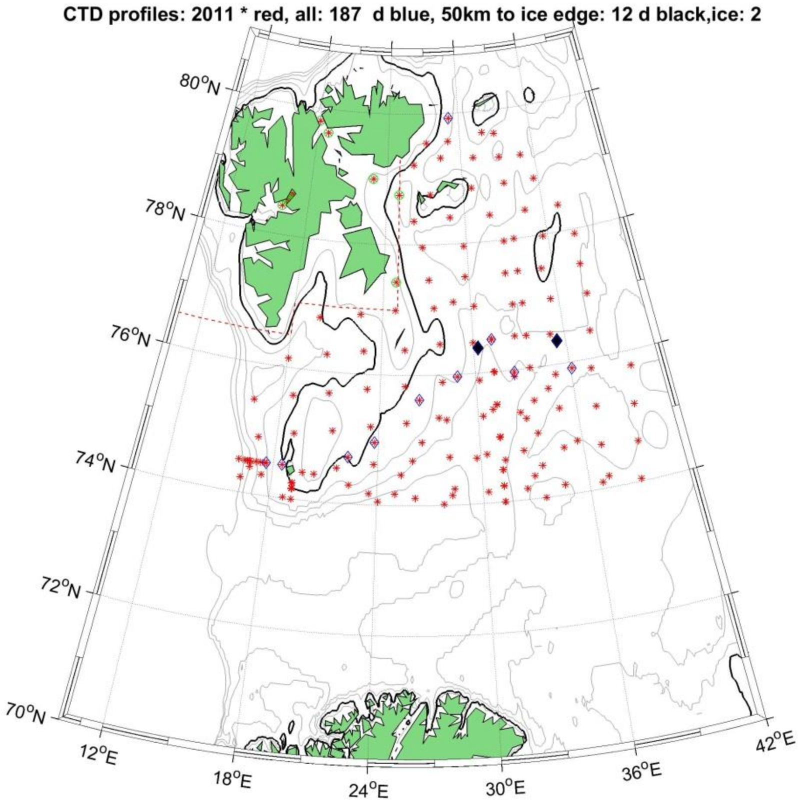
CTD profiles: 2009 * red, all: 224 d blue, 50km to ice edge: 25 d black,ice: 0

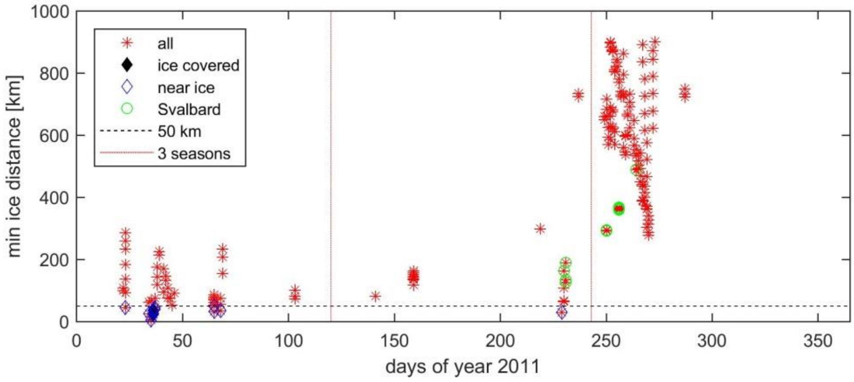




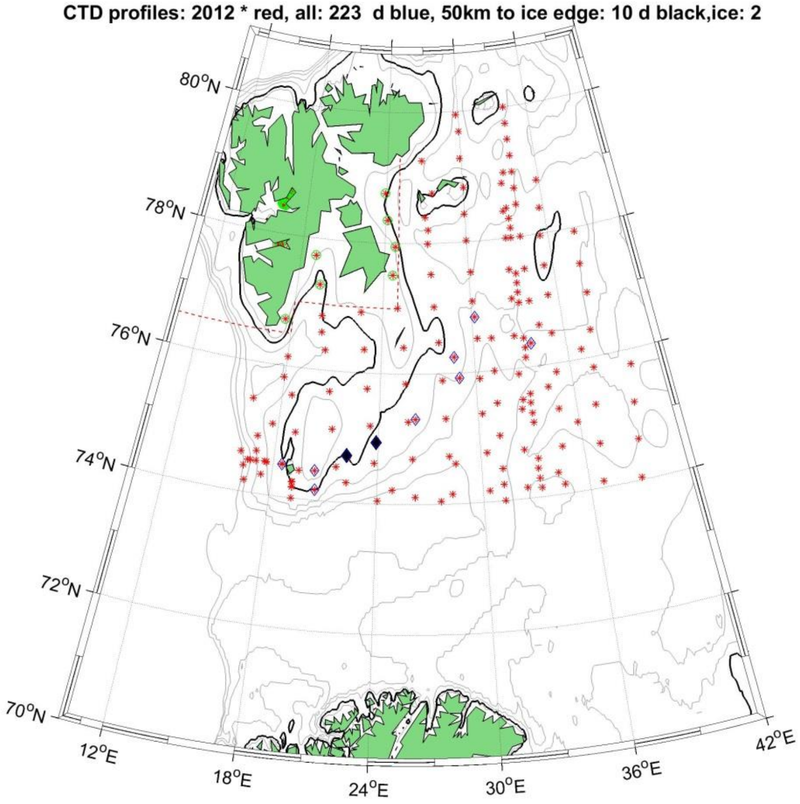

CTD profiles: 2010 * red, all: 214 d blue, 50km to ice edge: 15 d black,ice: 1
80°N
78°N
76°N
74°N
72°N
70°N
12°E
18°E
24°E
30°E
36°E
42°E

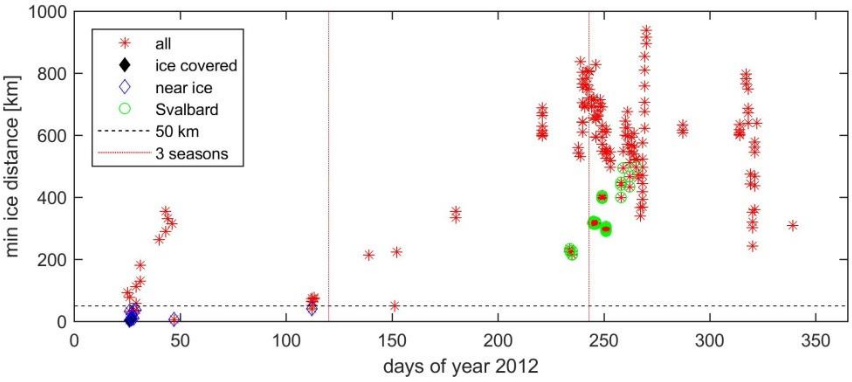

all
ice covered
near ice
Svalbard
50 km
3 seasons
min ice distance [km]
days of year 2010
0
200
400
600
800
1000
50
100
150
250
300
350


CTD profiles: 2011 * red, all: 187 d blue, 50km to ice edge: 12 d black,ice: 2
80°N
78°N
76°N
74°N
72°N
70°N
12°E
18°E
24°E
30°E
36°E
42°E

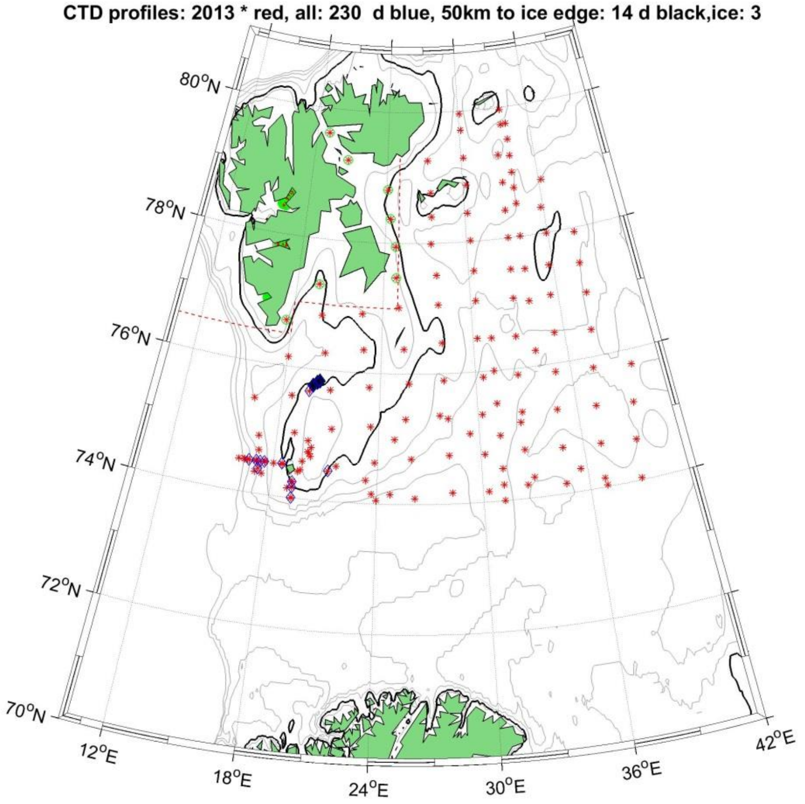

all
ice covered
near ice
Svalbard
50 km
3 seasons
min ice distance [km]
days of year 2011

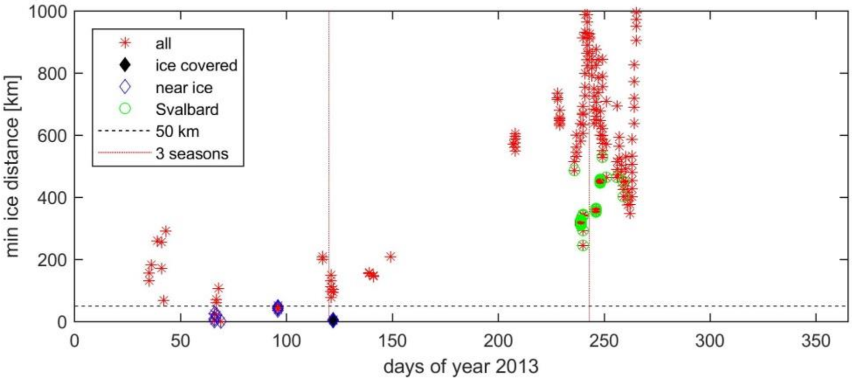
CTD profiles: 2012 * red, all: 223 d blue, 50km to ice edge: 10 d black,ice: 2

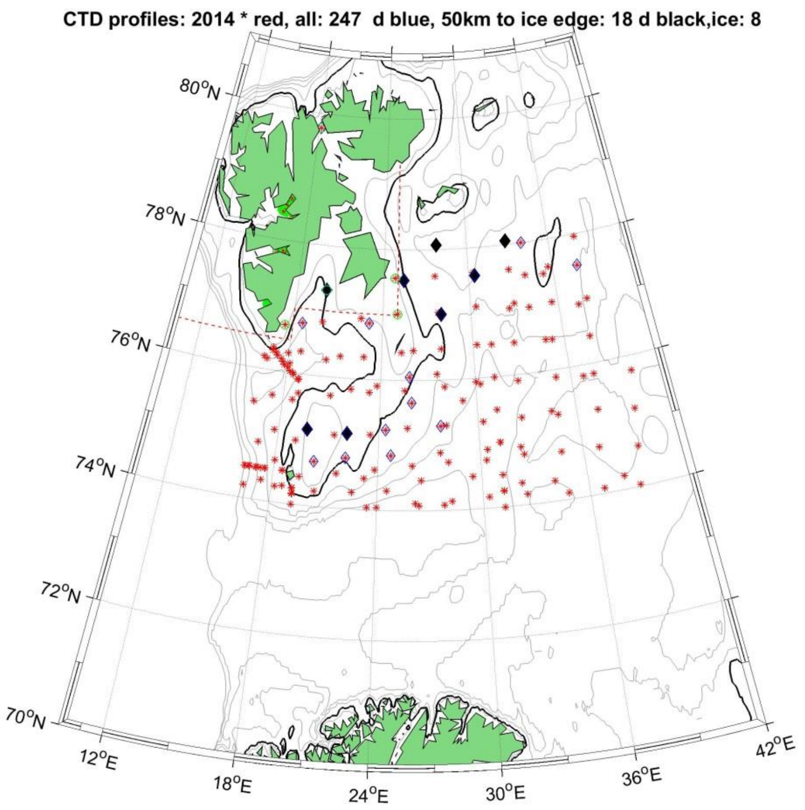


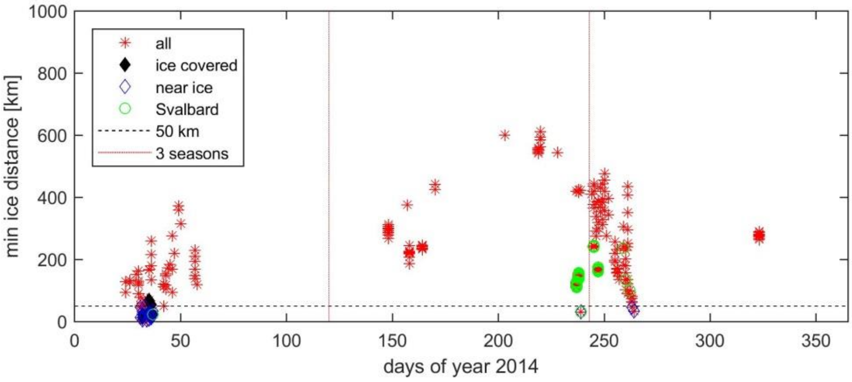


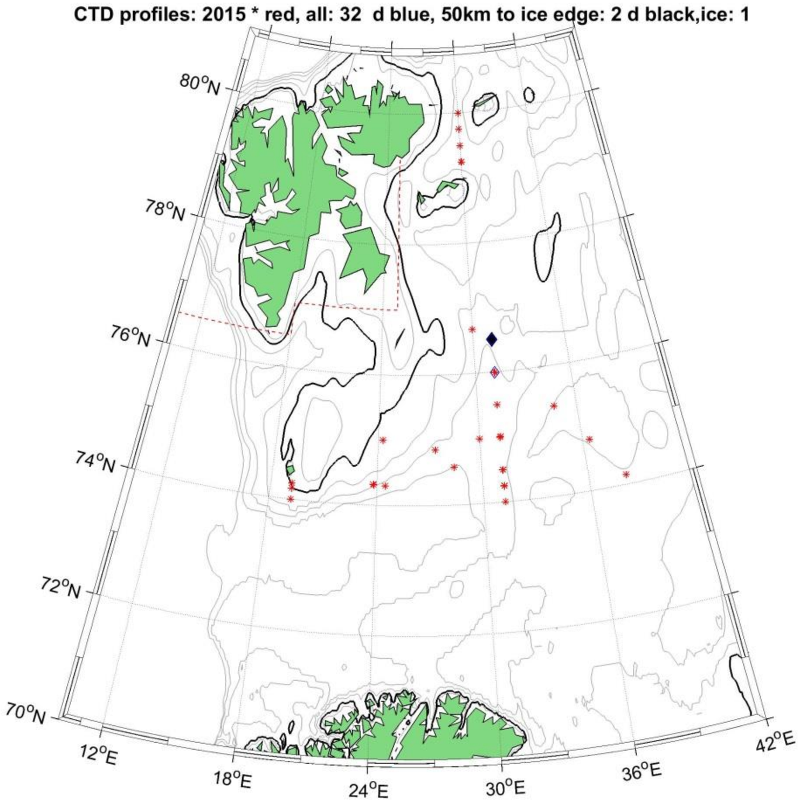
CTD profiles: 2013 * red, all: 230 d blue, 50km to ice edge: 14 d black,ice: 3

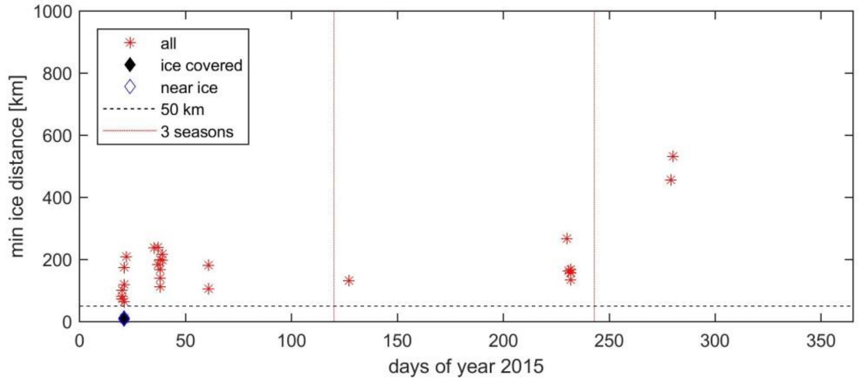




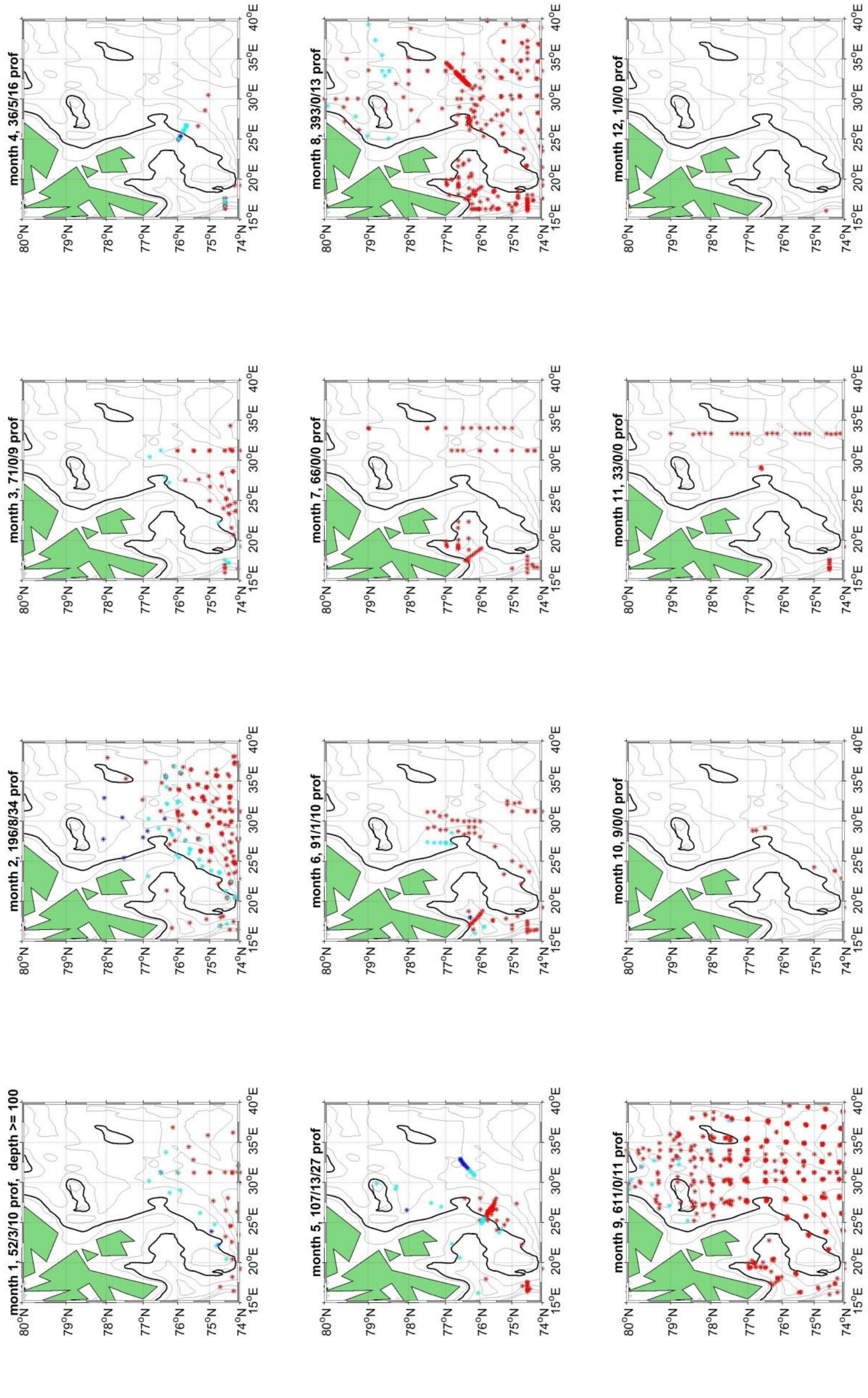

CTD profiles: 2014 * red, all: 247 d blue, 50km to ice edge: 18 d black,ice: 8
80°N
78°N
76°N
74°N
72°N
70°N
12°E
18°E
24°E
30°E
36°E
42°E


1000
800
600
400
200
0
min ice distance [km]
0
50
100
150
200
250
300
350
days of year 2014
all
ice covered
near ice
Svalbard
50 km
3 seasons


CTD profiles: 2015 * red, all: 32 d blue, 50km to ice edge: 2 d black,ice: 1
80°N
78°N
76°N
74°N
72°N
70°N
12°E
18°E
24°E
30°E
36°E
42°E


all
ice covered
near ice
50 km
3 seasons
min ice distance [km]
days of year 2015
0
200
400
600
800
1000
50
100
150
200
250
300
350

ANNEX II:
Spatial distribution of profiles per month for the time span 2006 to 2015



Spatial distribution of profiles per month: the title of each subplot gives the number of open water/ice/near-ice profiles, which are marked in red/blue/cyan in the map. Only profiles with a maximum measurement depth greater or equal 100 dbar are shown. *In den Text einbauen!!*

ANNEX III:
ISA test results: numbers corresponding to the pie-diagrams in table 3.

Month 1-4								
Method	Tmedian	Tmin	Tmedian	Tmin	Tmedian	Tmin	Tmedian	Tmin
Depth range [dbar]	50-20		20-10		50-20		20-10	
threshold	<= -1.75°C				<= -1.0°C			
Ice (21 obs)	8 38 %	12 57%	11 52%	11 52%	17 81 %	18 86 %	18 86 %	19 90 %
Near ice (88)	6 7 %	7 8 %	7 8 %	7 8 %	26 10 %	30 34 %	30 34%	30 34 %
Open water (328)	3 1 %	3 1 %	3 1 %	3 1 %	14 4 %	14 4 5	15 4 %	16 5 %

Month 5-8								
Method	Tmedian	Tmin	Tmedian	Tmin	Tmedian	Tmin	Tmedian	Tmin
Depth range [dbar]	50-20		20-10		50-20		20-10	
threshold	<= -1.75°C				<= -1.0°C			
Ice (17)	0	3 18 %	3 18 %	4 24%	11 65 %	16 95 %	16 95 %	16 95 %
Near ice (85)	4 5 %	7 8 %	3 4 %	3 4 %	42 49 %	54 64 %	28 33 %	31 36 %
Open water (741)	0	0	0	0	18 2 %	37 5 %	1 0.1 %	2 0.3 %

Month 9-12								
Method	Tmedian	Tmin	Tmedian	Tmin	Tmedian	Tmin	Tmedian	Tmin
Depth range [dbar]	50-20		20-10		50-20		20-10	
threshold	<= -1.75°C				<= -1.0°C			
Ice (-)	no data							
Near ice (13)	0	0	0	0	2 15 %	4 30%	1 8 %	1 8 %
Open water (729)	0	0	0	0	36 5 %	113 16 %	1 0.1 %	1 0.1 %