REPORT ON THE CURRENT STATE OF ICE AVOIDANCE METHODS AND RECOMMENDATIONS FOR DEPLOYING ARGO FLOATS IN THE ARCTIC OCEAN

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EXECUTIVE SUMMARY

The main goal of this deliverable is to improve the practices used in operating Argo floats in high-latitude conditions where ice is present, providing the basis for a future standardisation of the configuration of the European floats in the Arctic. This is achieved by examining the known experiments and their practices on several areas, with case studies. Based on these findings the methods have been further advanced looking at new deployments and their fine tuning of the parameters, recognizing the differences in various areas. The deliverable demonstrates clearly that it is vital to tune the parameters used in the Ice Avoiding Algorithms (ISA) based on the local conditions.

The deliverable gathers the best current knowledge of how to operate Argo floats in icy conditions, and aims to be an easy first step for introducing potential new users into operations in such conditions. This is further made easier by gathering a streamlined 'cheat sheet' in Annex I.

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1 Introduction

The operation of Argo floats in the polar oceans is challenging due to the presence of sea ice, which prevents the floats from surfacing and may damage them. Argo float operation under the sea ice and their survival through the period of seasonal ice cover (ice winter) is now possible thanks to four essential technological developments: On-board memory, ice detection methods and ice avoidance strategies, increased buoyancy capacity and two-way fast Iridium communication.

The resulting ice-capable floats have improved our ability to observe the full seasonal cycles of physical and biogeochemical processes in the polar oceans, especially in the Southern Ocean where they are widely used (e.g. SOCCOM project. Riser et al. (2018)). and where the first pilots were conducted Klatt et al. (2007). In comparison, the operation of Argo floats in the Arctic is more difficult, because it is also a marginal sea and has a complex and often shallow bathymetry, while the Southern Ocean is deeper and circumpolar in circulation. Therefore, the extension of the network in the Arctic has been modest and relatively slow.

The Nordic Seas, the Baltic Sea, and the Arctic proper, are regions of special interest for the European countries (see the Euro-Argo ERIC strategy, Euro-Argo-ERIC (2017)) due to their proximity and direct impact on their weather and climate. The decreasing trend in the extent of the permanent ice cover comes with an increase in the seasonally ice-covered regions making feasible the use of Argo floats to observe this rapidly changing region. Therefore, the Euro-Argo RISE project promotes the extension of the Argo network in the Arctic through this report that gathers the state-of-the-art practises used to operate Argo floats in the region.

The particularities and requirements for the operation of Argo Floats when sea ice is present are listed in section 2 . In section 3, the focus is on the methods and strategies for ice avoidance. There, the main focus is the ice sensing algorithm (ISA), a software-based approach to ice avoidance proposed by Klatt et al. (2007) for the Southern Ocean. The section highlights how the ISA can be adapted to local conditions, which is crucial for a successful operation in the Arctic region. Other approaches for ice detection are also presented.

Other aspects related to the floats operation under the ice, like the float's memory restrictions and methods to determine the under-ice positions, are the focus of section 4. This section also highlights the importance of the two-way Iridium communication, that allows to change the configurations remotely and activate different settings for the open water and sea ice covered seasons. The importance of adequate buoyancy engines, capable of overcome the strong haloclines typical of the Arctic waters, is also discussed.

The recent progress in the Baltic and in some Arctic regions has been possible thanks to pilot projects. In section 5 we highlight some pilot projects led by Euro-Argo partners in several polar regions in the Northern Hemisphere: Baffin Bay, Baltic Sea, Barents Sea, East Greenland Current and the Nansen Basin. The purpose of this section is to show how all the methods described in the previous sections come together to make up strategies to deal with the presence of sea ice in different regions and with different float models. The main recommendations about operating Argo floats under the ice are highlighted in the cheat sheet in Annex I (section 7). The main objective of these final sections is to facilitate the use of best practices for Argo floats operating in icy conditions. Finally, the lists of configuration parameters available for ice detection and avoidance for two float models are presented in Annex II (section 8): Arvor-I and Apex, which are the most deployed by the Euro-Argo partners in the region.

2 Operation in open water vs. under sea ice

The standard sampling cycle of a core Argo float is illustrated in (Figure 1). The cycle starts with (1) its descent from the surface to the drifting depth (1000 m), where the float (2) drifts with the currents for 10 days. Then the float (3) descends further to the profiling depth (2000 m) to then (4) ascend all the way to the surface, while measuring temperature and salinity, and other parameters in the case of biogeochemical floats. At the surface the float (5) establishes communication with the satellites to: determine the geographic position of the profile it just measured, send all the information regarding the last cycle, including the measurements and technical information, and to receive updates to its configuration.

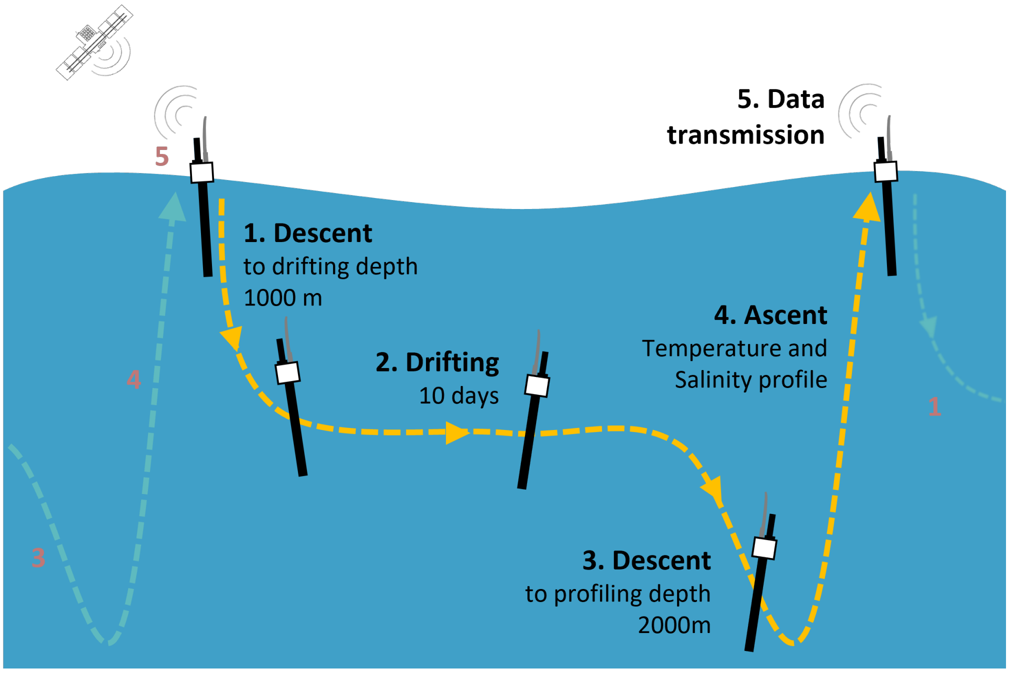


Figure 1: Standard Argo Float Cycle

The presence of sea ice modifies this typical cycle since the float can not reach the surface, where the satellite communication takes place (Figure 2). If the float (6) has detected ice it stops its ascend and stores the profile. Usually, the float starts the next cycle by performing its regular mission configuration starting with its descend to parking depth (1) sinking to the parking depth. When the float encounters open water and it can surface again, after one or many profiles under the ice, it (5+) transmits the current and the stored profiles.

Without GPS or Iridium positions for the under-ice profiles, alternative methods to determine or estimate them are needed. Positioning systems using RAFOS are in place in the Weddell Gyre, but they are expensive to maintain. The default method for estimating positions is linear interpolation between known positions, but better interpolation methods provide a more realistic trajectories. These interpolation procedures are currently applied during delay-mode quality control (see more in section 4.4 Geolocalisation).

Without satellite communication the data is not transmitted in real time and the float configuration

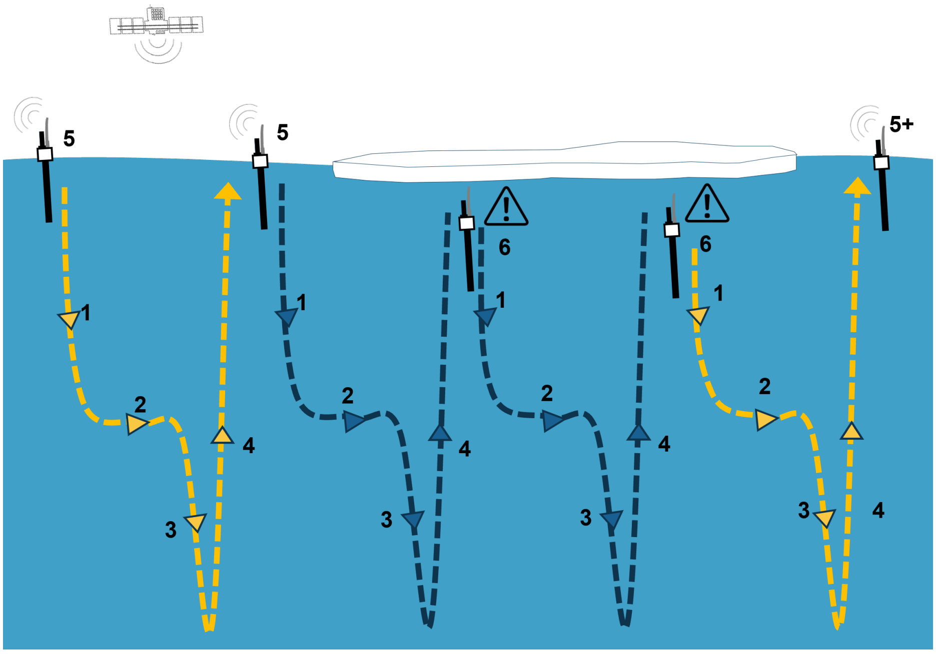


Figure 2: Under-ice Argo Float Cycle

cannot be updated. Therefore an ice-capable float needs:

- on-board memory to store the under-ice profiles
- iridium communication to change its parameters for different ice seasons. It is also preferred because of its fast transmission rates.

Given limited memory, the under-ice missions (sampling schemes) have to be appropriate for operation all the way through the ice winter. In cases of memory overflow, partial loss of the under-ice data occurs (see more in section 4.1 On-board memory). Satellite communication remains a must for the Argo float network, because it is needed to transmit the data collected. Without any transmission, as could happen if a float drifts into permanent ice zones, all profiles measured and the instrument are lost. Therefore, the use of Argo floats is limited to seasonal ice zones only.

As the sea ice seasonal zones in the Arctic are smaller in extent than in the Southern ocean, the potential for the operation of Argo floats there is also smaller. However, the steady growth of the seasonal ice zone in the northern hemisphere (due to the decline in the permanent ice extent) poses an opportunity for Argo to contribute to the larger Arctic observation system.

Methods and strategies for ice avoidance are crucial for the successful operation, as contact with sea ice can damage the float and thus considerably risks shortening its lifetime. Experimental deployments in the Weddell Sea during the early 2000s showed that standard floats had short lifetimes and low survival rates after the ice seasons, most likely due to the physical damage to the floats caused by the collision with the sea ice (Klatt et al. (2007)). The sensors and antenna, which are located at the top of the float, are endangered when the float hits the bottom of the ice layer on its trajectory towards the surface. Collisions with sea ice can also happen while the float is at the surface for satellite communication. In this case, the float's hull is also at risk of damage due to lateral pressure if caught between ice floes. Therefore, ice avoidance strategies are a must. Details about ice detection methods and ice avoidance strategies can be found in Section 3

Finally, the presence of melting sea ice and other freshwater sources cause considerable stratification at the surface. To change its buoyancy enough to cross the halocline, the float needs a larger oil volume than floats operating in the open ocean. This is discussed in section 4.

3 Ice avoidance methods

Klatt et al. (2007) reported that the standard floats deployed in the Weddell Sea by the Alfred Wegner Institute (Germany) before 2003, had a low probability (37%, n=35) of enduring a winter when encountering sea ice. During the second winter, six floats again entered the sea ice zone and only three of them prevailed until spring. None of these floats outlasted the third winter season. With this high mortality rate, the need for ice avoidance methods became clear. The authors proposed an Ice Sensing Algorithm (ISA), which uses the temperature measured by the float in the upper water column to predict the presence of sea ice before collision. They observed that in the Weddell Sea the upper water column usually had temperatures near-freezing point if sea ice was present, while the subsurface waters were warmer when the surface was ice-free. If the ISA predicted the presence of ice, the float aborted the ascent, skipping surfacing and satellite communication, and started the next cycle. The implementation of this ice avoidance strategy in Argo floats operating in the Southern Ocean allowed a considerable improvement of the float lifetimes in the region, making them comparable with those of floats operating in lower latitudes. As ISA is software based, i. e. does not require extra sensors or extra measurements, it is a cost-neutral approach in terms of energy budget and has therefore become the main approach to ice avoidance.

With time, the ice avoidance approaches have become more complex. Combining the use of several tests for ice detection, increases the float safety by allowing for backup tests which complement each other. Dedicated sensors for ice detection have been tested, but so far non has achieved commercial status. All of these components are presented in the following subsections.

3.1 Ice detection methods

Ice-capable floats use many software-based tests for ice detection. The most common ones are shown in Figure 3: the communication and pressure timeouts, and the ice sensing algorithms. Since they do not require extra sensors or extra measurements, using software-based test is in principle a cost-neutral approach in terms of energy budget. This increases our confidence in the ice detection process, since there are backups in case the others tests fail. All three options can have different outcomes and can be evaluated in combination to maximise the survival rate of the floats. The technical data contains information (flags) that indicates which of the tests was positive for ice presence. These technical data send back from the floats should be evaluated to check the performance of the ice detection methods.

3.1.1 Pressure change timeout

If a float gets stuck under sea ice during its ascent trajectory, pump actions and the resulting increase in volume would not result in a decrease of the measured pressure. This test, called 'ascent hanging'

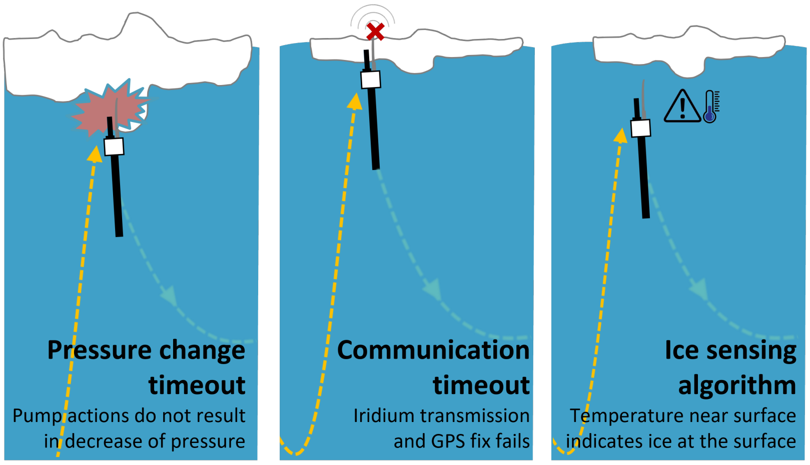


Figure 3: Ice detection methods

in NKE floats, it is implemented as a timeout parameter: if after ΔT minutes the float's pressure does not change, the float is considering stuck under ice. However, the presence of a strong halocline may cause false ice detection if the timeout set is shorter than the time needed by the float to overcome it. Therefore, this parameter should be set carefully.

APEX floats used in the Weddell Sea (Klatt et al. (2007)) used a specific pressure timeout period for the instances in which the ice sensing algorithm (see Section 3.1.3) does not detect ice, but the water is colder than -1,79°C in the layer above the one used for ISA. In this cases a failure to reach a pressure under 4 db after 6.4 minutes triggered an abortion of the surfacing attempt. The timeout value was calculated as twice the time expected for the float to reach 4 db starting at 20 db, assuming an ascent speed of 0.08m/s.

3.1.2 Communication timeout

If the float is near or at the surface, it will try to establish communication with the Iridium and GPS satellites, but if it is under ice the attempt will fail. Failure to establish communication after a certain time it is therefore also a proxy for ice presence. In NKE floats, the timeout values may be set to different values for Iridium and GPS. The analysis of French floats technical data, has shown that the default Arvor-I GPS timeout (5 min), lead to false ice detection in the Arctic, so their fleet uses a value of 15 minutes (internal communication).

IceApex (Teledyne Webb) floats used in the Weddell Sea also use a total communication time out. The float is only allowed to expend a certain time at the surface and commences to the descent phase. AWI floats uses a total communication timeout of 3h.

3.1.3 Ice Sensing Algorithms

3.1.3.1 Principle and settings

The principle underlying the Ice Sensing Algorithm (ISA) is that a relationship exists between the mixed layer (near surface) temperatures and the presence of sea ice at surface, with water under ice being comparatively colder than when the surface is ice-free. For the Weddell Sea, Klatt et al. (2007) examined Argo profiles from the first deployments in the region and determined that if the median temperature between 50 db and 20 db was colder than −1.79°C, which is near to the freezing temperature of seawater, sea ice was to be expected at the surface. To allow time for the evaluation, the floats were also programmed to reduce their ascent speed at a certain pressure level. A schematic for ISA is given in Figure 4, highlighting the parameters that must be adapted according to the local oceanographic conditions:

- Pressure for ascent speed reduction: P_{slow}
- Pressure layer to evaluate the temperature. Defined by P_1 (deepest pressure) and P_2 (shallower depth)
- Temperature threshold for ice detection. If the median temperature (T_{med}) in the $P_1 - P_2$ layer is lower than the threshold (T_{ice}), sea ice is expected at the surface.

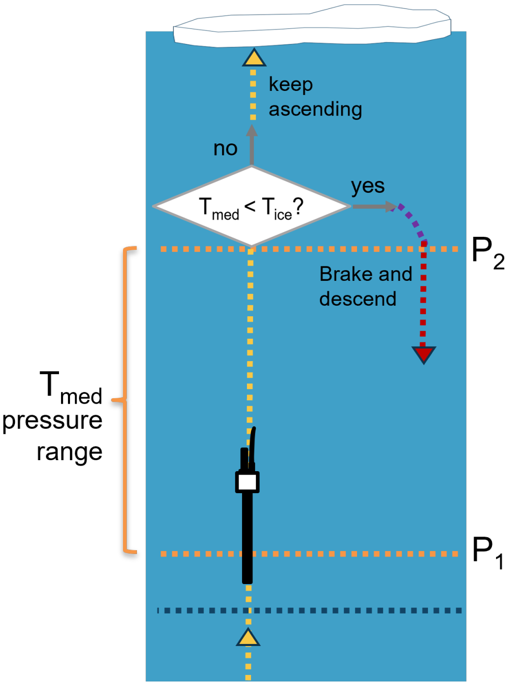


Figure 4: ISA principle

The ISA proposed by Klatt et al. (2007) for the Weddell Gyre, resulted in a substantial increase in the float survival rates, and were then used in the entire Southern Ocean. Smaller local changes have been selected on occasion as was done by Wong et al. (2011) near the Wilkes Land coast of Antarctica ($P_2 = 20$).

Once the ice sensing algorithm became a standard feature for Argo floats, the original parameters ($P_1 = 50$, $P_2 = 20$, $T_{ice} = -1.79$°C) are the ones set by default in many float models. However, the default settings by the manufacturers should be carefully checked since the upper water column temperature and its relationship with ice coverage depending on region and should be matched to deployment/operation area of the floats. In the Arctic, settings of ISA parameters were inconsistent and sometimes even used the default values. Float deployments in the Arctic have been fewer and not as successful in the past as in the Southern Ocean, often resulting in early loss of floats.

A more coherent approach to tuning the ISA to Arctic conditions began under EuroArgo leadership during the MOCCA project (Project No: SI2.709624, D4.4.2 Latarius and Klein (2018))). The authors recommended appropriate ISA settings for float deployments in the shallow Barents Sea by comparing profiles under-ice, near-ice (up to 50 km from the ice edge) and open-water profiles and determined $P_1 = 20$, $P_2 = 10$, and $T_{ice} = -1$°C as appropriate parameters for the Barents Sea. Further ISA tuning for other areas of interest in the Arctic (Figure 5) is part of the EuroArgo strategy regarding the high latitudes. In the past years, the Euro Argo ERIC members have deployed more floats in these areas and would benefit from a coordinated approach to define mission configurations and ice avoidance strategies. A collection of locally tuned parameters is given in Table 1.

Region	**Ocean**	**Pressure range P_2 - P_1 (dbar)**	**Threshold T_{ice} (°C)**
Weddel Gyre	Southern Ocean (Klatt et al. (2007))	20 – 50	-1.79
Weddel Gyre	Southern Ocean (AWI, Personal Communication, 2020)	40 - 15	-1.65
Wilkes Land	Southern Ocean (Wong and Riser (2011))	30-50	-1.79
Baffin Bay	Arctic Ocean (André et al. (2020))	10 – 30	-1.3 or -1.5
Barents Sea	Arctic Ocean (Latarius and Klein (2018))	10 – 20	-1.0
Nansen Basin	Arctic Ocean (this report)	10 – 30	- 1.4

Table 1: ISA parameters used in different regions

3.1.3.2 ISA local tuning

The main requirement to find appropriate ISA parameters for a certain region is to compile temperature profiles for the region, to distinguish the under-ice from open water subsurface conditions (Figure 6). Sea ice information associated with the selected profiles is extracted by matching their time and location to the sea ice satellite maps. The sea ice information is then used to classify the profiles in two groups: under-ice and open-water profiles. The criteria for classification may vary, since under-ice just means

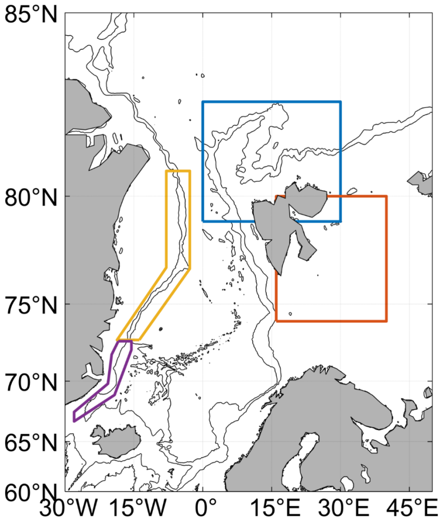


Figure 5: Seasonal sea ice regions of interest (Euro-Argo RISE project) where local ISA tuning is needed.

that one would like the ISA test to be positive for ice presence. For example André et al. (2020) used the AMSR2 sea ice concentration product and labelled under-ice profiles as those associated with concentrations larger than 10%, while in this report (see Nansen Basin case study5.5) the authors considered as under-ice, those profiles with sea ice concentrations larger than 1% . Latarius and Klein (2018) used the MASIE sea ice edge product, which uses several data sources which undergo a form of manual data fusion, labelling under-ice profiles all those inside the ice edge contour.

The ISA parameters selected by Klatt et al. (2007) and Latarius and Klein (2018) were based on the analysis and comparison of temperature profiles under the ice and open waters. However, their methodology is somewhat subjective since only some temperature thresholds were considered. At least in theory, the best ISA parameters are those that minimise the two possible errors in ice detection: the probability of the float being damage by the ice by coming into contact with it and the probability of missing the opportunity to surface. Since both depend on the T_{ice}, there is a trade-off between both errors.

To evaluate the performance of a set of ISA parameters, one calculates the T_{med} in the P_1 - P_2 pressure range for all profiles and then compares these results with the T_{ice} to calculate the probabilities of correct and incorrect ISA outputs. For the under-ice profiles, $T_{med} < T_{ice}$ result in a correct ISA output (ice detected), $T_{med} > T_{ice}$ result in false negatives (ISA fails to detect ice when it is present). For the open-water profiles median $T_{med} > T_{ice}$ result in correct outputs (ice not detected) and $T_{med} < T_{ice}$ result in false positives (ISA detects ice when it is not present). Since the events for each group, right and wrong ISA detections, are complementary (one occurs if and only if the other does not) their probabilities add up to 1. Latarius and Klein (2018) compared profiles under-ice, near-ice (up to 50 km from the ice edge) and open-water profiles to determine appropriate ISA parameters for the Barents Sea and then showed the improvement in the ISA performance by comparing the probabilities of correct and incorrect ISA outputs with those obtained with the default parameters, using pie charts for each profile group and ice season (in their Table 3). The data and the steps involved in the development of a locally tuned ISA algorithm are shown in Fig. 6 based on the work done in MOCCA.

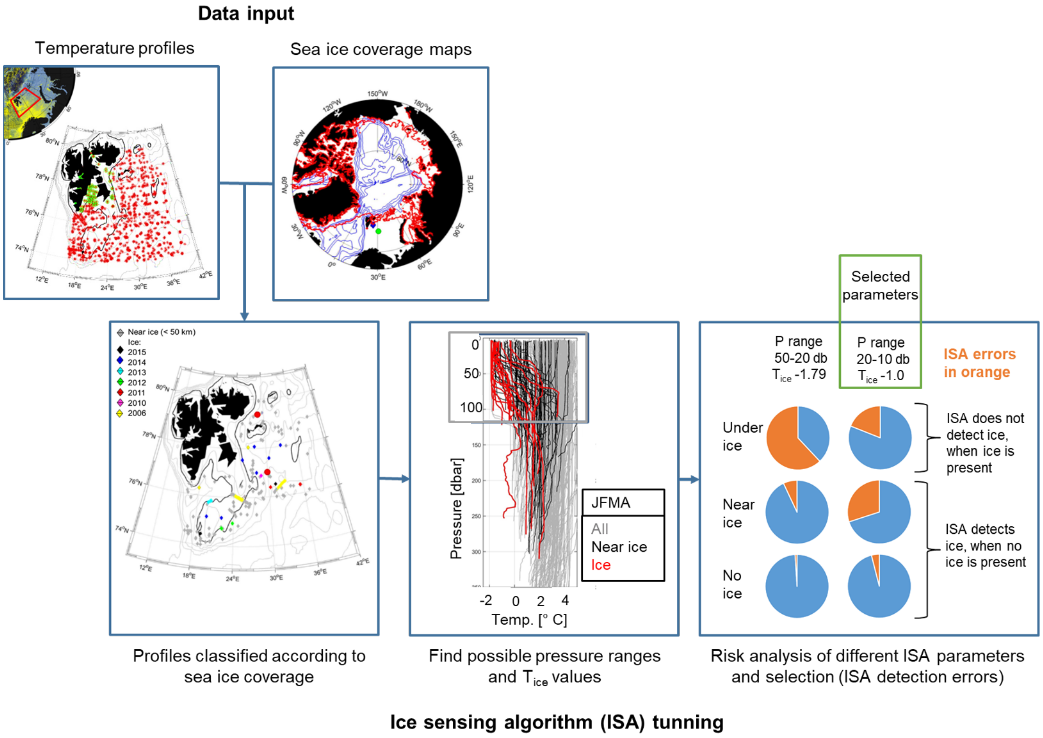


Figure 6: Data and steps for ISA local tuning of ISA. Example for the Barents Sea.

A more systematic approach to evaluate the performance of different parameters is presented in André et al. (2020) using data for the Baffin Bay. The authors use a decision plot where the probabilities of right and wrong ISA outcomes are plotted as a function of T_{ice}. The rationale behind these decision plots are shown in Fig. 7. In that case, the chosen ice threshold T_{ice} was -1.3 which resulted in an acceptable, and low level of both ISA errors. Another acceptable value is -1.4, with similar error probability, but higher risk of coming into contact with the ice. Preferring the higher T_{ice}, means the operators prioritize the integrity of the floats over the real-time transmission of the data, which is understandable since the project uses expensive BGC floats. The priorities may vary according to the purpose of the pilot project.

A more compact display of the decision plots is presented in André et al. (2020) were the probabilities of success and fail for ISA are plotted together, along with different sets of pressure ranges. An example of this type of plot is shown in Fig. 8 used data from the Nansen Basin. The ISA tuning in that region is part of the Euro-Argo RISE Workpackage 5 and conducted at BSH building on the work of MOCCA. The trade-off between the possible detection errors is evident in this plot. Successively higher temperature thresholds would result in a higher rate of success of ISA detecting the ice presence, but also in a higher rate of false positives (ISA detects ice but no ice is present). In other words, the higher the temperature threshold, the more the missed opportunities to surface. Conversely, the lower the temperature threshold, the more likely the float would be to crash with the ice. In this same plot, the probability never reaches a plateau around 0 (or 100%) and has to cope with an inherent uncertainty. This is to be expected in the Arctic where the correlation between ice and temperature is noisy due to non-local effects. In this case the presence of warmer waters in the upper layers may be associated to

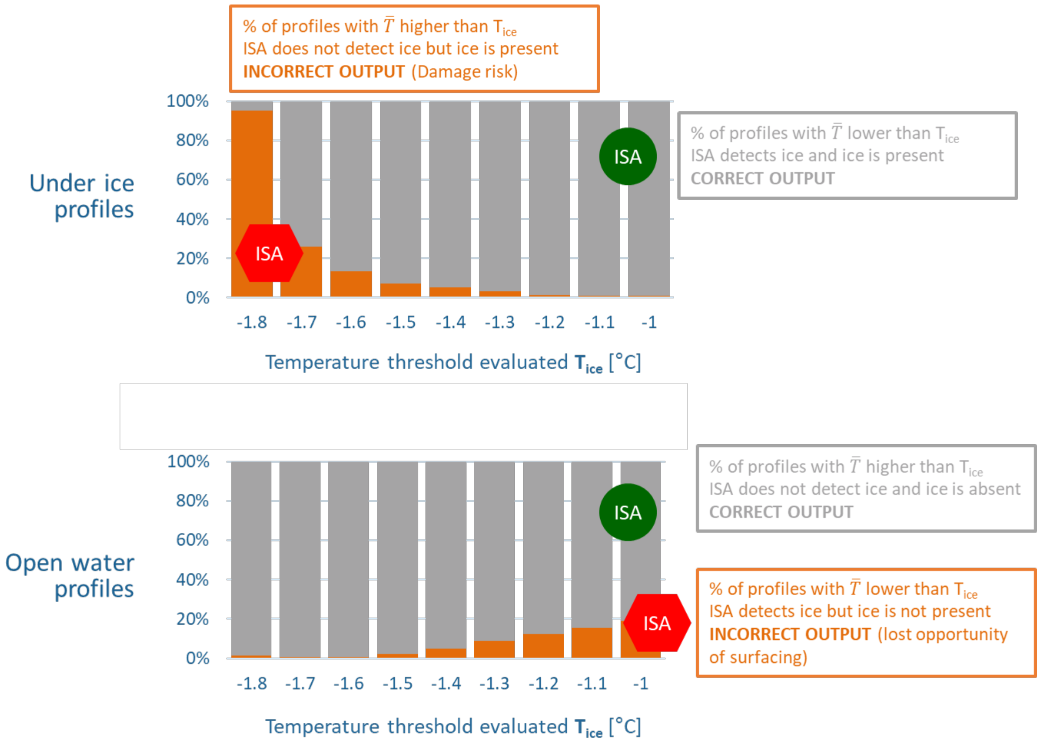


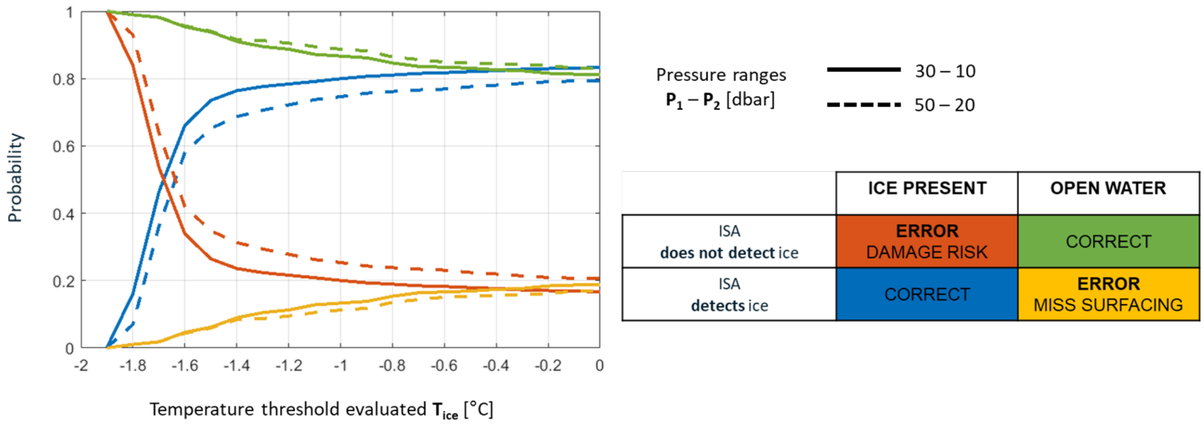
Figure 7: Risk analysis of different ISA thresholds. Example for the Baffin Bay using data from 14 Argo floats from the NAOS experiment (France): n = 1396 profiles André et al. (2020)

water intrusions from the Fram Strait.

The locally tuned decision plots (Fig. 8) are to examined by the float operators to make a decision on the 'best' parameters. Given the risk one is willing to take, no unique set of parameters can be prescribed. In this case, the chosen parameters were: $P_1 = 30$, $P_2 = 10$, and $T_{ice} = -1.4$°C. The code to calculate the probabilities and produce the decision plots will be uploaded in the EuroArgodev Github (`https://github.com/euroargodev/ISAdecisionplot`).

Experience from field experiments has shown that is desirable to monitor the floats carefully during early stages of their operation at sea and test that they are working as expected. An option is to activate ISA with an extremely low T_ice value, to avoid false ice detections which would lead to missing communication with the float too early on, and then successively change the temperature threshold from low values to high values. This close monitoring it is also useful in case the float drifts into an unexpected area, for which other ISA parameters maybe more appropriate.

The selected choice of optimal ISA parameter also needs to be checked against the technical abilities of the floats which are manufacturer dependant. It is desirable to evaluate the threshold temperature as close to the surface as possible, but it also needs time for the float to abort ascend, i. e. to 'brake' without hitting the ice. Apex floats do have a more limited buoyancy engine and are slower to brake than Arvor-I floats which may impact the ISA design. For instance, an Apex9 float deployed in the Barents Sea



	ICE PRESENT	OPEN WATER
ISA **does not detect** ice	**ERROR** DAMAGE RISK	CORRECT
ISA **detects** ice	CORRECT	**ERROR** MISS SURFACING

Figure 8: Decision plot for ISA local tuning. Data from the Nansen Basin. N = 1854 profiles

initially used the ISA parameters recommended in Latarius and Klein (2018) but then the upper pressure limit P_2 needed to be changed from 10 to 14 dbar so the float had time to brake (Angel-Benavides et al. (2020)).

It is important to notice that in the cases that the ISA detection is triggered, the uppermost part of the water column is not sampled (above P_2). This is illustrated with the temperature data from float WMO6903695 in Fig. 9. When the float is under-ice the minimum recorded pressure is around P_2 (17 dbar). Therefore, the profiles measured under the ice without triggering ISA (detected with one of the timeout detection methods) can be very useful for further refinement of the ISA algorithms.

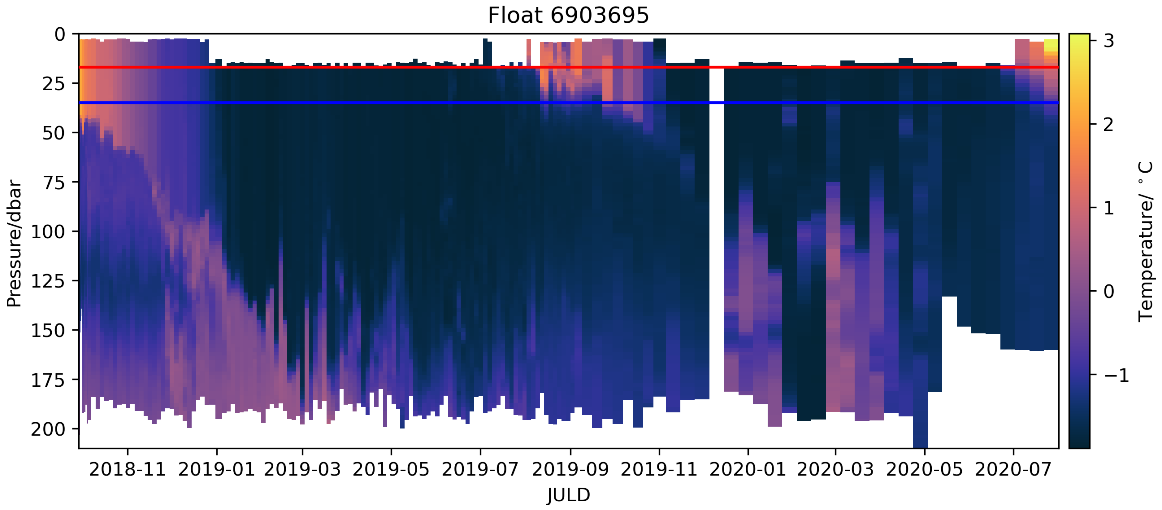


Figure 9: Float WMO 6903695 temperature measurements. Blue line indicates the depth where evaluation of the temperature starts, red line indicates the pressure where ISA activates.

3.1.4 Ice calendar

Due to the sea ice seasonality and the possibility of the float remaining long periods without surfacing, having the possibility of programming changes in the float configuration according to the date is very useful to better safeguard the float.

Apex floats have a parameter called "Active Ice Detection Month" which is a hexadecimal number,where each month is is a "one" bit in a 12-bit binary string. This offers the possibility of deciding in advance on which months the ice avoidance should be activated. This feature is the most basic version of an ice calendar.

The Provor CTS5-Payload Proice floats (André et al. (2020)) tested in the Baffin Bay NAOS experiment, include a more sophisticated feature. Script-based commands enable modifications to the configuration parameters of the under-ice float in the absence of satellite communication. For example, as the Baffin Bay is totally ice covered in winter, a 'Systematic Winter Stop' at 15 m depth was programmed in the early deployments. This preserved the floats integrity when the suitability of the locally tuned ISA was still under investigation. this provided additional security when the float ascend can be stopped at a given depth for a series of given months. This is particularly useful for areas where the dates of ice breakup are relatively known, like the Baffin Bay, where it occurs by the end of July at the latest.

The implementation of such a script-based ice calendar, useful to change all configuration settings, as a standard feature for floats operating in seasonal ice zones would be very useful for float operators. Currently, it is needed to closely monitor the ice conditions in the float vicinity to decide when to send the desired under-ice configuration via Iridium. The Euro-Argo Fleet monitoring website allows to overlay sea ice concentration maps to aid this task. However, operators aiming to maximize the number of profiles transmitted in real time may miss the window to send the more appropriate configuration for the ice winter.

3.1.5 Hardware-based

Several hardware-based ice detection methods for Argo floats have been tested. The theoretical advantage of this approach is that the presence of an exclusively dedicated sensor would allow the detection of ice above the float with more certainty and before contact with it. However, the modifications that the float requires to accommodate a new sensor are considerable. The changes in size and weight, together with the control and data management imply a lot of engineering and energy consumption. Until now, no sensor dedicated exclusively to ice avoidance has been integrated in a commercial float nor are they routinely used by any program. Moreover, the detection of local (single-point) ice conditions above an ascending float may not be enough to keep the float safe from the ice Klatt et al. (2007). The float could emerge in small open water patches in an ice field and could become trapped in it, therefore the wider vicinity of the float (1 km) would be more relevant for ice avoidance. Nevertheless, research and development of ice detection dedicated sensors for Argo floats could be important in the future if the small ice gaps and polynyas are to be exploited to increase the real time data stream during the ice winter.

3.1.5.1 Upward-looking acoustic altimeter

An upward-pointing acoustic altimeter (PS-A916, Teledyne) was tested in 14 Pro-ice floats in the Baffin Bay/NAOS project (see Fig. 10, right from André et al. (2020)) to check if it was possible to detect large objects above the float, such as icebergs, as well as sea ice. Due to its small size and low power consumption, it is well suited for use on autonomous platforms.

The altimeter uses a 200 kHz sonar with a range of 100 m (resolution 1 cm) and a ping rate of 5 Hz. The digital output of the sonar does not included information about the intensity of the return echo and it is simply the distance to the obstacle estimated from the time of flight at a fixed speed of 1,500 m/s. These outputs were corrected in post-processing using the real sound speed estimated from the floats' CTD measurements at ping and at surface. Also, the distances were converted to draught measurements by subtracting the pressure measured by the float. The 99% of a total of 3,236 sonar measurements (pings) are draughts of less than 5 meters, which distributions are shown in Fig. 11. For the best correction (at ping), the mean draught increases from 0.13 to 1.3 m in the ice winter, which can cautiously be interpreted as a sea-ice signature. But since the float cannot surface in winter, it can not reset its surface pressure and thus a small sensor drift might be hidden in draught estimates. The 18 profiles in which at least one draught measurement was higher than 5 m are shown in Fig. 11 along with the minimum depth reached by the float(dotted line), which is set to 15 m in winter. Two characteristics of the measurements point to their artificial nature. The draughts calculated from a single profile are highly variable and the floats were able to reach depths above the estimated draught, instead of being stopped by the object. The study concluded that a more accurate depth gauge would this be needed to have a direct detection of sea ice and estimation of its thickness. Moreover, the large the risk of false detection is too high compared to the risk of encountering an iceberg.

Figure 10: ProIce float tested in the Baffin bay. From André et al. (2020)

3.1.5.2 Optical sensor

Another method tested during the NAOS project André et al. (2020) is the optical detector described in Lagunas et al. (2018), based on depolarization of a laser's reflection on ice . It was tested during a prototype phase, on a profiling float deployed in 2016 (WMO6902668).

Lagunas et al. (2018) described an underwater sea-ice detection apparatus to be used on Argo floats, gliders and AUVs. The source is a polarized continuous wave (CW) diode-pumped solid-state laser (DPSS) module operating at 532 n m. A polarizing beam splitter separates light of S and P polarization states, which are detected by two photodetectors for each polarized component. Since sea-ice is a strong depolarizer, the ratio P/S is an indicator of the presence or absence of sea-ice. A value P = S = 0 indicates a

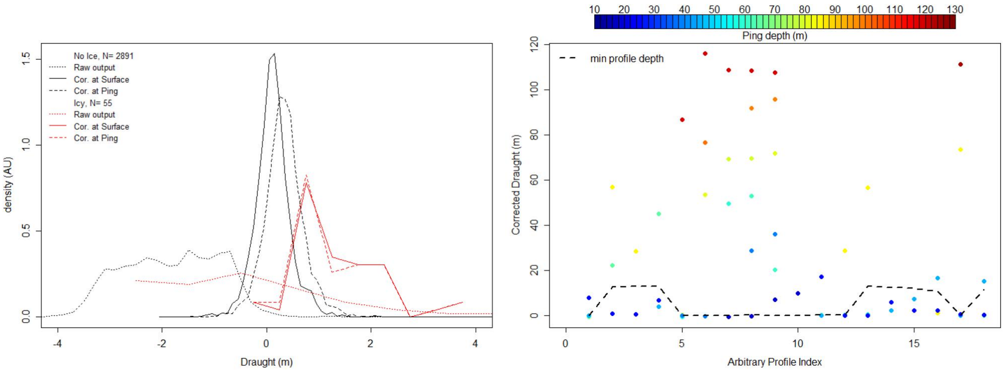


Figure 11: Sea ice draught estimates from sonar measurements. Left: Small draughts (shorter than 5 m) estimated from raw sonar distance (dotted lines) or from distance corrected for sound speed at ping depth (dashed lines) or to the surface (solid lines). The distributions are plotted in black for months where the probability of sea-ice cover is very low (August, September, and October) and in red for months where the probability of sea-ice cover is very high (December to June). Right: Large draughts (larger than 5 m) calculated from single profiles and minimum float depth. From André et al. (2020)

complete absence of ice, 0 < P=S < 1 denotes the presence of sea-ice and P = 1 denotes an unpolarized source. The system can detect sea ice at a distance of 12m.

Regarding its integration of the instrument on the float, the selection criteria of the laser took into account energy consumption as well as its effect on the hydrodynamics and buoyancy. These design constraints set limits on the laser technologies available (see Table 2 in Lagunas et al. (2018)). A 500mW DPSS laser module was chosen and build from components. The components and the instrument integrated in the Argo float are shown in Fig 12.

The laser ice detection system was installed on a Provor CTS5-ProIce BGC- float that was deployed during the Green Edge scientific mission in the Baffin Bay. Data acquired by the float on in open water conditions between 10.07.2016 and 31.10.2016, and therefore no ice to reflect the linearly polarized beam, shows that the return signal from the water-air interface is too weak and cannot be detected by the instrument. Unfortunately, the float was lost during its under ice period and no data is available to evaluate the performance of the ice detection method. Further deployments of floats equipped with the laser ice detection system were planned for 2018 and 2019.

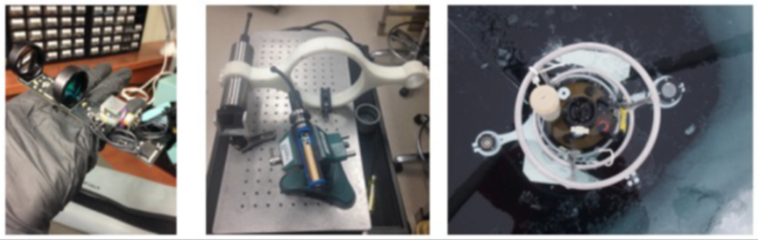


Figure 12: Laser ice detection system. Left: optics and electronics of the detector. Center: pressure housing and mounting collar. Right: Ice detection system mounted a BGC Argo float deployed in the Arctic Ocean.From Lagunas et al. (2018)

3.1.5.3 Internal shock detector

Partially tested during the NAOS project André et al. (2020). SignalQuest SQ-XLD shock based on acceleration measurements was used on a test float. Test trials were carried out in the Mediterranean Sea but since the sensor's results were too difficult to interpret, and were not further pursued. Moreover, as it is not recommended to touch ice, even briefly, the main goal should be to detect ice before contact to avert the risk of sticking.

3.2 Float actions after ice detection

Usually, once a float detected ice, it brakes and starts a new cycle. However, other float missions have been tested and implemented.

In Arvor-I floats and other NKE floats with ice detection, there are alternative behaviors, given by the parameters IC1 (Nb of day before surface emergence even with ice detected) and IC2 (Nb of detection to confirm Ice at surface) (see section 8.1). IC1 is to program the float to ascend, ignoring any ice detection, after a certain time period has expired. In case the ISA or one the other tests has prevent the float too long to ascend to the surface and the float might be lost anyway, so this emergency ascend would allow a risky but final chance to get back in touch with the float. IC2 is to request the float to confirm the absence of sea ice at the surface by requiring the float to have a certain number of negative ice detection tests before allowing the float to surface (parameter IC2).

Researchers from Woods Hole tested a float behavior that would allow the floats to surface in ice-covered waters to transmit data (Nevala (2005)). The float was programmed to sink to a shallower depth and then bounce again and again under the ice until it eventually founds an ice-free area, or a narrow crack (lead) between sea ice floes. The 'bouncing' against the underside of the ice could be repeated up to 100 times. The three experimental floats, had a modified antenna made of hard polyurethane that can withstand repeated impacts against the hard underside of sea ice (Fig. 13). The floats were deployed in summer 2006 during a seven-week cruise across the Arctic Ocean on boar the Swedish icebreaker Oden. Unfortunately, the floats were short-lived and contact was lost shortly after deployment, thus no data is available for evaluating the performance of this strategy.

A similar feature is available in the IceApex floats (Teledyne Webb) used by the Alfred Wegner Institute (AWI,Germany) in the Weddell Sea. This "Pok-em-on" option also allows repeated attempts to surface at the end of a cycle to try to find a gap in sea-ice cover. If the Pok-em-on option is on, after a failed attempt of surfacing, the float descents ΔP, drifts for Δt and retries to surface up to k times. The default configurations for these parameters are 100 dbar, 30 minutes and 12 times.

3.3 Other Ice Avoidance components

3.3.1 Seasonal configurations

Few experiences so far have shown that considering the seasonality of the ice climate might be beneficial in the float mission parameters. French floats operating in the Arctic, using a different GPS timeout depending on whether the ice detection is activated (5 min) or not (45 min).

Klatt et al. (2007) observed that the seasonal stratification played a role in the vertical ascend of the float. They also noted that the ISA performed better in autumn before ice starts to form and conditions were more homogeneous. Conversely, the performance was less consistent in spring. It was suggested

Figure 13: Float with hardened antenna deployed in Arctic from Nevala (2005)

to include an additional rule in spring and ask for one or more consequent ascents without triggered ice avoidance to allow the float to ascend to the surface.

As in most cases, changing the float configuration for the under-ice season requires sending the new parameters via Iridium. But sometimes the deployment opportunities are late in the open-water season and in such cases it is not certain if the float would be able to surface before being trapped under the ice. A solution for Arvor-I floats, but only for mission parameters (not ice avoidance parameters), is to make use of the two mission settings available and set the first mission with the desired open water parameters and a small number of cycles, and the second mission with the under-ice parameters.

3.3.2 Protection cages

Even with ice avoidance implemented, the floats may encounter ice occasionally and some floats have been modified to withstand them.

Cylindrical cages around the antenna, CTD and other sensors, have been used to protect the upper part of the float, which is the most sensitive part of the float. André et al. (2020) reported that there was no clear indication of the benefit of cages in the Baffin Bay (see Fig. 10). A cage may protect the antenna but had several points that could get caught under the ice, creating the risk of 'hanging', and was associated with increased power consumption due to the additional oil volume required for the ascent.

4 Other aspects of under-ice operation

4.1 On-board memory

A float planned to be deployed in icy conditions will likely be blocked from communications for several months. For this reason, it will need internal memory to store the measurements for the whole period, which depends on the mission configuration. This feature is currently available in most of the floats, and it prevents the loss of data due to problems with the satellite communication in the entire globe. The available memory for Iridium floats using the Short Burst Data (SBD) service, like the Arvor-I floats (NKE) operating in the Nansen Basin (Argo Germany), is expressed in SBD packets. NKE provides a spreadsheet to facilitate the calculations of memory consumption per cycle. The memory allocation for Arvor-I floats is described in the following. The amount of data generated in each (core) float cycle depends on the number of CTD measurements generated during the profiling and drift phases, which in turn depends on the mission configuration parameters. The determining parameters regarding the profiling phase are the thickness of the sampling layers, and the vertical resolution of the measurements. For the drifting phase, the drift sampling period and the cycle length determine the number of CTD measurements. Moreover, hydraulic and technical information is also generated for each cycle. Therefore, to calculate the memory used to store all the under-ice measurements, one multiplies the number of cycles the float is expected to complete under-ice by the memory needed per cycle. Different profile resolutions should be calculated so that the float operator may select the most suitable option (enough memory for the entire ice winter) and timely transmit it to the float before it goes under ice. For example, the CTD vertical sampling scheme could be reduced to collect less data but allowing to store all the profiles. Similar calculations are possible for all models and Iridium services. Floats using the Iridium RUDICS (Router Based Unrestricted Digital Internetworking Connectivity Solution) service, like Provor CTS4 and CTS5, use more usual computational units (Kbs) for such calculations.

There have been recent improvements in the memory capacity of Apex (Teledyne) and Arvor-I (NKE) floats making the memory calculations a less pressing issue during the deployment preparation. The Apex floats currently have 16 GB on-board memory, which is theoretically enough for over thousand profiles. In the latest generation of Arvor floats (Iridium SBD), the memory allocated has been increased from 1000 to 2400 SBD packets. Assuming a standard configuration [1] an Arvor-I float generates a total of 16 packets per cycle: 9 packets from CDT measurements and 7 more packets of technical, hydraulic, settings information. So, the last-generation of Arvor-I floats could store a maximum of 160 profiles and could last more than 4 years (1600 days) without Iridium connection.

However, checking that enough memory is available is mandatory to avoid any data loss, specially when deploying older float models or with older firmware in the seasonal ice zones, when high resolution sampling schemes are being used and when other sensors are present (biogeochemical). Therefore, it is also advisable to use a longer under-ice season in the calculations to obtain a more conservative estimate of the necessary memory and battery. Moreover, the currents could take the float into the transpolar drift and prevent communication for even longer periods, since the float would need to come out of the permanent ice zone. In this case, a more conservative estimate of memory and battery could prevent the loss of very valuable data. If such drift towards the permanent ice zone is detected during the open water season, it is advisable to select a very long cycle length, for example 1 month, to save enough memory and battery until the float reaches a seasonal ice zone again.

4.2 Iridium communication

Since 2013, the large majority of the floats deployed use Iridium for transmission. As Iridium is two-way communication allows the operators to remotely change the float configuration parameters as needed. Besides the mission parameters that determine the memory usage under-ice and the ice avoidance

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[1] cycle: 10 days; drift pressure: 1000 db; profile pressure: 2000 db; CTD layer thickness and layer bottom limit: surface 1 db and 10 db, intermediate 10 db and 200 db, bottom 25 db and 2000 db; Drift sampling period: 12h

settings, it also allows the adjustment of technical parameters, such buoyancy regulation. An alternative to change the float configuration without the need of satellite communication has been developed by NKE during the NAOS project. The experimental deployments of their 15 BGC floats in the Baffin Bay, use script-based commands to modify the configuration parameters according to the date (André et al. (2020)).

Another advantage of Iridium is its fast transmission rate, that allows the transmission of high resolution profiles in a matter of minutes, minimising the risk of collision with sea ice while on the surface. Compared with the transmission times of 6 to 12 hrs needed with the previous technology (System Argos), this shorter surfacing time aids the ice avoidance efforts. Still, a timeout test for total time at surface is used in Iridium equipped IceApex floats (see 3.1.2), which also prevents large float drifts at the surface.

To better supply the services needing real-time data, top-of-stack transmission (profiles acquired at last are transmitted first) is preferred to queue (profiles are transmitted in order of acquisition).

Another important aspect when operating under-ice is that once a float is able to surface again it will transmit a larger amount of data than usual. This may cause important transmission costs depending on the data plan. Usually the under-ice data is transmitted in chunks, since surface timeout parameters are in place to avoid that the float spends to much time in the surface. Therefore a larger amount of data is expected to be transmitted during some cycles after the float reemergence.

4.3 Buoyancy

Strong stratification and haloclines are usually found near the surface in seasonal ice zones, due to the presence of fresher water in the surface, especially in the melting season. Therefore, ice-capable floats need to have enough capacity to change their volume to overcome the stratification. Therefore, it is important to interact with the manufacturer about the buoyancy capacity of the floats to be deployed in the Arctic and compare it with the typical stratification in the region. Calculations to estimate if a float can overcome a certain density gradient can be found in Riser et al. (2018). According to Bittig et al. (2019) and Riser et al. (2018) biogeochemical Navis floats (SeaBird) are not recommended for use in the Arctic, due to a lack of buoyancy range. Arvor-I floats have a large buoyancy engine which makes them able to operate in environments with strong haloclines. APEX floats have a smaller buoyancy range and need to be ballasted according to the target area. In the NAOS/Baffin Bay deployments the buoyancy of the floats has been adjusted, by adding syntactic foam, to achieve the theoretical density range of a Provor from 1000 to 1038 kg/m3 (Andre et al. 2020).

4.4 Geolocalisation

Profiles measured under ice lack a geolocalisation since the float was unable to surface and acquire a GPS or Iridium position. Currently, the default method for under ice position estimation is simple linear interpolation of the trajectory between the last point received before the under-ice period and the first one after it. The linear interpolation in latitude-longitude does not necessary equals to the shortest distance (great circle path) but it is easy to implement automatically, making it ideal for real-time processing, and good enough for regional applications. However, linear interpolation may yields trajectories that cross the continental shelf or land.

More refined interpolation methods have been proposed:

- Linear interpolation in potential vorticity (PV) coordinates Chamberlain et al. (2018)

  The flow at high latitudes is almost barotropic (unidirectional in the entire water column) and thus $PV \simeq fh_{-1}$, where f is the Coriolis parameter and h is the bottom depth. Therefore, the flow likely follows fh_{-1} contours, and the linear interpolation in this PV space is done using the along-PV and across-PV axis. They found the PV interpolated positions were better than linear interpolation for their dataset in the Weddell Gyre. According to Yamazaki et al. (2020), the main limitations of this method are the necessity of computationally deriving PV axes to do the interpolation, and that the method is not able to interpolate the positions in some cross-isobath trajectories.

- Bathymetry constrained interpolation using profiles depth from floats groundings (Wallace et al. (2020))

  Experiences in the Adélie Land shelf have shown that while being close to the coast a parking depth at the bottom can give additional guidance towards interpolated positions. So while the float is still in the vicinity of the coast and in water depth less than 2000m a strategy of ”park-on-bottom” can be implemented, by using a deep parking depth. The authors proposed a method in which the bathymetry measured by the float (grounding depth) is used to constrain the possible under-ice positions. The algorithm found the shortest path between known profile locations such that the bottom depths measured by the float while parking match the known bathymetry. The algorithm works simultaneously forward from the last position before the ice season and backwards from the first position after the ice season, finding the regions of matching bathymetry using a searching radius given by an assumed float speed multiplied by the time difference between profiles. Both forward and backward paths must meet in the middle, which discards many possible paths. The algorithm is run iteratively using a range of possible speeds until the shortest path is found. This method yields trajectories with better accuracy than those obtained linearly interpolated positions. However it works well only in regions where the bathymetry is well known and variable.

  Although the authors reported that the floats ”can survive multiple encounters with the seafloor” in their shelf region, the increased risk of hull damage, along with the impact of this strategy in the energy budget, should be considered when deployments in other the regions are planned.

- Bathymetry following interpolation Yamazaki et al. (2020)

  This method interpolates missing (under ice) positions following the bathymetry contours and performs best on the continental margins because the flow there predominantly follows the isobaths. This scheme linearly interpolates the water depth (instead of the distance) between the two points available positions, thus avoiding unrealistic positions above land. This method is currently used in in the context of the Workpackage 5 of the Euro-Argo RISE project. The Python code for its implementation has been shared by the authors on the EuroArgoDev Github collaborative platform `https://github.com/euroargodev/terrain-following`. The code also offers the option to include float grounding depth information to improve the estimations, when the parking at the bottom strategy is being used or due to unexpected groundings.

  In Figure 14 below, the output of the terrain-following code is shown, for float 7900549 which was deployed by the German national program in the Sophia Basin. The float went under ice for an extended period and surfaced 8 month later in the Laptev Sea. The linearly interpolated positions result in an artificial track of the float over land. The terrain-following interpolation shows a more plausible trajectory along the continental slope while the float is drifting in the boundary currents.

In the Weddell Gyre underwater estimation of float locations can be performed since an array of underwater sound source exists and floats are equipped with RAFOS antenna. No such system exists in the Arctic ocean and the performance of such an array would need to be evaluated first. So far only APEX floats have implemented a RAFOS antenna. The principle of the geolocalisation with the RAFOS method and the data processing are presented in Klatt et al. (2007).

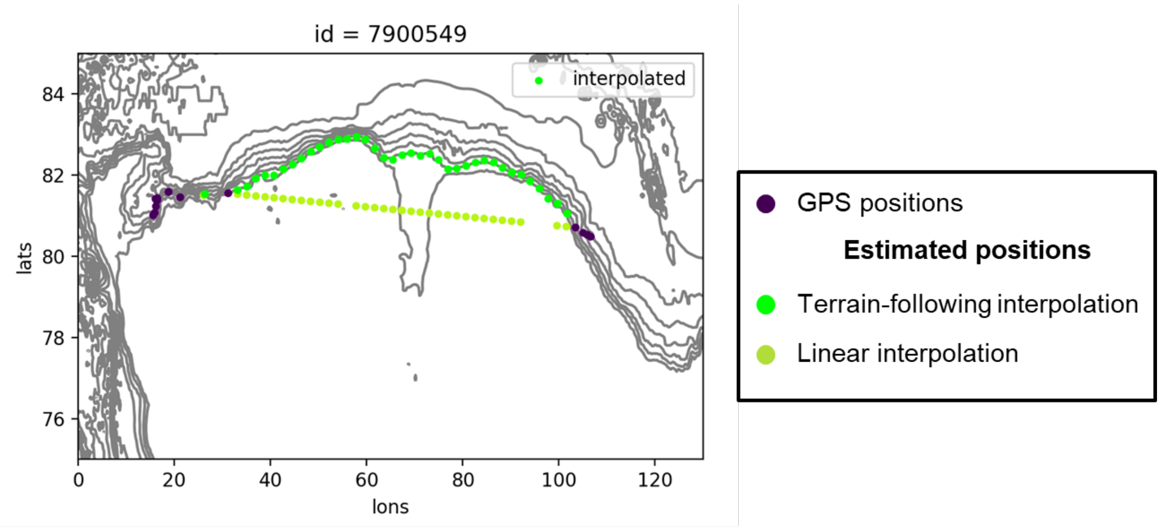


Figure 14: Positions of open water and under ice profiles for float WMO 790 0549. Under ice positions were estimated with the Yamazaki et al. (2020) code

5 Case studies

The recent progress in the Northern Hemisphere has been possible thanks to pilot projects aiming to test and further develop under ice technologies for Argo floats or to study specific oceanographic processes. In this section, we present several case studies of float deployments in different seasonally ice covered regions in the Arctic Ocean, as well as one in the Baltic Sea, on which Euro-Argo partners were involved.

Some United States projects are noteworthy. In the Arctic, the Arctic Heat Open Science Project (`https://www.pmel.noaa.gov/arctic-heat/`) made aerial deployments of MRV ALAMO (Air-Launched Autonomous Micro-Observer) floats in the Chukchi Sea (2016). Results of this project were reported on Wood et al. (2018). The main lesson learned for air deployed floats, was that the water-soluble materials parachute used to secure the package dissolved too slowly in cold water. This caused that the parachute stay attached for some days leading to large energy consumption, due to the weight and drag. The Stratified Ocean Dynamics in the Arctic (SODA) also deployed MRV ALAMO floats in the Beaufort Gyre `https://apl.uw.edu/project/project.php?id=soda`.In the Southern Ocean, the Southern Ocean Carbon and Climate Observations and Modeling project (SOCCOM) funded by the United States

National Science Foundation, is currently responsible for the operation of the largest fleet of ice capable floats (`https://soccom.princeton.edu/`). A technical paper describing the floats capabilities is available (Riser et al. (2018)). The floats are programmed to start a new cycle after detecting ice and the ISA parameters used for ice detection: T_{ice}: 1.788C, P_1:50 db P_2:20 db. The floats collect data to within a range of 5–25 meters below the sea surface when under ice.

In the following case studies, we present the ice avoidance strategies and the decision process behind their use, as well as some recommendations for the Argo floats operation in these regions.

5.1 Baffin Bay

The NAOS project (Novel Argo Observing System) in the Baffin Bay had significant legacy for the expansion of the Argo Program to the Arctic Ocean. The technical paper André et al. (2020) provides detailed information about the operation on seasonal sea ice regions and the testing of new hardware and float prototypes. The main achievements are: a systematic approach to the ISA local tuning (see section 3.1.3), the exploration of three hardware based ice detection methods (altimeter, optical and internal shock detector, see section 3.1.5), and the test of a new float prototype.

The Pro-Ice float tested in the Baffin Bay was a prototype of the Provor CTS5 carrying BGC sensors. With its large reserve of buoyancy, the Provor is particularly well suited to polar areas with a high-density gradient. The float carries two boards, one of which is dedicated to the sensors 'Payload acquisition board' and the other to the operation of the float 'navigation board'. The new electronics of the CTS5 are also particularly effective for under-ice navigation thanks to their data storage capabilities and fast telemetry. A commercial version of the prototype, the Provor CTS5 is now available from the manufacturer NKE.

The WMO Numbers and performance of floats in the Baffin Bay are summarized in Fig. 16.

ISA local tuning

The water masses in Baffin Bay are very different from those in the Antarctic with larger freshwater inlets. These characteristics required a local tuning of the ISA. It was based on 1396 CTD profiles from Pro-Ice floats deployed in Baffin Bay (Fig. 16) were combined with a Sea Ice Concentration (SIC) estimated from the Advanced Microwave Scanning Radiometer 2 (AMSR2). A SIC threshold of 10% was used to decide if the area was ice-covered and a positive outcome of the ISA test should be expected. For each CTD profile, the median temperature was processed for two depth ranges: the historical one between 50 and 20 dbar and a new one between 30 and 10 dbars. Then, four probabilities were calculated depending on the ISA threshold: no ice (SIC < 10%) with a negative ISA, no ice with a positive ISA, ice (SIC > 10%) with a positive ISA, and finally ice with a negative ISA (Fig. 15). The Optimal ISA parametrisation will minimize the two wrong results: ice with a negative ISA and no ice with a positive ISA. The selected parameters were T_{ice}: -1.3 C, P_1:30 db P_2:10. These parameters allow for probabilities of 3.5% for the most dangerous scenario – ice is present but not detected by ISA –, and 8.4% for the no ice present but ISA triggered scenario. The pressure range used for the Antarctic would have resulted inn an equivalent probability of 3.5% for the first case but 45% for the second.

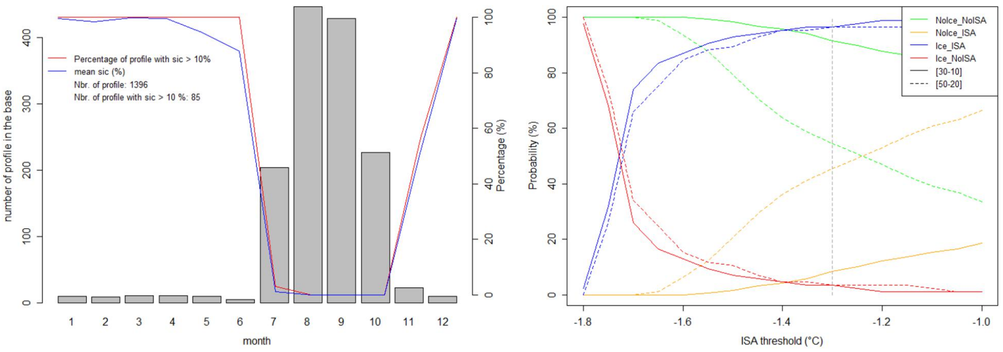


Figure 15: from André et al. (2020)

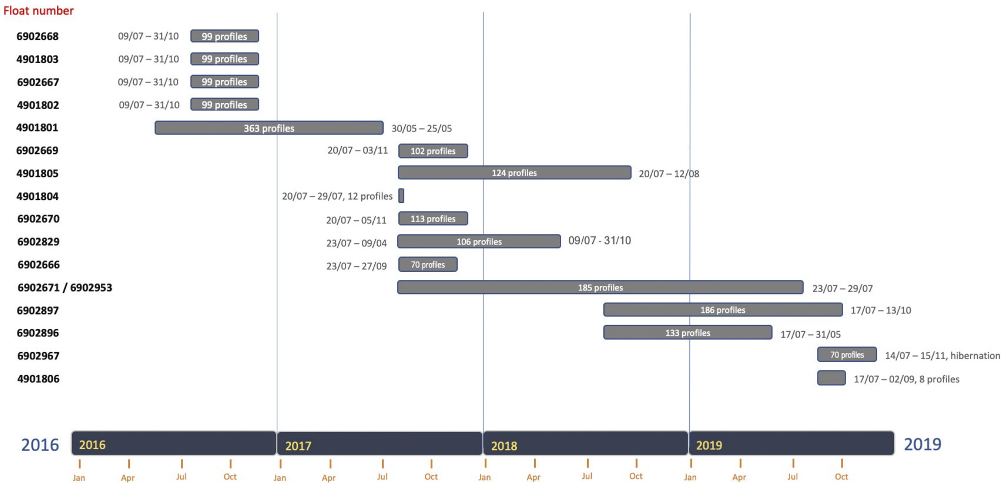


Figure 16: from Le Traon et al. (2020): WMO Numbers and performance of floats in the Baffin Bay

5.2 Baltic Sea

The floats deployed on the Baltic Sea are certain to end up in ice free zone after winter, as the Baltic Sea has only a seasonal ice cover. This combined with the small area, and relatively easy retrieval, makes it a good candidate for experimenting with ISA algorithms. Northern parts of Baltic Sea (Bothnian Sea and Bothnian Bay) have had floats with ISA algorithms since 2016 (table 2, Figure 17).

First deployments on the Bothnian Sea were by the FMI to test the Ice Sensing Algorithm (ISA) time constraints, the manually set months, in which the algorithm is active. The ice detection temperature was set to 2.2 °C, high enough to make sure it will trigger during the set ISA active months. From these experiences we could see how the actual detection process worked out, and could further determine the values used for actual ice detection missions.

Float 6902023 winter 2016-2017 deployed on the Bothnian Sea drifted successfully under ice from February to April.

The next winter, 2017-2018 there were three floats with ISA algorithm testing. The missions are listed on table 2. On winter 2019-2020 there was an Arvor-I type float with ISA algorithm in testing, but id did not encounter icy conditions during it's mission. The float was experiencing issues on sur-

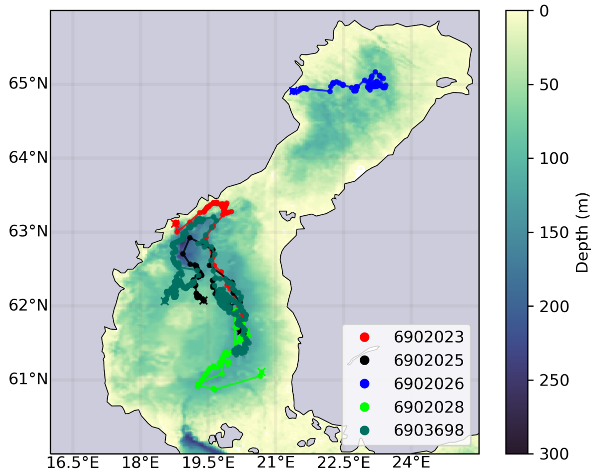


Figure 17: Missions trajectories considered in the Baltic Sea

facing during the autumn. This stopped the ascent several times before the surface. The reason for this behaviour, as determined after discussions with NKE, was that the 'ascent hanging' feature of the float might have activated. The feature stops the ascent of the float in 10 m depth, if it deems that the ascent has been too slow. In the Baltic Sea this can happen due strong haloclines which can in some cases throw the algorithm off. This was remedied by lengthening the timeout period (CONFIG_IceDetectionNoVerticalMotionTimeOut_csec) from 80 seconds to 100 seconds, which seemed to help for this float.

WMO	**Deployed**	**Recovered**	**Months under ice**	**Area**	**Notes**
6902023	2016-07-13	2018-01-25	≈6	Bothnian Sea	stuck on bottom too
6902025	2017-05-04	2018-10-02	<1	Bothnian Sea	
6902026	2017-06-06	2019-06-02	4 + 3	Bothnian Bay	two winters, first also stuck on bottom
6902028	2017-08-07	2018-09-04	≈2	Bothnian Sea	
6903698	2019-05-30	2021-09-25	-	Bothnian Sea	Arvor, no ice encountered

Table 2: Baltic Sea ISA missions considered

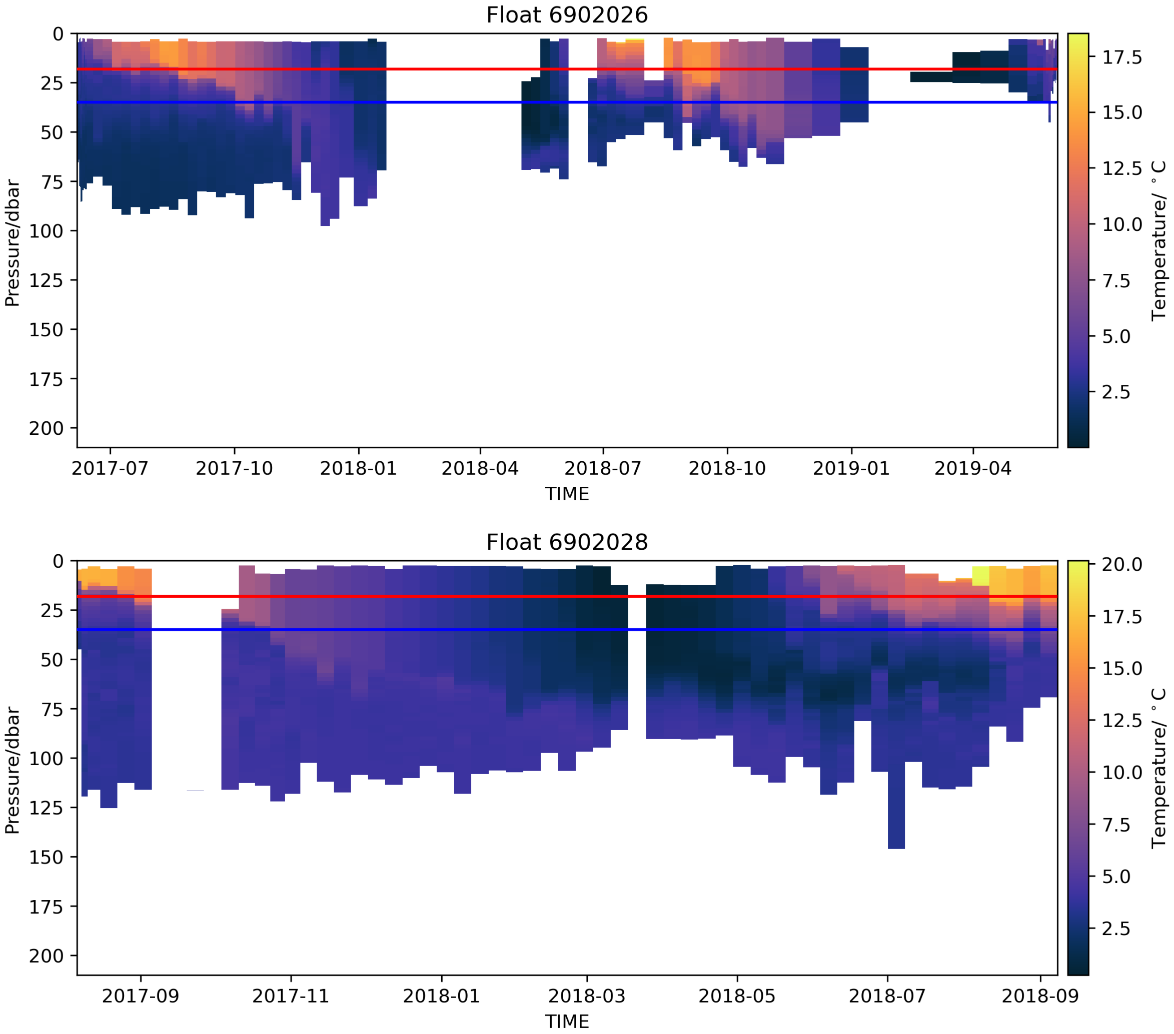


Figure 18: Upper figure: Float WMO 6902026 temperature measurements. In addition to ice, this float operated on very shallow areas. In winter 2018 it got stuck to the bottom in addition to under ice, so very little profiles were acquired. Lower figure: float WMO 6902028 temperature measurements. The float got stuck on the bottom for two months on autumn 2017. For winter 2018 it remained successfully two months under ice measuring. Blue lines indicates the depth where evaluation of the temperature starts, red lines indicates the pressure where ISA activates.

Recommendations

ISA can, and should be turned off during summer months (at least from May to October) completely. Trigger temperature varies with the salinity of the target area, this is indicated in table 3. In the Gulf of Bothnia, especially in the Bothnian Bay, floats that operate throughout the year will need an ISA, or have considerable risk of being lost prematurely.

During most winters nowadays the ice does not reach the Baltic proper. As such floats can be operated there even without an ISA algorithm, however it is advisable to have the option to apply one in case of a harsh winters. FMI has adopted the practice to have the ISA algorithm turned off (IceMonths = 0x00 on Apex floats, ICE_ISA_TEMP_THRESHOLD = -1790 on Arvor floats) unless the forecasts project for exceptionally harsh winter.

Bothnian Bay and Bothnian Sea deployments easily drift on very shallow areas, and such have a risk of hitting the bottom and getting stuck in addition to the ice collisions. For this reason, it is good to monitor the floats on the area frequently and adjust float diving depth and ISA activation manually when possible.

Parameter	Value	Notes
Ice detection pressure	35	
Ice evasion pressure	18	
Temperature	+0.2 – +0.4 °C	
Ice months	none to Nov - Apr	

Table 3: Baltic Sea ISA recommendations for APEX floats. The optimal trigger temperature varies with the salinity. +0.2 °C was used in the Gulf of Bothnia Area, +0.4 °C on the Baltic Proper.

5.3 Barents Sea

First experiment by FMI on Barents sea started on 28.9.2018 with a float deployment at 78° N, 30° E. In preparation for this deployment an ISA local tuning was performed at BSH.

ISA tuning

The ISA local tuning for the Barents Sea is described in Latarius and Klein (2018) and was developed as part of the MOCCA project, as mentioned in section 3.1.3. Some details about the data and the test is given below:

- Hydrographic profiles: Profiles between 74 °N and 80°N, and between 16 °E to 40 °E collected between 2006 to 2015 were extracted from the Unified Database for Arctic and Subarctic Hydrography (UDASH) published in PANGAEA and described in Behrendt et al. (2018). A total of 2439 profiles, all but 16 profiles correspond to by ship-based CTDs. The profiles near the coast and in the fjords of Svalbard were then removed leaving a total of 2022 profiles. These profiles were not representative of the float operation region due to their extreme fresh water surface layer.

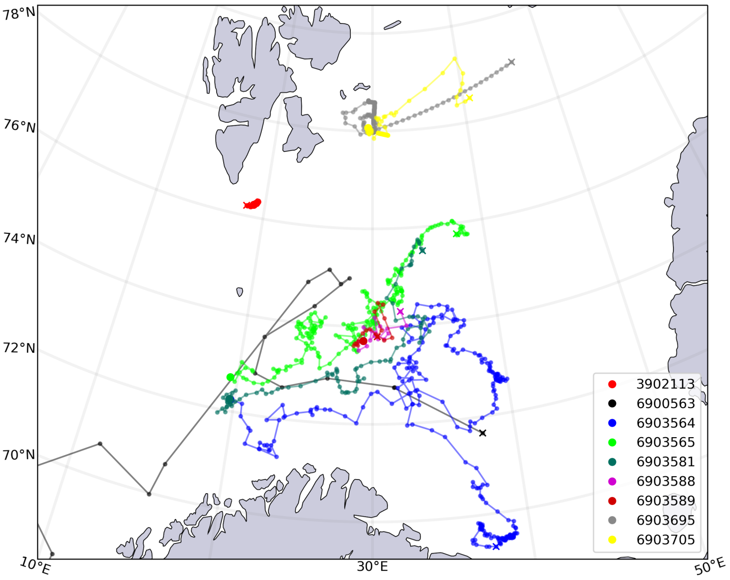


Figure 19: Argo floats in the Barents Sea for the Euro-Argo RISE partners. WMO 3902113 (IOPAN), WMO 6900563 (BSH), WMOs 6903564, 6903565, 6903581, 6903588, 6903589 (IMR, Norway) and WMOs 3903695 and 3903705 (FMI)

- Ice coverage: The Multisensor Analyzed Sea Ice Extent - Northern Hemisphere shapefiles (MASIE-NH) were used to establish if the profiles 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 and result from a manual fusion of satellite data, operational sea ice charts and other sources. The dataset was selected because it was expected to provide a more accurate ice edge than the sea ice satellite data alone.

- Data for ISA tuning: Only approximately 2 % of the hydrographic profiles (38) were taken in ice-covered regions and 10% within 50 km distance to the ice edge (186) , but most of the profiles are from open water. Most measurements are taken during the retreat of the ice coverage in spring. From these profiles, only those with data down to 100 db were used for the ISA analysis. The analysis was done using three different time spans: January to April, May, to September and October to December. Distinct characteristics of ice and near-ice profiles were found. On the basis of these characteristics an ISA was suggested for the Barents Sea and compared to the ISA for the Weddell Sea. The chosen parameters were: $P_1 = 20$, $P_2 = 10$, and $T_{ice} = -1$°C.

- Other tests: In the Arctic 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. The use of the minimum temperature instead of the median temperature for ISA was also tested, although this method is not yet implemented in the ISA software. It would have the advantage of being independent of the layer thickness and resulted in similar probability errors. In the field, the computation of the minimum temperature is done on the raw data, while the ISA tests used quality controlled data. The use of a minimum value can lead to wrong detections, because the raw data might include spikes, but it could be considered in the future, if some pre-processing could be included. The authors also tested salinity and density as indicators of the presence or absence of sea ice, but no useful relationship was observed.

Float operation

WMO	Deployed	last profile	Months under ice	Area	Notes
6903695	2018-09-28	2020-09-28	8 + 8	Barents Sea	two winters
6903705	2020-10-14	2021-11-02	7	Barents Sea	ongoing

Table 4: Barents Sea ISA missions considered

The Apex float used for this test had controller version apf11, In contrast to apf-9 in the floats operated in the Baltic Sea. Before the risk of the ice cover, we changed the ISA trigger temperature temporally from the intended -1.0 °C to -1.4 °C to ensure it won't trigger for as long as the conditions looked safe, based on satellite observations. This gave us possibilities to check the operation of the algorithm until the approach of winter conditions and fine tune the final setup. This is an example of manual piloting sometimes needed (Angel-Benavides et al. (2020)), especially when operating in new areas: changing the profiling period, diving depths or ice avoidance parameters manually based on earlier profiles gives the opportunity to keep the mission going, while looking for optimal parametrisation for the area.

The new version of the controller did have some changes, which were not optimal for the ice avoidance, most notably the priority of the ice detection sampling processing was lowered, which could cause the ISA analysis being delayed by other processes, and thus react too slowly. The discussions with Teledyne Webb personnel have been fruitful, and this issue should be remedied in new versions. However, the slow brake of the float made necessary a change of the pressure range used for the ISA evaluation (see Table 5).

Recommendations

Parameter	Value	Notes
Ice detection pressure	35	
Ice evasion pressure	17	
Temperature	-1.0 °C	-1.5 °C at deployment
Ice months	all	start with deployment months disabled

Table 5: Parameters used and recommended for Apex type floats operating east from Svalbard. Deployments were made with lower trigger temperature and with start months disabled for ISA. First profiles can be used to check that everything works without risk of losing float by too sensitive ISA parameters.

5.4 East Greenland Current

An analysis of the historical sampling in the East Greenland current (EGC) was performed in WP2 and is detailed in the report D2.3 'A European strategy plan with regard to the Argo extension in WBC and other boundary regions'(Euro-Argo-RISE (2020)). A total of 53 floats had sampled the EGC area (see 5 for definition) by the end of 2020. Most of the floats drifted into the boundary current area only for a few cycles and only a few of them were deployed in the EGC close to the shelf. Since ice coverage in the Nordic Seas is restricted to the shelf region east of Greenland (20) and the deep basins are ice free, the use of ISA has only recently received attention and the majority of floats deployed after 2009 did not use ISA.

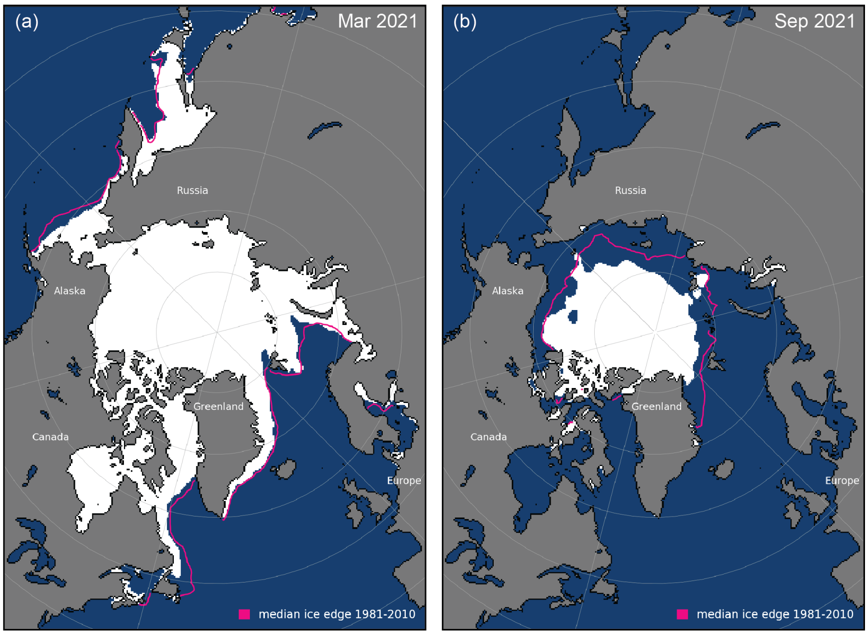


Figure 20: Seasonal ice extent at the time of maximum ice extend (left) and minimum ice extend (right) in 2021. The magenta line indicates the long term mean (1981-2010). from https://arctic.noaa.gov/Report-Card/Report-Card-2021/ArtMID/8022/ArticleID/945/Sea-Ice

As can be seen in Fig. 20 the seasonal cycle of sea ice in the EGC is characterized by a maximum annual extent in March, decreasing through spring and summer to an annual minimum extent in September. Sea ice extent defined as the total area covered by at least 15 percent ice concentration (Fig. 20) shows long-term seasonal means in magenta together with the actual situations from 2021.

As can be seen on Fig. 20 the seasonal minimum ice east of Greenland shows considerable less extend in 2021 than in the long-term mean. Summer 2021 was marked by general low pressure over the Arctic Ocean. This brought relatively cloudier conditions and divergent ice circulation that, along with the thicker Beaufort and Chukchi Seas ice, slowed the decline in ice extent. The summer circulation in 2021 also limited ice export through the Fram Strait, resulting in the unusual occurrence of a nearly ice-free East Greenland shelf during much of the summer. Please note that the long-term ice extend line coincides with the shelf edge (1000m contour).

Few of the floats deployed after 2009 had implemented an ISA, and those who did use widely different ISA settings. Only recently this has attracted renewed interest. During the French NAOS experiment Arvor-I floats were deployed close the shelf edge east of Greenland in 2017. Two of the floats (6902726 and 6902728) did drift within the EGC at the shelf edge, while 6902726 did mostly stay out of the shelf, 6902728 drifted onshore and eventually passed Denmark Strait into the Subpolar North Atlantic. These floats used modified ISA settings evaluating the median temperature at depth between 10-40 m and using a threshold of -1.6°C. The trajectory of both floats (Fig. 21) shows long stretches of straight lines and the quality flag for position indicates that they were indeed linearly interpolated. Although identify those profiles with missing satellite positions that were replaced by estimated ones (POSITION QC=8) is a good place to start if one is trying to identify which profiles were collected under ice, not all profiles with POSITION QC = 8 are necessarily under-ice profiles. In principle, satellite positions maybe missing because the float: 1) never reached the surface because ice was detected via ISA or pressure change timeout, 2) the float reached the surface but could not establish communication with the satellite (ice detected via satellite timeout), or 3) the float established communication but did not obtain a position fix.

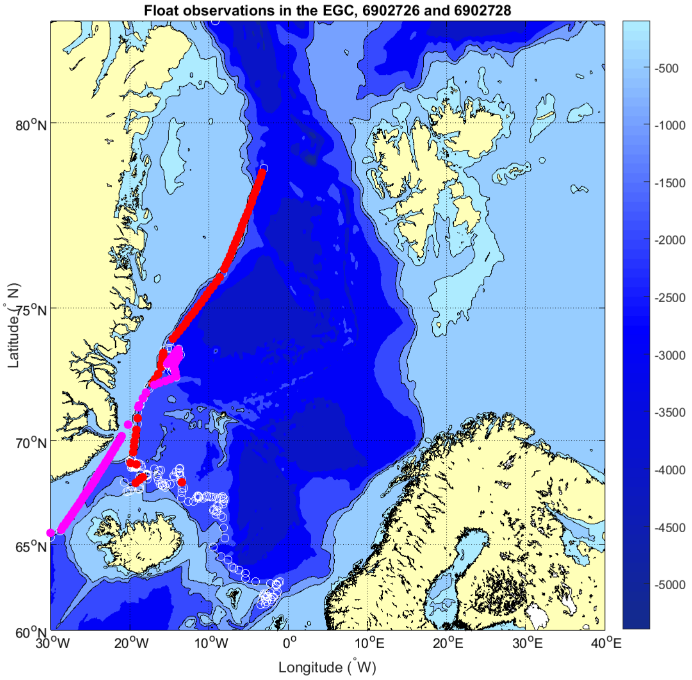


Figure 21: Trajectories of floats 6902726 (red) and 6902728 (magenta) deployed 2017 in the framework of NAOS. Full circles indicate that positions were linearly interpolated

As can be seen in Fig. 22 (left panel), the temperature profiles measured by float 6902726 varies over a wide range in the near surface layer. Cycles in which this float could surface and get in contact with the satellites are mostly warmer than -1.0 °C, the ISA T_ice parameter value used by some US floats in the area. Cycles flagged with POSITION QC = 8 are divided in those marked with (in red) and without an ice flag (in b lue). Some of the profiles without an ice flag stop at 10-5 below the surface, and it is unclear why the float stopped the ascent before reaching the surface but did not triggered any ice detection test. Similarly, the reason why some of the profiles without an ice flag (black) reached the surface, but did not obtained a satellite position is unclear. These issues deserve further investigation.

Most of the profiles with an ice detection flag (red profiles) didn't reach the surface. Ascend was either aborted by ISA (cycles 24-25, 29-30,35-37, 38, 44-47,49) or physically by pressure change timeout (cycles 3-7, 9, 11). On two occasions (cycles 26, 31) the communication timeout was triggered. It also becomes clear that in this area relying on ISA alone instead of the combination of the three test, would have led to a smaller number of ice detection. This is evident in Fig. 22 (left panel), where only a few of the temperature profiles pass through the green box, which represent the ISA parameters. All of the profiles in the green box are vertically homogeneous, but other profiles in this subgroup have a much more complex vertical structure with intrusions of warm water at the lower range of the ISA detection layer.

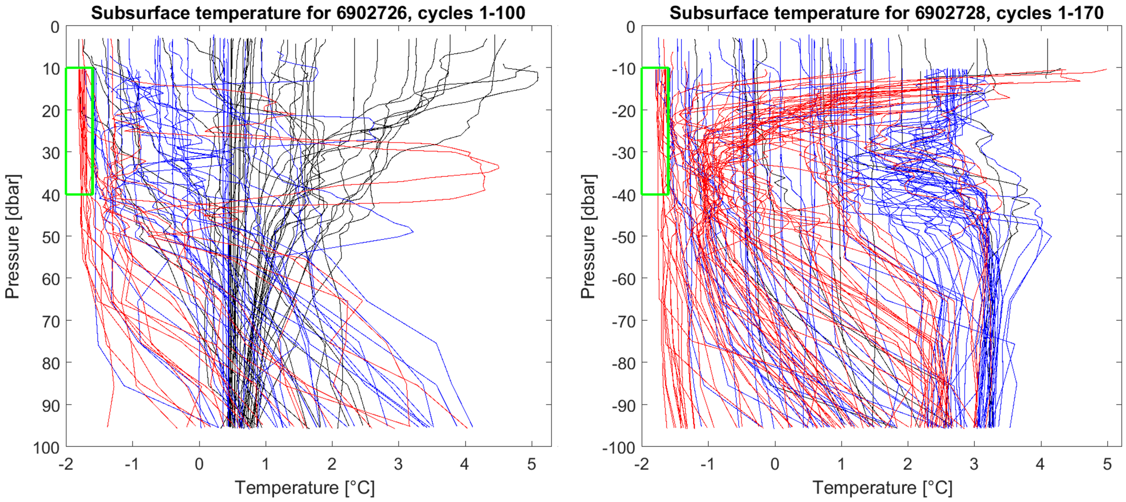


Figure 22: Upper 100 m temperatures for cycles 1-100 from float WMO 6902726 (left) and WMO 6902728 (right). All cycles with missing satellite position replaced by an estimated one (POSITION QC = 8) are plotted in: blue if no ice flag was triggered; and red if the ice flag was triggered. In black all profiles with satellite positions. The pressure range and temperature threshold for ISA is indicated by the green box.

The EGC float 6902728 sampled even more complex structures (Fig. 22, right panel). The majority of the cycles with POSITION QC = 8 have been plotted in red, indicating that they have an ice detection flag. Most of them have aborted ascend at 10 m (pressure change timeout in cycles 5-26, 32-33, 43-44, 136-154, 156, 158-160, 165-169, 175-176, 180, 184) and only few of them pass through the ISA detection box (cycles 85-87, 193, 123-126, 129-133). A large number of them show increasing temperatures up to 4°C in the top of the ISA detection layer. However, they aborted their ascent around 10 dbar, which must be due to pressure change timeouts. Another three cycles reported ice flag communication timeout (102, 131, 135). Similar "ascend hanging" around 10 dbar is seen in relatively warm waters of the profiles without an ice flag (in blue) , while a lower number of profiles reaches the surface, but still does not have a satellite position.

This observations will be taken into account when using the methods described in the next case study to recommend some ISA parameters for this region, as part of the Euro-Argo RISE project.

5.5 Nansen Basin

ISA tuning

The ISA local tuning for the Nansen Basin as described here was done in preparation for the deployment of Argo floats from the German National Program (BSH) in summer 2020 and to provide with adequate ice detection parameters for all Euro-Argo partners that operate floats in the region (e.g. Poland, France and Norway). The data used is described below.

- Hydrographic profiles: Profiles between 79 °N and 85°N, and between 5 °E to 50 °E collected between 2006 and 2020 were compiled from four public sources of CTD profiles: the Unified Database for Arctic and Subarctic Hydrography (UDASH) Behrendt et al. (2018), the International Council for the Exploration of the Sea (ICES), the Marine Mammals Exploring the Oceans Pole to Pole (MEOP) consortium (Treasure et al. (2017)) and the Argo float program. Since the UDASH database contains ICES profiles, only profiles acquired after the publication of UDASH were acquired. Only good profiles and good samples were kept. Profiles acquired directly from ICES, whose data set does not have quality flags, were visually inspected and no profiles were removed. Only profiles with maximum recording pressure deeper than 100 db were kept. The profiles collected over water depths shallower than 500 m (e.g. the Barents Sea and the coastal region) were removed, as well as those West of Svalbard over water depths deeper than 2000 m (Greenland Basin). A total of 1854 profiles satisfied the selection criteria.

- Ice coverage

  The Near Real Time (NRT, 10 km resolution) images from the Global Sea Ice Concentration data set from the EUMETSAT Ocean and Sea Ice Satellite Application Facility (OSI-SAF) were used to classify the CTD profiles according to the ice presence. For this end a Matlab toolbox was written and can be accessed in the EuroArgoDev Github (`https://github.com/euroargodev/seaice_profile`), which also calculates the distance to the nearest ice pixel. Profiles with sea ice concentration larger than 1% were considered as under-ice profiles.

- Data for ISA tuning

  The majority of profiles were acquired from UDASH (45.6 %), followed by MEOP (30.4 %), ICES (15.7 %) and ARGO (8.14 %). Most of the profiles (1463) were collected under ice, which is 79 % of the total. Most of those under ice data were collected by ice tethered platforms (ITP, 41.1 %) or by marine mammals (34.59 %), and only 4 % come from Argo floats. From the open water profiles, most of the profiles were obtained from ships (62 %), followed by Argo floats (23 %) and marine mammals (15 %). This distribution shows the importance of using a multi-platform data set to obtain enough data for ISA tuning.

  The ISA decision plot resulting from this data is shown in Fig. 8 and discussed in section 3.1.3. The chosen parameters for the deployments were: $P_1 = 30$, $P_2 = 10$, and $T_{ice} = -1.4$°C. The positions of the profiles used for the ISA development classified accordingly to their result for the ISA evaluation are shown in Fig. 23.

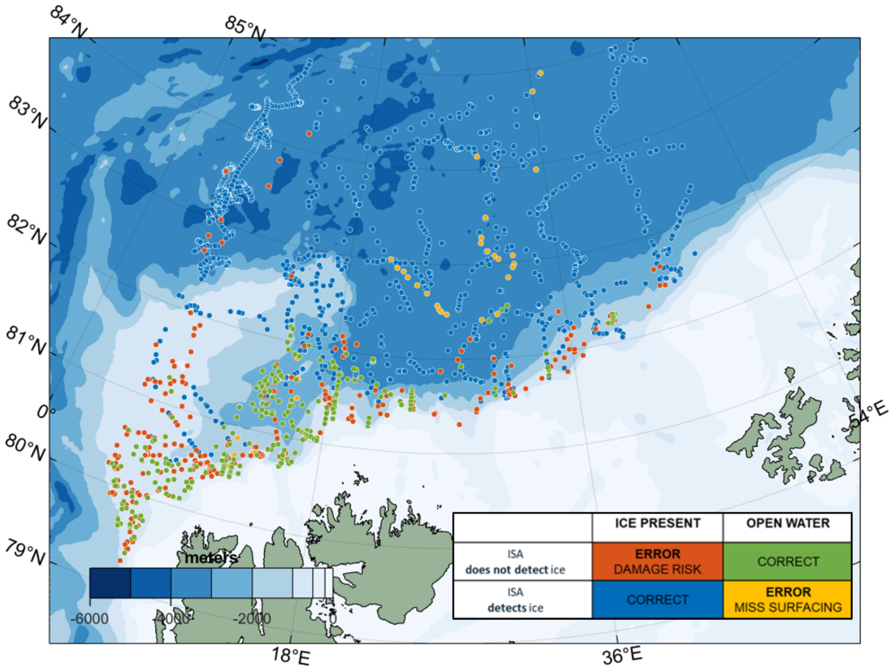


Figure 23: Profiles used for ISA development. The positions are color-coded according to the ISA result using $P_1 = 30$, $P_2 = 10$, and $T_{ice} = -1.4$°C.

Float operation: WMO6902729

This ARVOR-I float was initially deployed in the Nordic Seas (October 2017) by the French Naval Hydrographic and Oceanographic Service, SHOM (Service Hydrographique et Océanographique de la Marine) and then drifted to the region North of Svalbard and finally reached the Nansen Basin. The float survived two sea ice seasons there and sent data for the last time in October 2020. As contribution to the preparation of the German Deployment in the region, the French operators (Noé Poffa, IFREMER and Camille Daubord, SHOM) reported the following:

- The ISA configurations used for this float were: $P_1 = 30$, $P_2 = 10$, and $T_{ice} = -1.4$°C. The ISA works well under closed ice (100%) ice concentration since the underlying temperature mixed layer is usually deeper than 50 m. The ISA performance is worse with lower ice concentrations since the temperature mixed layer is usually shallower than 40 m. Moreover, sometimes there is no clear T mixed layer.

- The ice detection through the communication timeout (“satellite mask” in Fig. 24 was mostly associated with T(0-20m)<-1.6°C but T(<20m)>-1.6°C). Given the large number of occasions in which the ice was detected through this test instead of ISA, one could infer that these case does not imply less protection of the float, since the float survived two winters with this configuration.

- Many cycles under ice (135 to 172, and 236 to 286) went missing due to lack of memory. The float was operating in a 3 day cycle during the summer of 2018 and it went under ice before receiving the winter configuration (7 day cycle). This could be avoided with closer monitoring of the ice

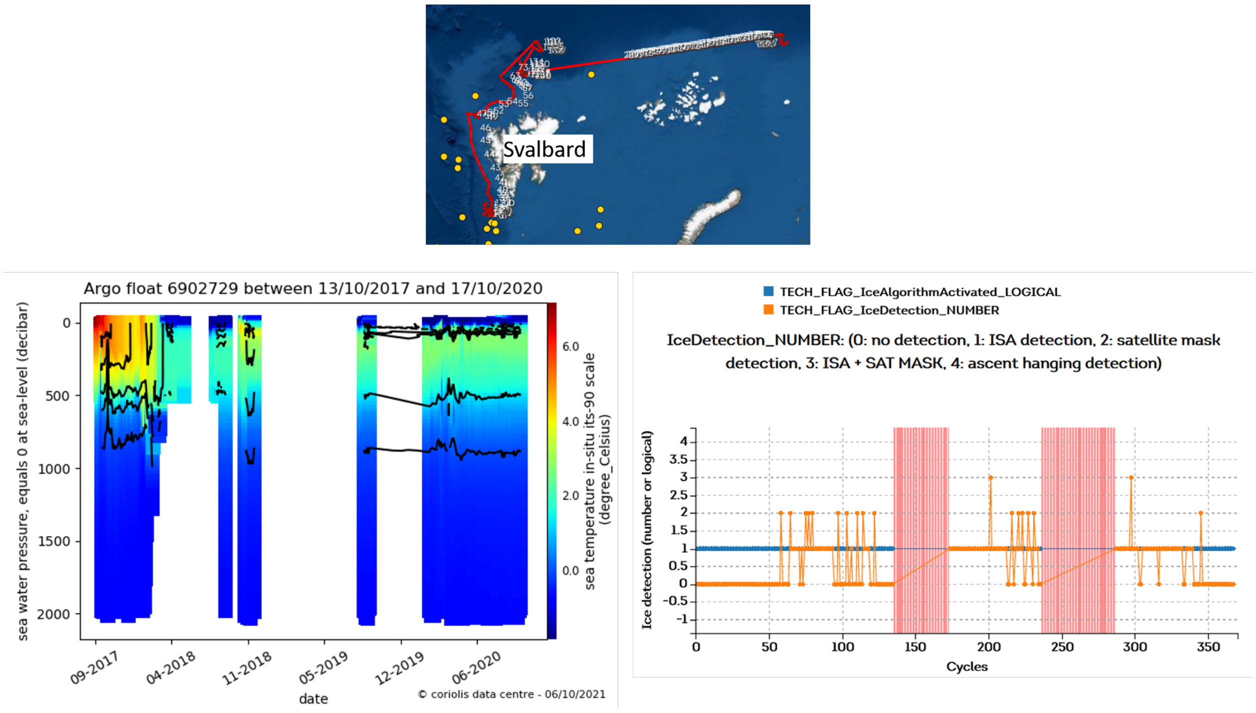


Figure 24: Float WMO6902729 data from the Euro-Argo Fleet Monitoring website. In the upper panel the float trajectory. In the lower panel: the temperature profiles showing the missing data due to lack of memory (left) and the ice detection technical information (right)

conditions.

The ice detection timeout were increased to avoid false detections: the pressure change timeout (IC12) was increased to 80 minutes, and the GPS communication timeout (IC10) was increased to 15 minutes.

- Two technical parameters were also modified from their default configuration to ensure proper vertical displacement. The nominal duration of pump activation in emergence (TC4) was increased to 2800 cs to ensure proper emergence. And the grounding criteria: cumulative volume (TC10) was increased to 100 cm3 to avoid getting stuck at the surface while diving in cold water.

Float operation: WMO7900549

The BSH Arvor-I Float 7900549 was deployed on 02.10.2020 in the Sophia Basin (North of Svalbard) and went under ice shortly after 20.11.2020. During this first ice free period, the IC1 parameter (Nb of day before surface emergence even with ice detected) was sometimes set to the same value as the cycle length (parameter MC2). In this way, the ice detection data was, but the float would try to reach the surface even if ice was being (erroneously) detected. The float surfaced again on 20.08.2021. The float drifted eastward with the boundary current from the Sophia basin to become the first Argo Float to cross the Kara Sea into the Laptev Sea (Fig. 25). The float measured under ice for 9 months and 34 profiles were stored on the float (one profile per week). The temperature section shown in Fig. 26 shows an abrupt change of hydrographic parameters in the Laptev sea. All the changes in the technical parameters and ice detection timeout tests recommended by the French operators were implemented. The locally tuned ISA, worked appropriately allowing the survival of the float under the ice. The ISA ice detection flag was the only one that was reported by the float. The under-ice positions were estimated via terrain-following interpolation (Yamazaki et al. (2020) see section 4.4). After surfacing the float received altered mission configurations with profiling once every 2 days (almost stationary) and then every 3 days. Despite close monitoring of the sea ice conditions during summer 2021, the float did not received its winter mission configuration (7 days) before going under the ice. However, this should not result in lost of data since the float has the latest firmware and enough memory to store data over more than 9 months of sea ice coverage.

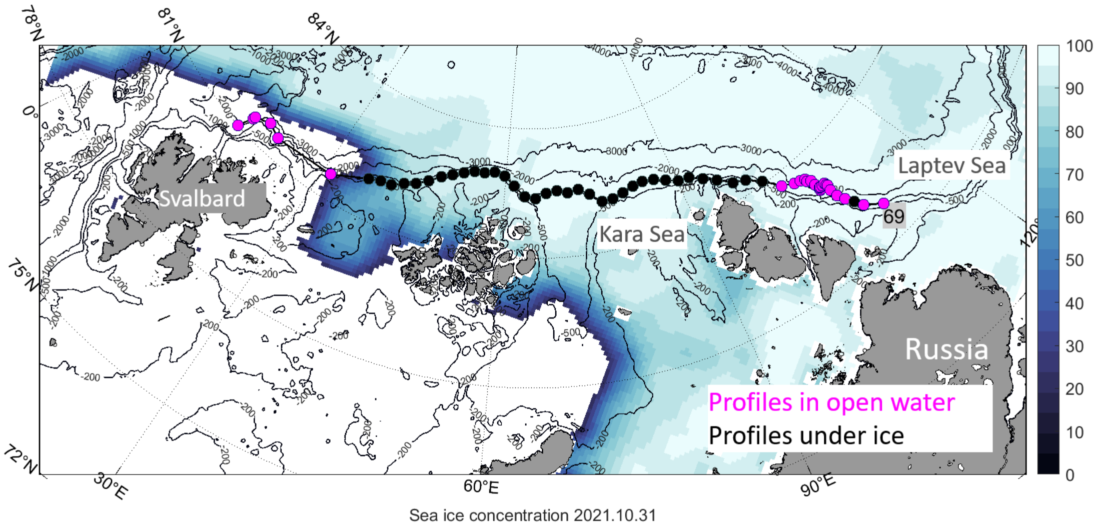


Figure 25: Float WMO7900549 trajectory: from Sophia basin to Laptev sea

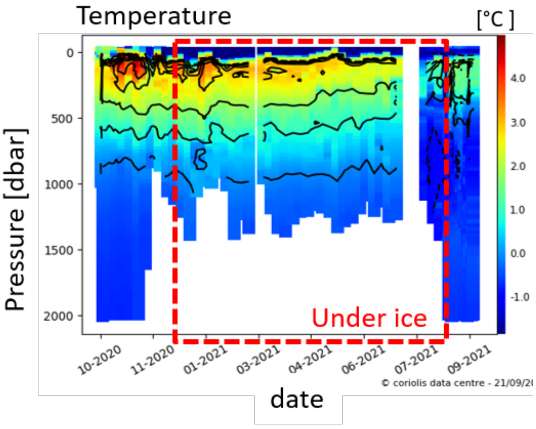


Figure 26: Temperature section from float WMO7900549

6 Conclusions

A form of ice avoidance is required for meaningful Argo operations in the Arctic. The software-based ice sensing algorithm (ISA) and the auxiliary pressure change and communication timeout tests, are the preferred methods over the hardware based approaches. Software-based ice detection algorithms are available for several float models, are more economical and have been tested out in several missions in comparison to hardware options. This can change in the future, as the hardware based approaches develop further.

The ISA algorithm works well in the Arctic, but it requires careful tuning to suit specific areas of operation. On the other hand, some floats that operated in the East Greenland Current and the Nansen Basin without a properly tuned ISA, have shown that the timeout tests may provide appropriate protection for the floats operating under the ice. Therefore, all three detection methods are important for the operation in the Arctic, since they complement each other, and should be carefully configured. This process benefits largely if the tools to evaluate the success of the ice avoiding strategies are easily available, as well as information about the parameters, performances and experiences of previous Argo missions in the area of interest. Moreover, when doing first deployments on a certain area, it is good practice to test the float operation before the ice winter, to ensure to the best of abilities the functionality of the float as well as the ice detection parameterisation.

Further investigation about the performance of the ice detection methods in different regions, as well as survival rates analysis, would be helpful to progress with the expansion of the Argo array in the northern high latitudes. Here we focused on experiences from a few floats, but many more floats have operated in the Arctic. However, the data required for such studies is not easily available. In the OceanOps platform, a search for Iridium Argo floats with ice detection that have operated in the Arctic (see more in Annex II) retrieves an incomplete list. The list contains almost exclusively European floats, and is still missing other European floats that do have ice detection, according to their technical parameters. For this reason we recommend that those in charge of the notification process in the OceanOps platform double check if the metadata information regarding ice detection has been appropriately provided for their floats. Similarly, finding the profiles with an ice flag is currently a complicated task . To find profiles for which an ice flag was raised one needs to access auxiliary technical data that, if available at the GDAC level, it is stored in a separate netcdf file. For this reason, we recommend to make the configuration and technical data regarding ice avoidance always available at the GDAC level, and to add an ice flag to the profile data files.

This report aims to compile information of the current status and recommendations on operating Argo floats on the Arctic. Further work still is required for keeping such information up to date as new experiences gather up, as well as to make the distribution of experiences as low-barrier as possible. It is also vital to have methods of describing unsuccessful strategies on operations, so that they can be further improved or avoided. For this end, it would be advisable to form an European level task force to exchange the information on Arctic operations and to keep the information of such activities up to date, and easily available. The information and requirement for evolving Arctic missions should also be discussed with the float manufacturers on regular basis, to ensure they know the needs of the community.

7 Annex I: Cheat sheet for Argo floats operation in seasonal ice regions

Deployment and under-ice operation:

- Get information about the sea ice seasonal cycle in the region of interest.
- Identify the ice free months on the target area. The float deployment should take place during that period. If possible deploy the floats at the beginning of the ice free season.
- Make sure that the floats have an ISA algorithm available. Check the float manuals for a list of needed parameters.
- Review (this document) for the previous experiences and parametrisation (temperature, trigger depths) for the area. If necessary, perform a local ISA tuning for the region.
- Once the float has been deployed and given enough operation time in ice free conditions, test the float operation with the ISA option deactivated, and with ISA option activated but with a temperature threshold low enough not to be triggered.
- Ensure that the battery/memory of the float are enough for the under-ice period. Different mission parameters maybe necessary.
- Overcautious ISA algorithm can cause unneeded loss location info and upper layer data. When possible, operators may keep ISA manually off as long as the region is free of sea ice (use satellite-derived) sea ice maps.

Summary of float requirements:

- Internal memory
- Enough battery to last through expected ice season
- Buoyancy engine capable to overcome the typical haloclines present in the region
- Software-based ice detection methods, including ISA.
- Iridium communication

Useful Toolboxes in the EuroArgoDev

1. ISA parameter decision plots `https://github.com/euroargodev/ISAdecisionplot`
2. Distance to ice `https://github.com/euroargodev/seaice_profile`
3. terrain following `https://github.com/euroargodev/terrain-following`

8 Annex II: Float Types and Parameters Available

In the OceanOps platform, a search for Argo floats operating in the Arctic, equipped with ice detection and using Iridium communication retrieves a total of 94 floats, with only 4 floats from non-European programs (2 from Canada and 2 from the US). This is an incomplete list. The data displayed in OceanOps rely on float information that is manually provided during the registration process of each float in the platform, which sometimes results in incomplete metadata. The distribution of those floats per model is shown in Fig. 27. The most used float models are the Arvor-I (NKE) and Apex (Teledyne), and therefore are the focus of this section. Other NKE models (PROVOR and ARVOR-D) are also used in the region, but their ice avoidance options are similar to Arvor-I and are thus not included in this Annex. In the past Nemo floats (Optimare) were deployed by AWI (Germany) and IOPAN (Poland) but this model is not produced anymore. The special features of the PROVOR-CTS5 are also mentioned.

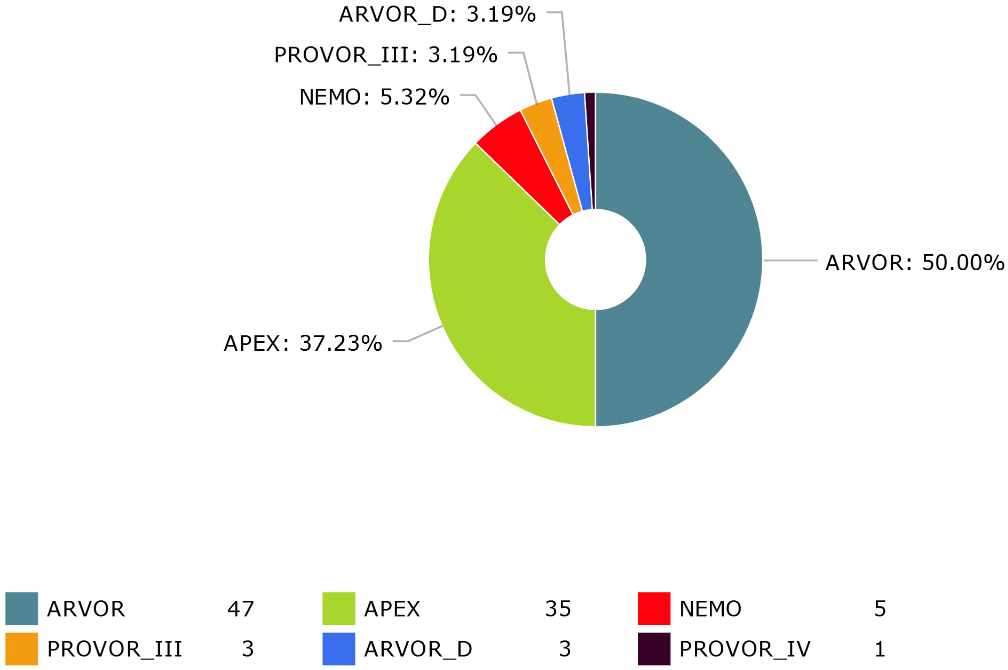
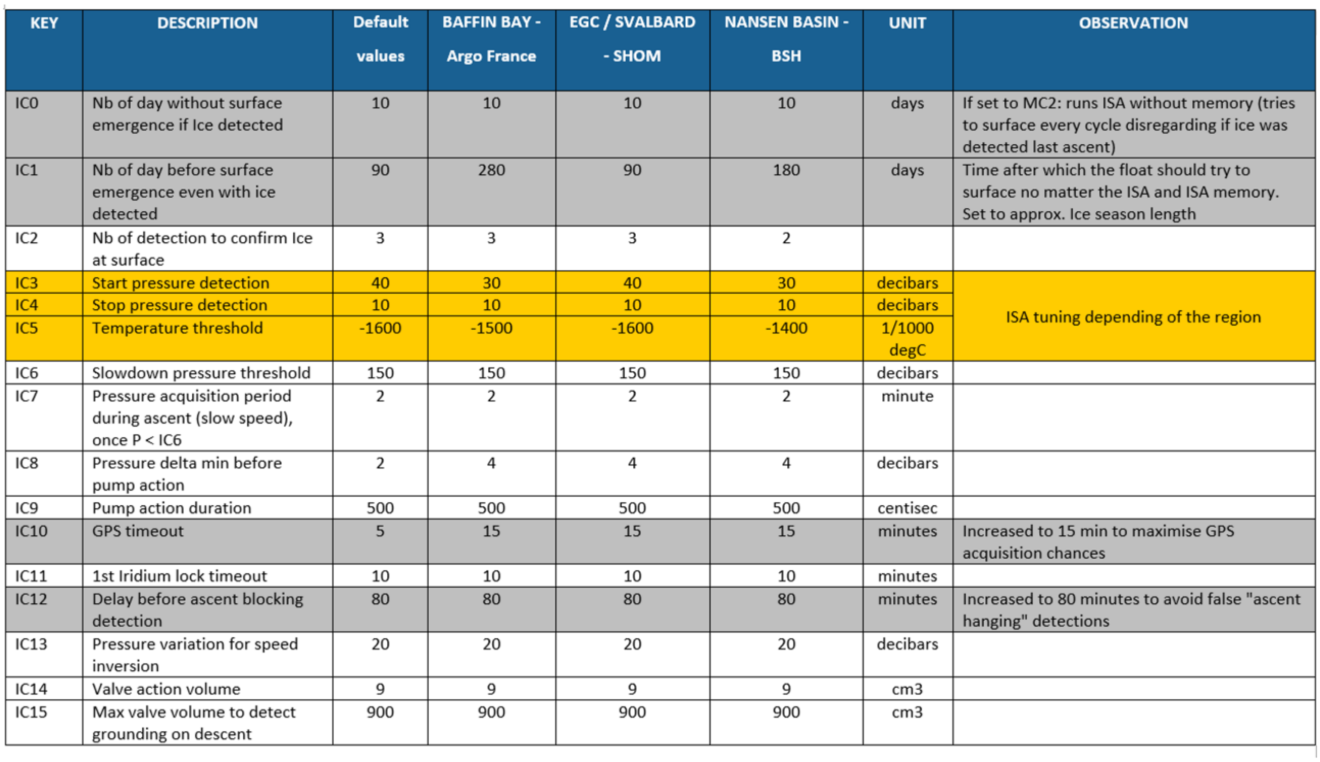


Figure 27: Float models operating in the Arctic

8.1 ARVOR-I (IFREMER, SHOM, BSH, IO PAN, IMR)

The following Table shows the ice detection configurations available for Arvor-I floats, along with the winter configurations used by IFREMER, SHOM and BSH.



KEY	DESCRIPTION	Default values	BAFFIN BAY - Argo France	EGC / SVALBARD - SHOM	NANSEN BASIN - BSH	UNIT	OBSERVATION
IC0	Nb of day without surface emergence if Ice detected	10	10	10	10	days	If set to MC2: runs ISA without memory (tries to surface every cycle disregarding if ice was detected last ascent)
IC1	Nb of day before surface emergence even with ice detected	90	280	90	180	days	Time after which the float should try to surface no matter the ISA and ISA memory. Set to approx. Ice season length
IC2	Nb of detection to confirm Ice at surface	3	3	3	2		
IC3	Start pressure detection	40	30	40	30	decibars	ISA tuning depending of the region
IC4	Stop pressure detection	10	10	10	10	decibars	
IC5	Temperature threshold	-1600	-1500	-1600	-1400	1/1000 degC	
IC6	Slowdown pressure threshold	150	150	150	150	decibars	
IC7	Pressure acquisition period during ascent (slow speed), once P < IC6	2	2	2	2	minute	
IC8	Pressure delta min before pump action	2	4	4	4	decibars	
IC9	Pump action duration	500	500	500	500	centisec	
IC10	GPS timeout	5	15	15	15	minutes	Increased to 15 min to maximise GPS acquisition chances
IC11	1st Iridium lock timeout	10	10	10	10	minutes	
IC12	Delay before ascent blocking detection	80	80	80	80	minutes	Increased to 80 minutes to avoid false "ascent hanging" detections
IC13	Pressure variation for speed inversion	20	20	20	20	decibars	
IC14	Valve action volume	9	9	9	9	cm3	
IC15	Max valve volume to detect grounding on descent	900	900	900	900	cm3	

Figure 28: ARVOR-I ice detection parameters

8.2 APEX (FMI)

8.2.1 Apex 9

Older version of the current (as of writing) APF-11 controller. No longer available, but many of the earlier test have been made with this type of floats. The manual for these: (Webb (2010))

8.2.2 Apex 11

The current (as of writing) controller version of the Apex Argo floats. The full manual can be found from (Webb (2021)).

For Apex floats The ISA algorithm is setup by 5 parameters:

ActiveIceDetectionMonth default: 0x000. the value is a hexadecimal number,where each month is a “one” bit in a 12-bit binary string representing January (000000000001) to December (100000000000)

IceDetectionP default: 50 dbar. The pressure in decibars at which temperature data collection for determining the mixed layer temperature begins.

IceEvasionP default: 20 dbar. The pressure in which the float begins to process the the mixed layer temperature; if the temperature is below IceCriticalT, the ascent is halted and the float transitions to the Park Descent phase of a new mission. IceEvasionP should be at least 15 decibars less than IceDetectionP.

IceCriticalT default: -1.78 Celsius. The water temperature in Celsius below which ice is determined to be present.

IceBreakupDays default: 14 days. The period in days over which the float avoids the surface due to the possible presence of large, crushing icebergs. The period starts with the first determination of the nonpresence of ice after having determined the presence of ice over the previous missions.

8.3 PROVOR,CTS5 (LOV)

The Provor CTS5-USEA (JCOMMOPS PROVOR V) benefits from the legacy of the Provor CTS4 and Provor CTS5-Payload (prototype BGC float used in Baffin Bay as part of the NAOS project in collaboration with the Takuvik lab). Its ice avoidance options are very similar to those of the Arvor-I. The script system allows to modify any parameter (profiling period, ISA parameters, sensor acquisition, etc) based on a date criterion and without the need of a communication. It also has more powerful Iridium Rudics communication and profile data storage on SD card.

References

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