Preliminary results of shallow coastal float operations in the Baltic Sea

Ref.: D6.4_V1.2

Date: 30/09/2020

Euro-Argo Research Infrastructure Sustainability and Enhancement Project (EA RISE Project) - 824131

Document under EC review

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no 824131.
Call INFRADEV-03-2018-2019: Individual support to ESFRI and other world-class research infrastructures

Document Reference

Project	Euro-Argo RISE - 824131
Deliverable number	D6.4
Deliverable title	Preliminary results of shallow coastal float operations in the Baltic Sea
Description	Report that will be written a short time after the float deployments in the Baltic Sea. Preliminary results about the set-up configuration and sampling scheme will be described.
Work Package number	6
Work Package title	Extension to Marginal Seas
Lead Institute	FMI
Lead authors	Simo-Matti Siiriä, Małgorzata Merchel, Waldemar Walczowski, Laura Tuomi
Contributors	Luca Arduini Plaisant
Submission date	30 September 2020
Due date	[M21] 30 September 2020
Comments	-
Accepted by	Giulio Notarstefano

Document History

Version	Issue Date	Authors	Comments
v1.0	04/09/2020	Simo-Matti Siiriä, Małgorzata Merchel, Waldemar Walczowski, Laura Tuomi	Draft version
v1.1	24/09/2020	Simo-Matti Siiriä, Małgorzata Merchel, Waldemar Walczowski, Laura Tuomi	Refined version after comments from WP leader and coordination
v1.2	30/09/2020	Simo-Matti Siiriä, Małgorzata Merchel, Waldemar Walczowski, Laura Tuomi, Luca Arduini Plaisant	Updated version after comments from project lead.

EXECUTIVE SUMMARY

Main outcomes of this deliverable are two fold:

This document presents the first preliminary description of the Argo float operation challenges and best practices in various areas on the Baltic Sea.

It also describes the latest preliminary results of the newly deployed Argo floats deployed on Northern Baltic Proper and Gulf of Gdansk, specifically for the Euro-Argo RISE project. The early assessment at this point of the test is that both areas look promising for the Argo deployment. The floats in Northern Baltic Proper will have a considerable amount of bottom contacts, and it looks this is needed to keep them confined in the desired area. Float in the Gulf of Gdansk is operated by keeping it at the bottom during the drifting period. This is shown to limit its movement considerably, still keeping it operational.

TABLE OF CONTENT

Introduction and special challenges of the Baltic Sea

Argo floats were developed for oceanic measurements. The most commonly-used Argo float type (Core Argo) is a small, autonomous, free drifting underwater platform that measures the temperature and conductivity of seawater vs pressure. The maximum profiling depth is 2000 m. The typical deep-ocean work cycle of such a float is shown in Fig. 1. Floats are programmed to dive to a 'parking depth' of 1000 m and to drift for approximately ten days. They then descend to the profiling depth of 2000 m. Temperature, conductivity, pressure and other water properties are recorded during the drift and ascent (six to sixteen hours). Once back at the surface, the float transmits data via satellite in near-real-time (NRT).

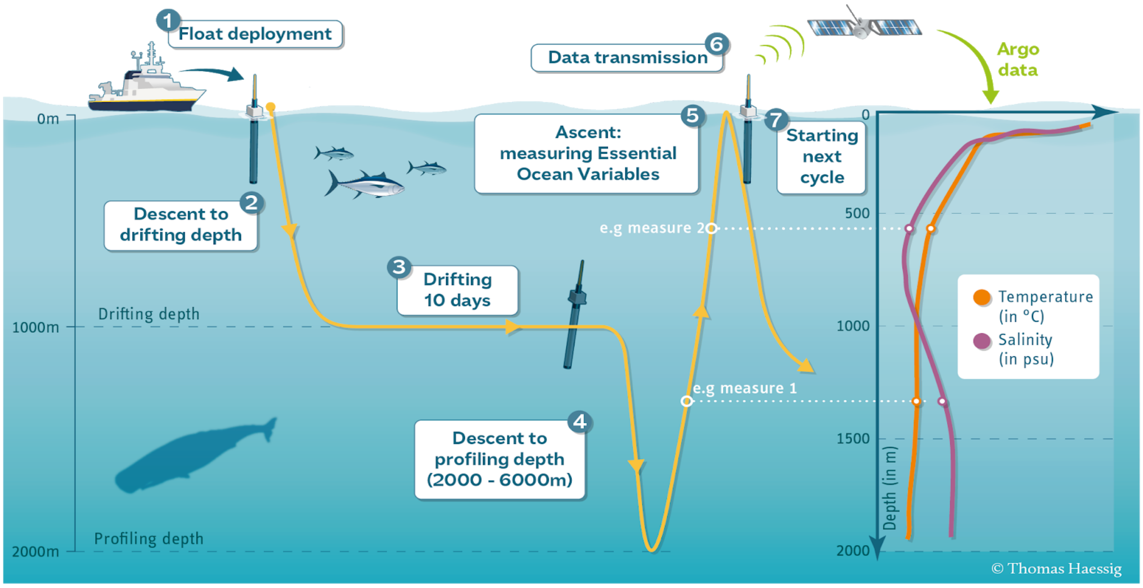

Figure 1: Core Argo float typical deep ocean cycle. Illustration credits: Thomas Haessig

Rapidly progressing climate change has focused the interest of climatologists and weather services on the ocean. There was a need to create a system that, in place of thinly spaced oceanographic stations, would provide near-real-time information about the thermal state of the ocean from a global network of monitoring instruments. Argo floats ideally fit these needs. After years of successful use of Argo floats at the large oceans, members of the Argo community from marginal seas countries decided to test these devices in shallow waters.

Argo floats have been deployed on the Baltic Sea since 2012. First deployments were performed by Finnish oceanographers from Finnish Meteorological Institute in the Bothnian Sea, the northern part of the Baltic Sea. In 2016 Polish oceanographers from Institute of Oceanology Polish Academy of Sciences (IO PAN) deployed the first Argo floats on the Southern Baltic Sea.

Extending the Argo operation in Baltic Sea, and other marginal seas, poses some extra challenges not encountered when operating in large oceans. Most immediate challenges with confined areas is how to keep the floats from getting stuck to shores, or at the bottom. Other challenges come from the varying stratification and salinity of the different areas, which require setting up floats specifically for certain areas. In addition to these, high traffic and in some locations, the ice conditions pose other issues that need to be taken care of.

Limited operation area however does also offer some positive sides for the Argo operation. With limited depth there are some areas deeper than their surroundings, where the bathymetry can be used in advantage to keep the floats confined in certain locations. In addition, as the distances to shore are limited, and a large part of the Baltic Sea is visited occasionally by research vessels or even coastal guards, it is possible to recover the floats when they approach their operating limits, thus saving resources, and obtaining more specific knowledge on the wear the device endures.

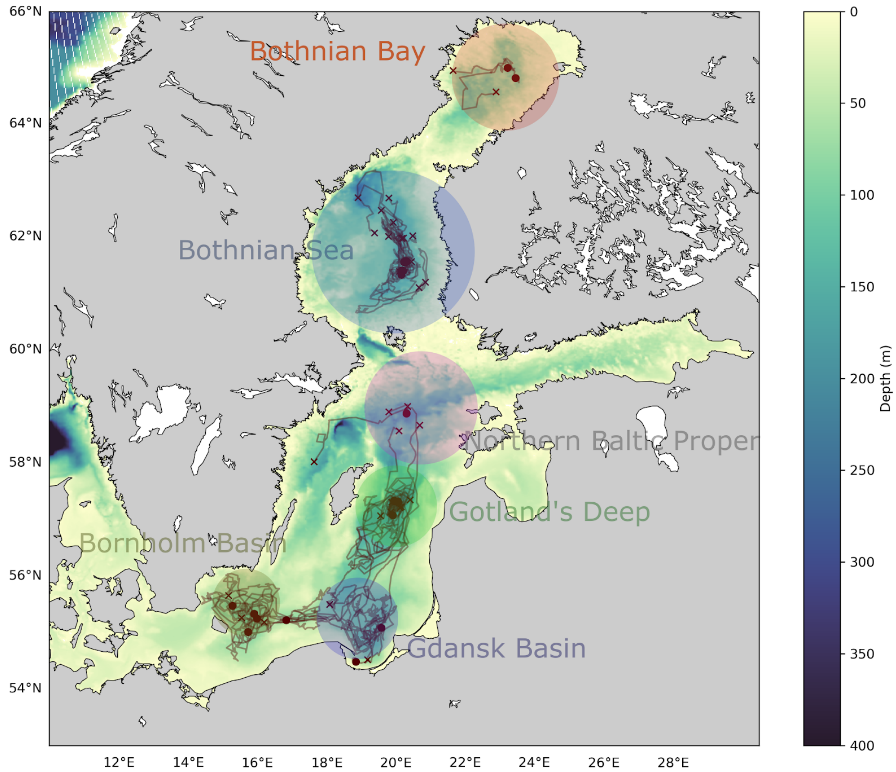

Figure 2: The deployment areas on the Baltic Sea, and trajectories of all Baltic Sea Argo missions performed so far (from 2012 until 2020).

General Control Practices

Interactivity

The main distinction between the operation of Argo floats on the large ocean and the Baltic Sea is the interactivity needed. While most open ocean deployments are mostly fire-and-forget, the floats on the Baltic Sea need more monitoring and occasional change of diving depth or frequency, as the float moves to a different kind of an area.

When deciding the diving depth, the aim is to have as long a profile as possible, but also to avoid unnecessary bottom contacts, as each one risks the float to get stuck. It has been shown that in suitable areas, for example in the Gotland deep (Siiriä et al. 2018), the float can stay in a confined area with proper diving depth. In this case the average depth of around 200-220 m proved to keep the float in the area with reasonable contacts to the bottom. Principle here is to keep it deep enough that the 'walls' of the area keep the float from escaping.

Experiences in the Southern Baltic Sea have so far indicated that the float control interactively during the mission is needed rather rarely. Avoiding coast approaches required adjustments to settings in few missions (described below), and occasionally the parking depth or profiling frequency is changed.

Interactivity is also required during possible float recovery, as it makes it possible to instruct the float to remain on surface during the recovery.

Initial analysis of the adjustment frequency performed with tools developed in WP 2.1 shown in Fig. 3 demonstrates the necessity of the interactive operation in many cases in this area, as most of the missions studied have required several adjustments during their mission.

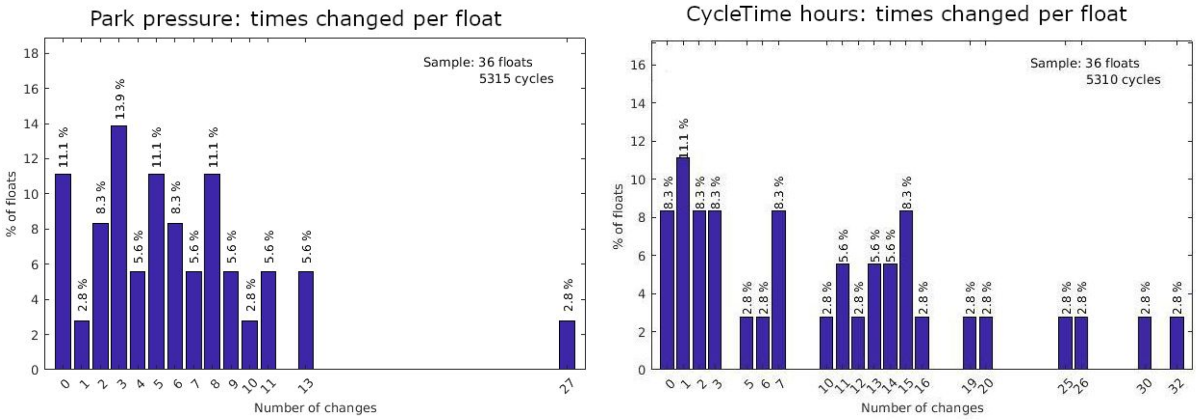

Figure 3: The amount of changes in float configurations during missions on the park pressure (left) and cycle length (right). Image attribution (Euro-Argo).

Profiling frequency and mission length

Typical profiling frequency, when the float is in a relatively stable position has been kept on a 7 - 10 days cycle. However, if there is a foreseeable problem, like strong winds, or the float is suspected to drift on a more shallow area, it has been increased up to a daily frequency, in order to react faster.

With varying diving depths, the floats often have to adjust their piston position setup to match the desired diving depth, which consumes battery, as well as the occasional higher frequency measuring periods. As these control adjustments consume energy, the total possible mission length will be determined in part on how often these adjustments will be required. The maximum mission time will be shortened In an environment where the needs for adjustments are frequent, which empathises the need to develop the optimal control methods, which least need for adjustments. Another aspect resulting in shorter average missions is that the floats are often recovered when cruise is nearby, and it is estimated that the batteries might not last over next winter. Shorter missions are compensated by the fact that the same float can often be used on several missions, after battery change and maintenance.

It seems reasonable and logical to increase the frequency of profiling in small, shelf seas. In the Baltic Sea processes take place in different temporal and spatial scales than in the ocean. Therefore in the first, 2016 IO PAN float missions, we applied a one-day profiling frequency. Now usually two days period is used for common monitoring missions. At the present stage, this gives us a sufficient horizontal resolution of the measurements. Only in case of experimental missions (e.g. using a float as a 'virtual mooring') we use one-day long periods. Also during recovery, before applying the recovery mode, we usually shorten the working period even to 6 hours, to have better flexibility in two-way communication with the float.

Missions of our 'monitoring' floats are long. Usually, floats are deployed in the Bornholm Basin and after some period drift through the Słupsk Furrow into Gdansk Deep and Gotland Basin. The ARVOR float deployed from the MOCCA project, WMO number 3901941 worked from September 2017 to September 2019, giving 382 profiles and was recovered. Float WMO 3902101 was deployed by Argo Poland in February 2019 in the Bornholm Basin, recovered in February 2020 in Western Bornholm Basin. In September 2018 float WMO 3902106 was deployed in the Bornholm Basin, in June 2019 it began drifting eastwards and now works in the Gotland Basin. By August 2020 it had delivered 355 CTD/O_2 profiles.

One of the aims of so long deployments was testing the batteries capacity within specific environmental conditions.

Float Recovery

As the Baltic Sea is a relatively small area, it is often practical to recover the floats when their operational time is approaching its end. This requires a bit of planning though, as recovery missions as such would be too expensive, but as a part of a cruise planned otherways, it is well practical. FMI has also co-operated with Finnish coastal guards in recovering some floats when they have been suitably close to shore.

For recovery to succeed, the float needs to be set interactively in a recovery mode, in which it stays on surface, and transmits its location.

After recovery the batteries of the float need to be changed. So far this has been done for the Apex floats by Webb-research. During the battery change the float's physical condition has been examined, the sensors calibrated and the float's balancing checked. This is a good opportunity to note how much battery was available, and how worn the instrument in generally is after a mission.

When the same float is re-deployed it is given a new WMO number, which is good to note, as for floats that are re-used the WMO describes a mission, rather than individual float.

Configuring for deployment area

Each float that is to be deployed on Baltic Sea needs to be set up based on the area it is targeted to. The initial diving depth and piston position must be set so that the float is sure to 'wake up' and start adjusting it's piston position before hitting the bottom. Also, as the floats have limited ability to change their buoyancy, the physical balancing of the float must be set so that the range of densities it is likely to encounter is matched. This is relatively easy to do on the areas we have earlier experiences, as we know where the floats are expected to move. In new deployment areas this is more uncertain.

ARVOR floats were adjusted to work in the Southern Baltic conditions by removing 250 g of ballast from the hull. In case of the O2 floats, lighter elements were used for construction. In one case using bigger floatation foam was necessary.

In the initial phase of using the ARVOR floats, experiments were performed to improve their operation. Various grounding algorithms, drifting depths and communication procedures were tested. Increasing parking depth accuracy improved float behaviour during the drifting phase, changing the grounding strategy and allowing touching bottom eliminated the ‘false bottom’ effect. Optimization of float settings meant that the devices are now able to reach the sea bed, where water with salinity higher than 17 was observed; previously tested APEX floats were able to reach depth occupied by water with salinity up to 12. The usual parking depth used by IOPAN is 40 - 50 m.

The bottom contacts are frequent in most deployment areas in the Baltic Sea. The analysis tools developed in WP 2.1 have been used to illustrate the distribution of the detected ground contacts in Fig. 4. Profile files from Apex floats with firmware versions anterior to APF11 do not contain the grounding information. Roughly 44 % of the profiles in the Baltic Sea are from such floats, as such not all groundings are shown. This does, however illustrate that the grounding events are far from rare in the Baltic Sea operations.

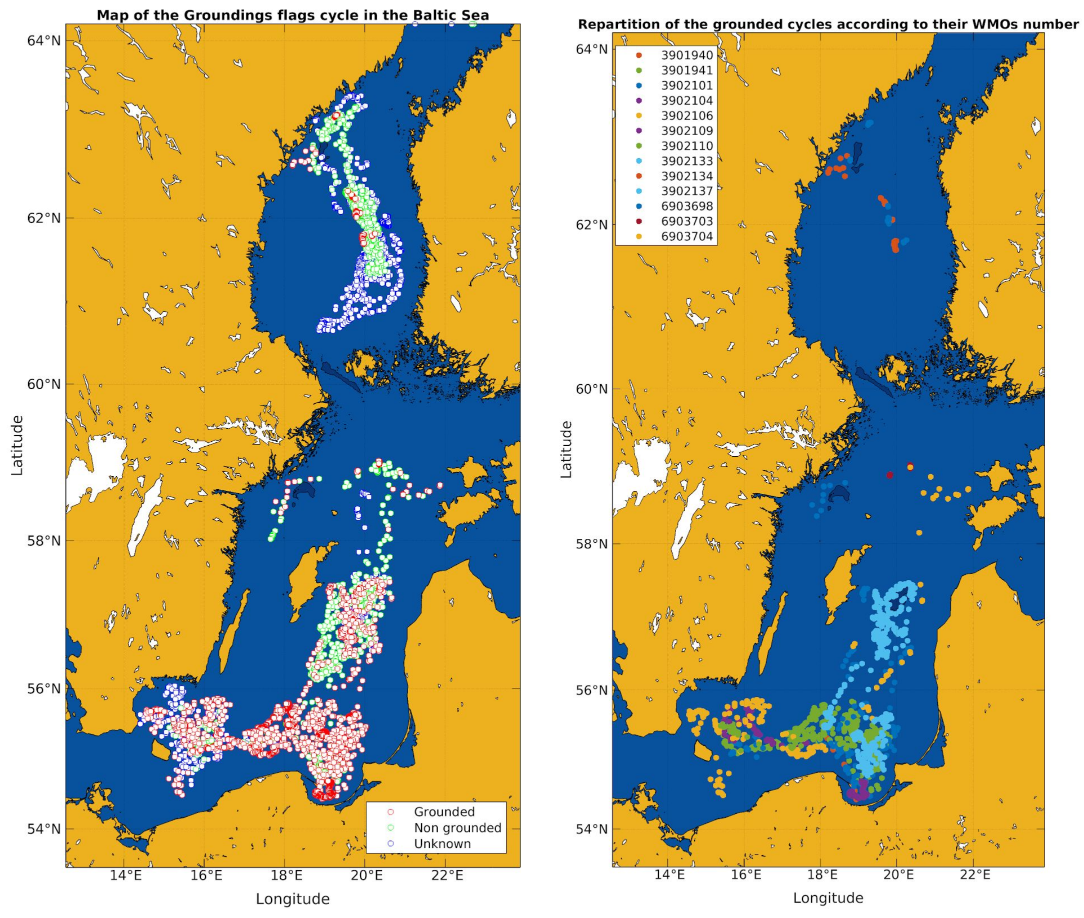

Figure 4: on left: all Baltic Sea profiles colored by grounding status. Blue marks indicate profiles with no information in the analysis. On right, grounded profiles colored by corresponding missions. (Image attribution: Euro-Argo)

Risk of collisions, shore, bottom, ice

Float ending to an area too shallow or shore needs to be avoided, as it will end the mission, and risk losing the float itself either by getting stuck to the bottom, or being taken. So far, we have mostly managed to avoid this first by ensuring the deployment areas are as deep as possible, and keeping the diving depths deep enough to prevent the float from travelling too far on the shallow area. Sometimes it is reasonable to keep the float in the diving depth for a longer period, for example during strong wind situations, where there has been risk that the float would move too much, if it surfaces.

In the first deployments on the Baltic Sea, we were very cautious of not letting the float hit the bottom, as the risk of losing the float seemed considerable compared to the risk of it moving further from the designated area. At least in the first experimented areas, namely Gotland Deep and Bothnian Sea, it seems now that getting stuck to the bottom is relatively rare. Too conservative diving depths then again often result in the float escaping the planned area. The planned diving depth should not, however, be too deep on the area where it is not possible to reach, as the float will keep trying to get lower, moving it's piston, which will consume the energy reserves needlessly.

In the northern part of the Baltic Sea the floats need to handle ice cover. This requires the use of specific ice avoidance algorithms (ISA). If and when the float enters under ice, it will be impossible to control it again, before it re-emerges. For this reason it is especially important to decide carefully the attempted diving depths on the cycles the ice is expected. For the techniques for ice avoidance, a separate report is in preparation within the project.

Shallow water, high vessels traffic, proximity to shores, fisherman activity – there are factors which may disturb the Argo float mission. In the Argo-Poland project, we even reserved money for a charter of small vessels or yachts for 'rescue' actions. Experiences from more than three years of Southern Baltic Argo exploitation show that shallow shelf seas can also be explored with these floats. Contact with the sea bed (grounding), proximity to the shore and collisions with ships are not as dangerous for the float as had seemed earlier. We purposely profile to the bottom, because the bottom layer is the most important for Baltic Sea ecology, especially in the water transition region. Analysis of the technical data show that in some cases floats had to make additional pump actions to come unstuck from the bottom. Fortunately, ARVOR floats have a big bladder and buoyancy reserve. Additional pump actions consume more energy, but float never stuck to the bottom. In case of the more expensive BGC floats, we consider equipping floats with a 'rescue system' – dropped ballast released in case the float's dive much longer than planned. The Baltic Sea wracks and fisherman nets can pose a danger if tangled around a float.

The shore proximity may be more dangerous. Therefore we use 'parking depth' at level 40 - 50 m to avoid floats' drift close to the shore. Experiences with our first floats show that even in case of excessive approaching to a coast, there is a possibility to influence float trajectory. In the case of APEX float approaching Sweden coast in 2016 during hurricane 'Barbara' using results of a numerical model, weather forecast we adjusted float settings to allow float's drift offshore.

The danger of collision with a vessel is rather little. Most of the time floats spend at the parking depth (40-50 m), at the surface float is a short time (25 minutes). Also, ascent and descent time at potentially dangerous (0-10 m) depth are short. Fisherman activity may be a problem. The case of the lost APEX float caught by fisherman almost one and a half years after losing may be a good example.

Other problems arising from the coast approaching may be political ones. There are no problems with floats drifting in Swedish, Danish or German Exclusive Economic Zone, although these issues are not regulated by law. Whereas there are no experiences with Russian authority. IO PAN repeatedly attempted contact with Argo Focal Point of the Russian Federation, but without response.

Notes and control practices for specific areas

Areas within the Baltic Sea vary considerably from each other both on bathymetry, salinity and stratification. Some areas need specific considerations when deployment is planned. This chapter describes the considerations known.

Southern Baltic Proper

The exchange of water between the North Sea and the Baltic through the narrow, shallow Danish Straits is very important for the entire Baltic Sea environment. This very limited exchange maintains brackish water conditions in the Baltic. Major Baltic Inflows (MBI) are the main source of deep-water ventilation in the central Baltic basins and govern environmental conditions below the halocline to a significant extent. The dense, salty, oxygen-rich water inflows through the Arkona Basin, the Bornholm Basin, the Słupsk Furrow, to the Eastern Gotland Basin and the Gdansk Basin. The Słupsk Furrow is the only deep connection between the Bornholm and Gotland basins (Fig. 5) and the only pathway for eastward deep-water advection. The deep inflow of dense water from the one hand and surface outflow of brackish water from the other hand constitute a kind of estuarine circulation and shape Southern Baltic hydrographic conditions. Upper layer salinity is low – about 7. Horizontal gradients in the upper layer are rather low, properties of water change in the seasonal cycle. The lower layer is much salty: from 18 in Arkona Basin, 16 in Bornholm Basin, 14 in Gdansk Deep to 12 in Eastern Gotland Basin. The vertical gradient of density (pycnocline) is shaped by salinity differences. Contrary to the surface, in the bottom layer horizontal gradients are high. Properties of water (mostly salinity) are shaped by inflows from the North Sea, during advection towards east water dilutes, salinity and temperature changes.

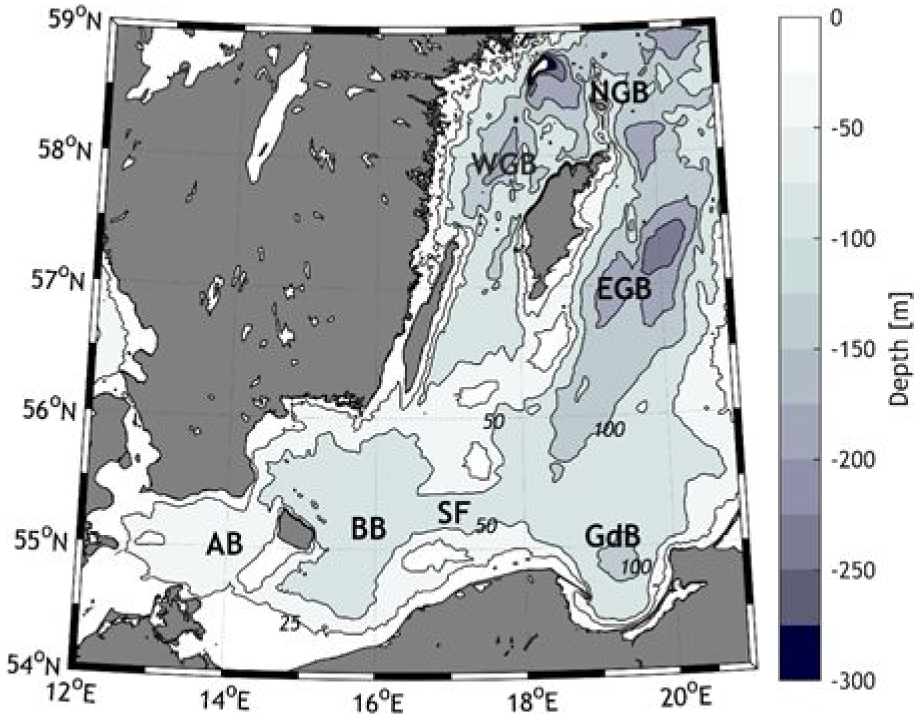

Figure 5: Main basins of the Baltic Proper: Arkona Basin (AB), Bornholm Basin (BB), Gdansk Basin (GdB), Eastern Gotland Basin (EGB), Western Gotland Basin (WGB), Northern Gotland Basin (NGB) and Słupsk Furrow (SF). (Image attribution: IOPAN)

High differences in density between the upper and lower layer of the Southern Baltic was the biggest problem to resolve after the first deployments of Argo float in this region. Vertical movement of the float is forced by a change of the external bladder volume; if the total volume of the bladder is too small, the float's buoyancy difference may be too small to overcome the pycnocline.

Gotland deep

Gotland deep is a confined area, with deepest point of 239 m. Surface salinity on Gotland Deep is around 7 psu, while bottom values stay near 12-13 psu. A float deployed here should manage in respective densities.

With our current experiences, it seems that with an average diving depth of around 200 m, the float can often be confined into a rather small area, with little need to later control.

Northern Baltic proper

Northern Baltic proper is the latest deployment area experimented with. Surface salinity on the deployment area is 6-7 psu, bottom values are around 12-13 psu. Deepest point in the area is around 170 m, and the aim is to keep the floats in the 150 m area. Compared to earlier deployment areas, it is more dynamic, and the bathymetry is less clear in its shape.

Bothnian Sea

Surface salinity on Bothnian sea varies around 4.2 to 5.7 units, near bottom (around 100 m) 6 to 6.8 psu, so a float deployed here should be able to manage this density difference. Usually floats have been deployed around 61° 30'N 20° 18'E.

Bathymetry has a long, deep area, where the float can be confined, which can be seen in figure 2 and 8. Floats deployed on this area tend to stay confined in the deep parts of the Bothnian Sea. Their area of operation however is wide, floats tend to end up over hundred kilometers from the place of deployment, northwards. Latest Arvor float has as of writing measured its first profiles as expected, and has travelled so far just about one kilometer during the first month.

It is possible that floats encounter ice during their missions, so an ice-sensing-algorithm is good to be available.

Bay of Bothnia

Bay of bothnia is very shallow in general, average depth being roughly 40 m, and deepest point being 146 m. This makes the area challenging for keeping the float operational without bottom contacts, and even with those, the risk of getting close to the shores is larger than in other areas.

Area has ice cover for most winters, so ice sensing algorithms are required for missions.

Missions performed

At 2020-07-20 a total of over 30 Argo missions have been performed in the Baltic Sea. Their routes have been plotted on figure 2. The list of all missions performed is in appendix 1.

Missions on Bay of Bothnia

Bay of Bothnia is the northernmost area of the Baltic Sea. So far two missions have been performed here, the main focus being on ice-avoiding algorithms. Figure 6 shows the routes of the two experiments, and figure 7 the profile data.

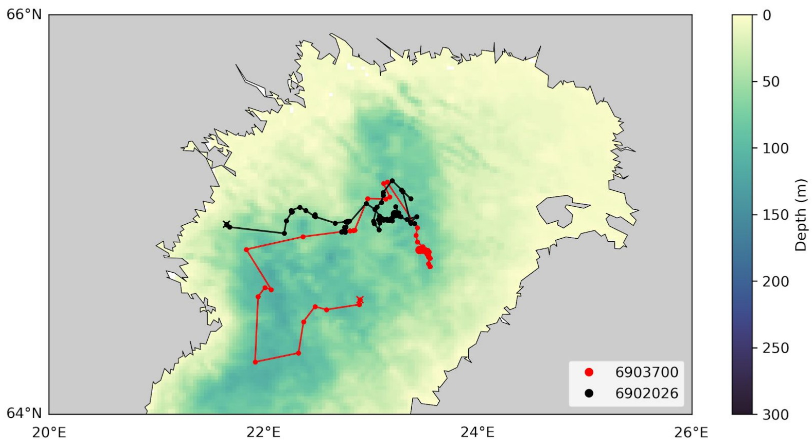

Figure 6: Missions on the Bay of Bothnia, and the bathymetry. Area is often ice covered during winter, which limits the control of the missions. Bathymetry data from IOW (Seifert et al 2001) (Image attribution: FMI)

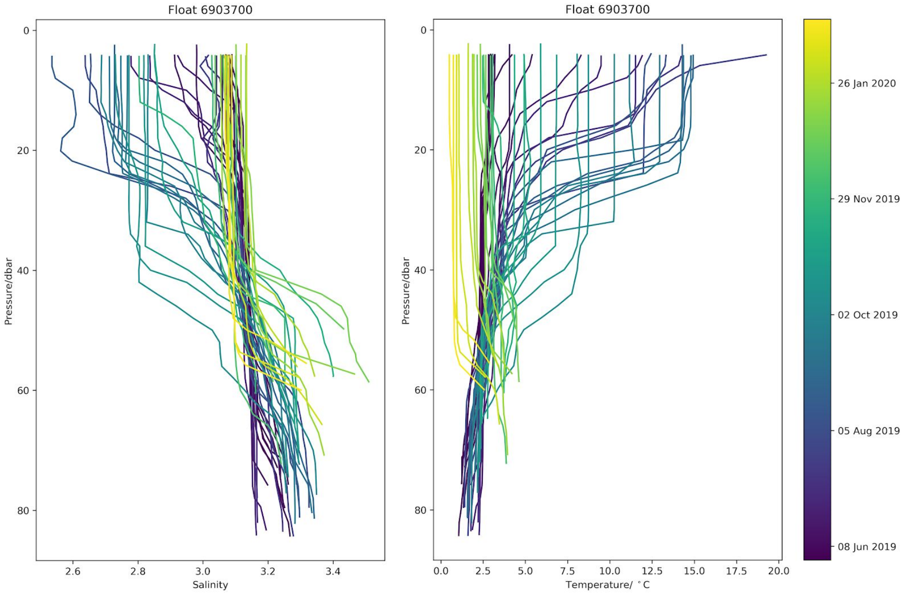

Figure 7: Salinity and temperature profiles from the mission 6903700. Due to the ice avoiding algorithm, most of the profiles end before the surface. (Image attribution: FMI)

Missions on Bothnian Sea

Bothnian Sea is the area, where Baltic Sea Argo operations started, first mission in 2012 and as of writing 12 missions total. Figure 8 shows the trajectories of the three latest missions. Latest one, started June 2020, is a new test for Baltic Sea. This one has landing-spikes on it, and is programmed to dive deep enough to always get bottom contact. It also has only one way communication, so cannot be further controlled. So far, during two months it has moved around 1 km from the original place, which is considerably less than typical floats, and has performed well. The mission is planned to end in the summer 2021, at which point the float will remain on the surface, and a recovery is attempted.

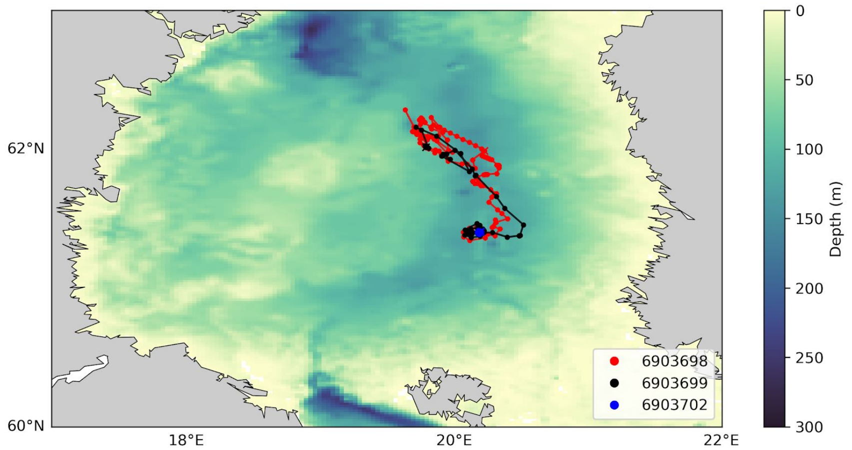

Figure 8: Latest missions on the Bothnian Sea, and the bathymetry. Blue dot shows latest, Arvor-C type float deployed 2020-06-16. (Image attribution: FMI)

Missions on Northern Baltic Proper

As of writing, the northern Baltic proper is a new experimental area for the Baltic floats. New floats have been deployed, one from Argo-Finland, and another from the Euro-Argo RISE project, complementing the national one. Both were deployed on the same cruise at the same place near HELCOM measuring point LL11 (N 58° 53’ E 20° 18.8) on June 10th 2020. LL19 is approximately 170 meters deep. The aim is to keep the floats in at least 150 meters deep area. One of the floats is Apex type, and the other Arvor-I. Thus it is possible to study the performance of both types of floats in the area.

Floats were programmed to stay most of the time at 150 meters depth. This makes them collide to the bottom rather frequently. As the area is rather dynamic, this was deemed a good tactic in order to keep the float on the designated area for as long as possible. From figure 10 can be seen the bottom contacts for the Apex float. While common, there is no indication that it had problems getting back up after the collisions in this area.

Profiling frequency is kept initially higher, so that the float operation is quickly confirmed, and the first adjustments based on observations can be done faster. After the float operation is confirmed, the schedule is lengthened. For the first ten profiles both floats were kept in rather frequent profiling: roughly 6 hour cycle for Arvor float, and 10 hour cycle for Apex. A one to two day cycle was kept for the following week. During this time, the float seemed to stay rather well in their place, so the cycle was changed to one week.

During the weekly measuring period, both floats moved once a considerably long distance, as can be seen on figure 9. For the Arvor float, the longer travel was a bit over 30 km, and for Apex approximately 14 km. Typically both floats moved less than one kilometer between profiles.

Figures 11 and 12 present the salinity and temperature profiles of both floats. In general they show similar, systematic profiles. As the floats ended up bit far apart for the later profiles, the temperature structures in the surface are different. Salinity value in the Arvor cycle number 5 indicates that the sensor has got clogged, or otherwise produced a faulty profile. Other than that the sensors in both floats seem to operate as supposed.

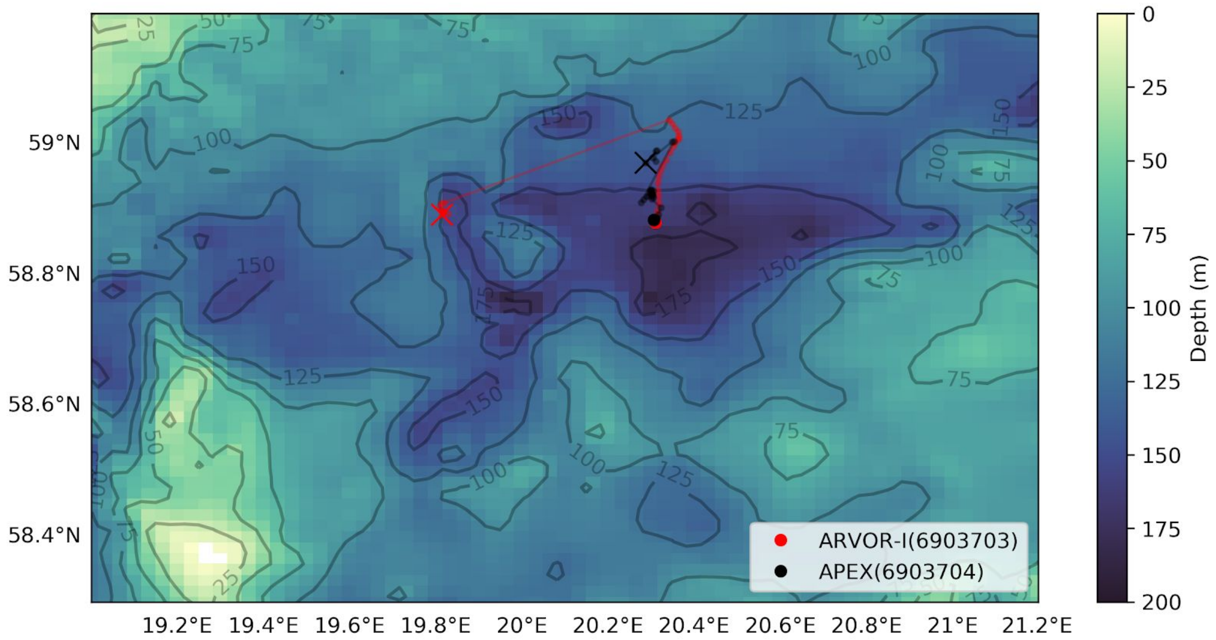

Figure 9: Trajectories of the two floats deployed on the Northern Baltic proper as of 2020-07-27. Large Dots indicate deployment place, X the latest profile. (Image attribution: FMI)

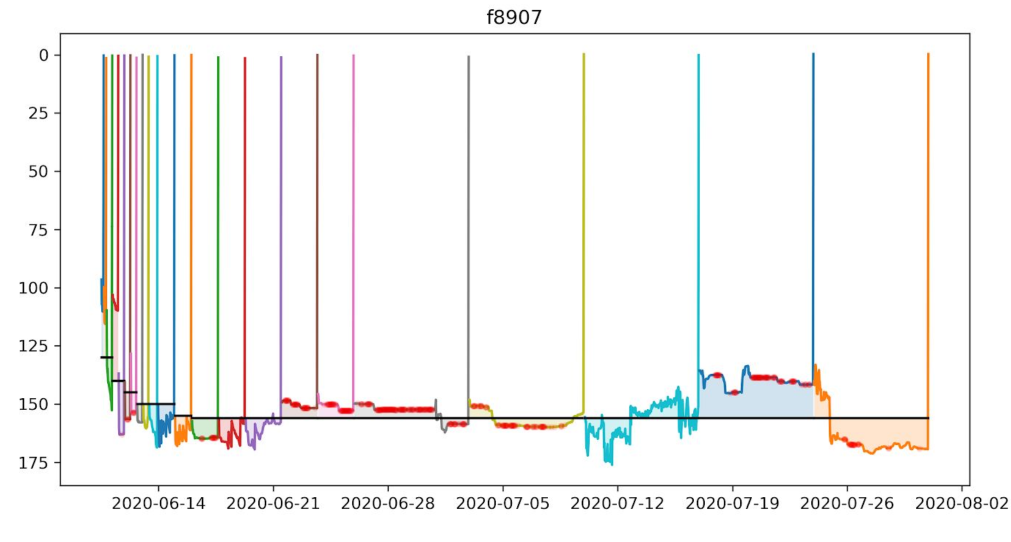

Figure 10: diving pressures of the Apex float 6903704 (each profile cycle in separate color) in comparison to the set depth (black). Red dots indicate probable bottom contacts. This is determined based on less than 5 cm depth change during a 5 hour period.(Image attribution: FMI)

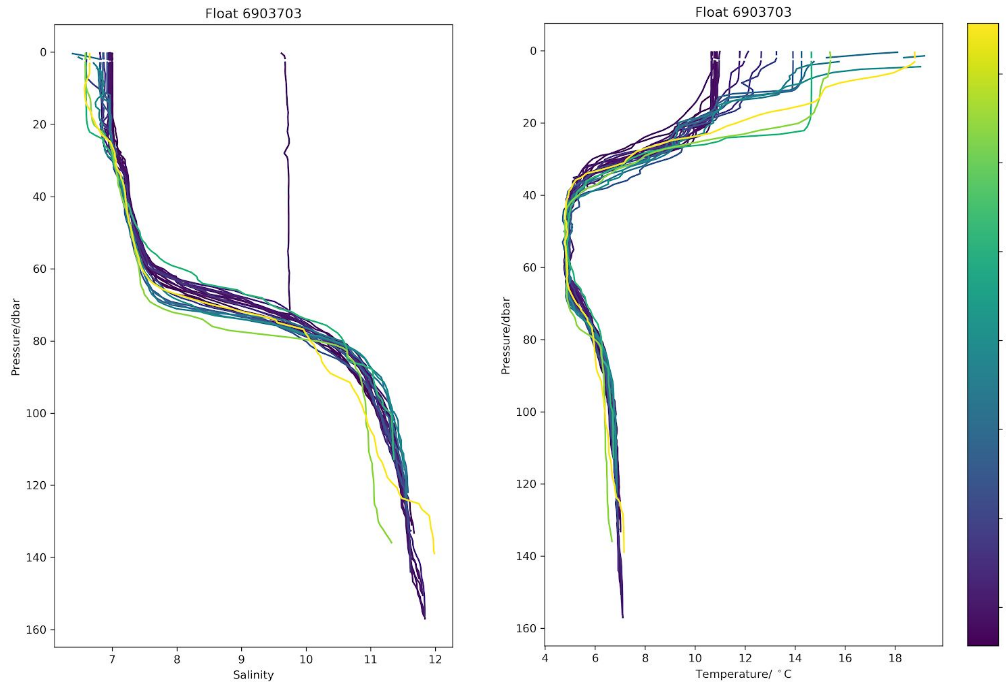

Figure 11: Salinity and temperature profiles of the Arvor-I float (WMO 6903703) From the start of the mission (Image attribution: FMI)

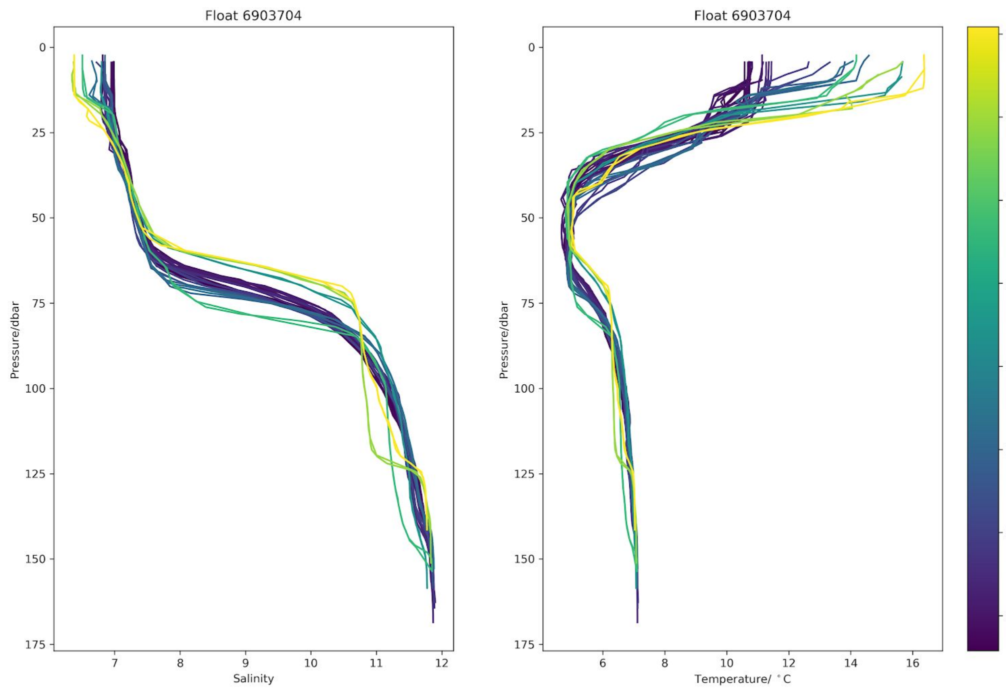

Figure 12: Salinity and temperature profiles of the Apex float (WMO 6903704) from the start of the mission (Image attribution: FMI)

First experiences on the northern Baltic Proper indicate that both float types (Apex and Arvor-I) are promising. The bottom contacts have been numerous, and deemed necessary in order to keep the float on study area as well as possible. It seems the floats have not had troubles getting back up after the contacts, so thus far this seems a reasonable method of operation on the area.

Missions on Baltic Proper

The Gotland Deep area in Baltic Proper has been the area with best success in containing the floats constantly on a small area. After the first experiments, the floats have generally stayed well within 50 km or less from the area of deployment (57.3 °N, 20.0 °E). The seven day cycle with average diving depth of roughly 200-220 meters has proven to be a good operating method for these floats. In many missions, this has required only little manual intervention. Figure 13 shows the latest three missions on a map, and figure 14 an example profile cloud from the ongoing mission 6903701 (red line in figure 13). From the salinity profile, it can be seen that few profiles have failed, as the sensor has most likely got clogged. This happens occasionally, and is something that needs to be considered in the quality control, but hasn't been shown to cause any lasting problem with the float.

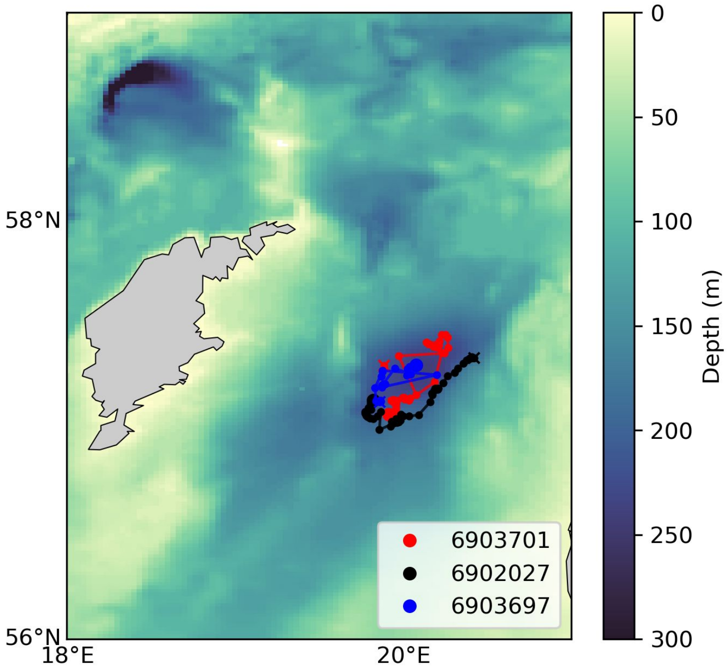

Figure 13: Latest missions on the Baltic Proper. Float movement is rather well confined on the Gotland Deep, and has stayed that way for several missions. (Image attribution: FMI)

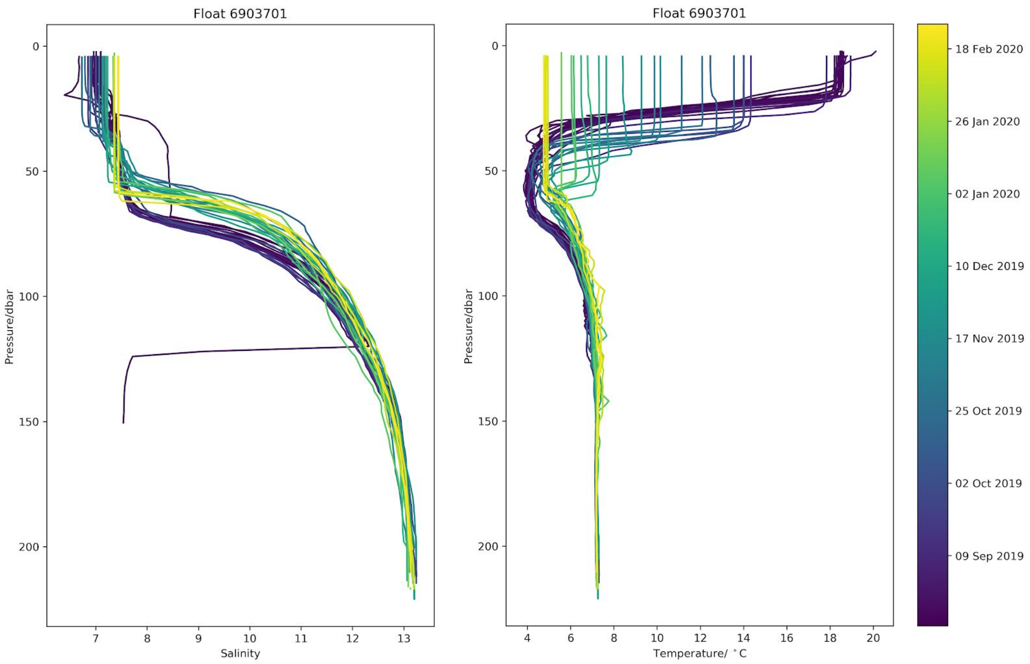

Figure 14: Salinity (left) and temperature (right) data from the latest Baltic Proper mission (WMO 6903701)*. Color indicates time of the profile. (Image attribution: FMI)*

Missions on Southern Baltic

First experiences of Polish oceanographers revealed problems with pycnocline. The first Polish float was deployed in the Baltic Sea on 21 November 2016. This was also an APEX float, ballasted in accordance with the southern Baltic Sea water density. It was an experimental mission, aimed at testing the float in southern Baltic Sea conditions and training the issuing of commands for remotely controlling the float settings. In addition, the possibilities of indirectly controlling float drift were tested by altering the 'parking depth' or forcing the float to stay at the surface. The course of this first mission (WMO 6902036) was dramatic, coinciding as it did with the passage of hurricane 'Barbara' across the Baltic Sea region. The wind strength reached 11° B. During this time the float got very close to the Swedish coast (Fig. 15), entering shallow waters. Ongoing weather forecasts and the results from a numerical model working in real-time at IO PAN were used to adjust the float's settings, enabling it to drift away from the shore. The float survived, transmitting data daily and was recovered during a cruise of *r/v Oceania* in January 2017.

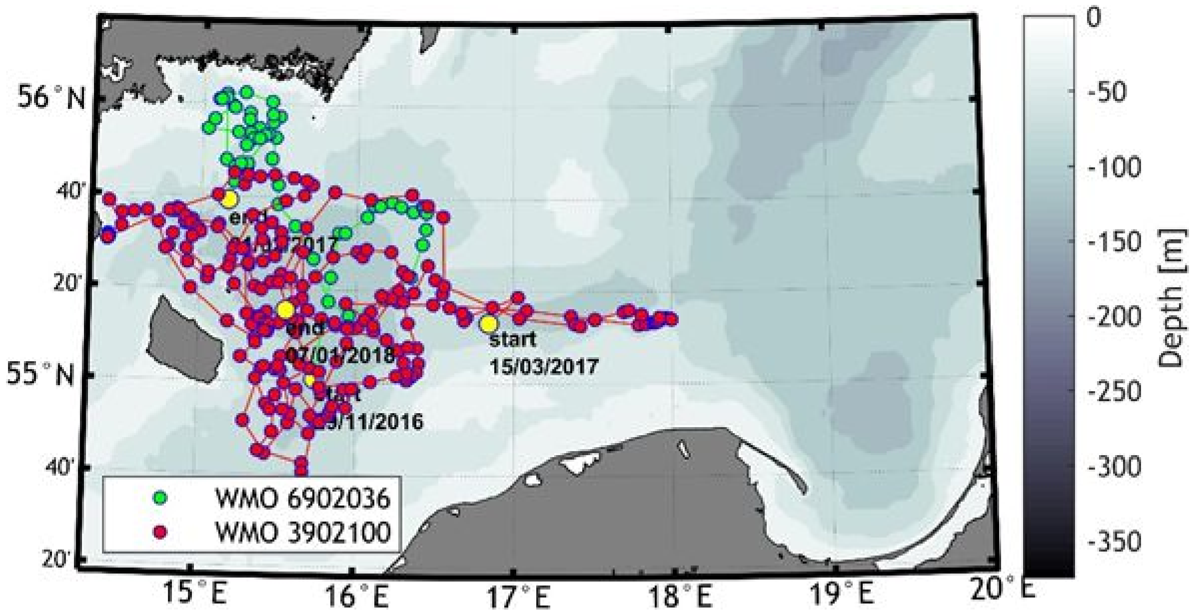

Figure 15: Pathways of the first Polish Argo float in the Baltic Sea during two deployments, as WMO 6902036 and WMO 6902100. (Image attribution: IOPAN)

This first mission yielded 56 CTD profiles and provided valuable experience regarding the behaviour of Argo floats in the Baltic Sea in general and the APEX float in particular. But even so, the mission met with limited success: the strong pycnocline prevented the float from reaching the sea bed, 'false grounding' occurred during every descent, the float stopped at a maximum depth of 60 m (Fig. 16), reaching water with salinity up to 12.5. The float's small bladder capacity made it incapable of adjusting its buoyancy to the southern Baltic deep's steep vertical density gradients.

The procedure to recover the float was also a valuable experience. Following the practice of our Finnish colleagues, we decided to re-use Baltic Argo floats many times. Unlike the deep ocean, the small dimensions of the Baltic Sea make float recovery cost-effective. Additional advantages for IOPAN are the numerous cruises of *r/v Oceania*, during which floats can be recovered and re-launched. Only the weather can hamper this practice. Strong winds and high waves make it hard to pick out the float: as it drifts across the water surface, only its antenna and a small part of the sensors protrude from the water surface.

The recovered float from the first mission (WMO 6902036) was redeployed as WMO 3902100 during the *r/v Oceania* cruise in March 2017. It worked for almost a year until January 2018, data transmission ceasing a week before its planned recovery. In both missions, this APEX float produced 280 profiles, providing valuable data on the hydrography of the upper layer and the pycnocline of the Bornholm Basin. Interestingly, this float was trawled by an Estonian fishing boat near Władysławowo in the summer of 2019.

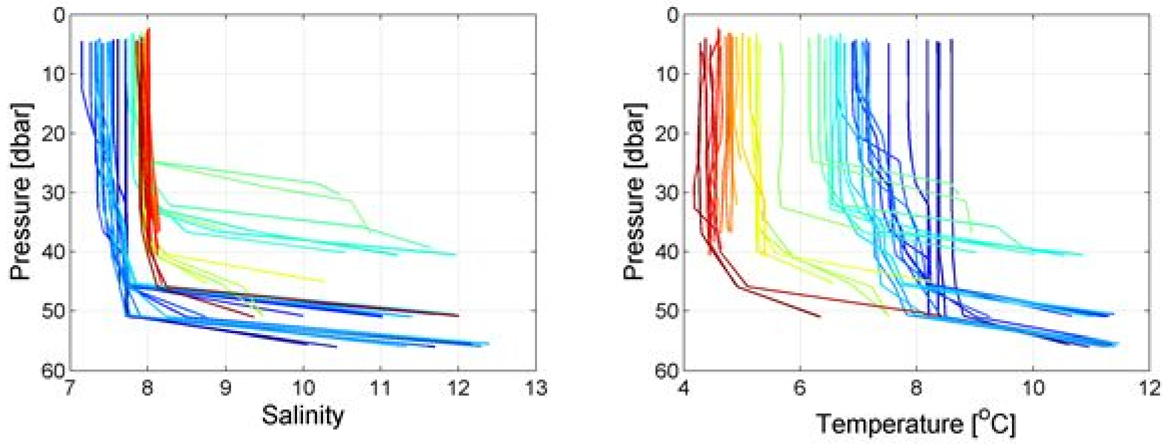

Figure 16: Temperature and salinity profiles obtained during the first mission of the WMO 6902036 float. (Image attribution: IOPAN)

In the Southern Baltic deeps, the bottom water layer is the most important and we needed profiles from the surface to the bottom. After unsuccessful experiments with another APEX float, we decided to change the float type. Good opportunity for this was the offer of Euro-Argo to test NKE ARVOR floats in cooperation with the Monitoring the Ocean Climate Change with Argo (MOCCA) project. The advantages of the ARVOR float is bigger than APEX's bladder capacity (850 ml versus 600 ml), which gives a wider range of floats buoyancy changes and better opportunities to cross the pycnocline. The floats were adapted to the Baltic Sea density by removing 250 g of ballast from the hull. The first ARVOR float was launched in the Gdansk Deep in September 2017, but after a few days, due to the dangerous approach to the shore, the float WMO 3901940 was taken by *r/v Oceania*. The float was redeployed in November 2017 with WMO number 3902133. The second MOCCA project float was deployed in September 2017 with WMO number 3901941. This float was recovered by *r/v Oceania* in summer 2019 after performing an impressive number of 382 profiles. The float was sent to the manufacturer for maintenance, sensor calibration and battery exchange.

In the initial phase of float activity, experiments were performed to improve their work. The various grounding algorithms, drifting depths and communication procedures were tested. Optimization of the float's settings enabled the devices to reach the bottom, measuring salinity above 17. During the float's mission also a period of profiling was changed. Initially, we used profiling every day. Finally, we use a 2-day profiling period in most missions.

Due to the successful experience with ARVOR in the Baltic Sea, IOPAN decided to purchase these devices for the needs of the Argo-Poland project. Thanks to the Ministry of Science and Higher Education funds, it would be possible to buy two floats with additional dissolved oxygen (DO) concentration sensors. Monitoring of the dissolved oxygen dynamics is very important from the Baltic Sea ecology point of view. Floats with the DO sensor belong to the Biogeochemical (BGC) floats class. The first Polish ARVOR BGC float (WMO 3902101) was deployed in the Bornholm Basin in February 2018 (Fig. 17). The float worked in 2-days long cycle. After two months the float drifted from the Bornholm Basin to the Gdansk Deep. Transition through the Slupsk Furrow, the main pathways of deep-water eastward advection, took 20 days. At the fastest section between profile 29 and 30, drift mean speed exceeded 20 cm/s and was much higher than mean drift speed in Bornholm Basin. The float stayed in the Gdansk Deep until January 2019 performing 130 dives, and next drifted to the Gotland Deep. Also, in this case transition between basins was fast, with mean velocities between profiles up to 18 cm/s. From the Eastern Gotland Basin the float made an anticyclonic loop cross the Northern Gotland Basin to the Western Gotland Basin. In February 2020 the float was recovered by Polish sailing yacht *s/y Magnus Zaremba*. The yacht was chartered by IOPAN purposely to this mission. The float was recovered west of the northern tip of Gotland Island, in the Western Gotland Basin (Fig. 17). It had performed 360 CTD/O_2 profiles (Fig. 18).

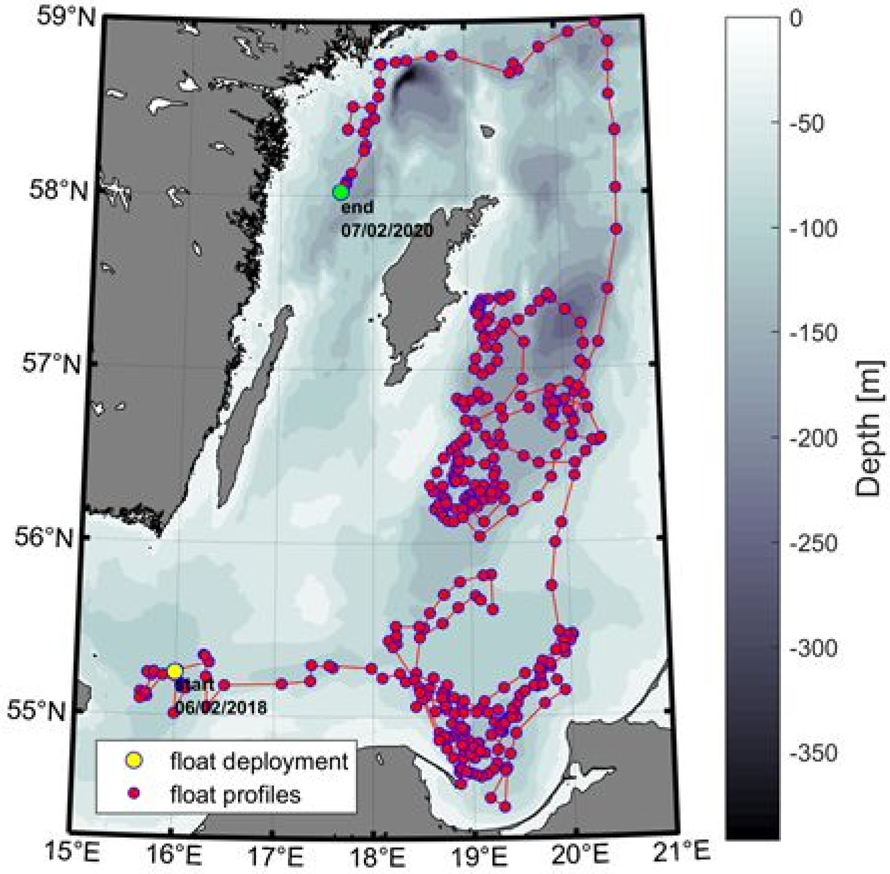

Figure 17: Pathways of the first Polish Argo ARVOR float in the Baltic Sea, WMO 3902101. (Image attribution: IOPAN)

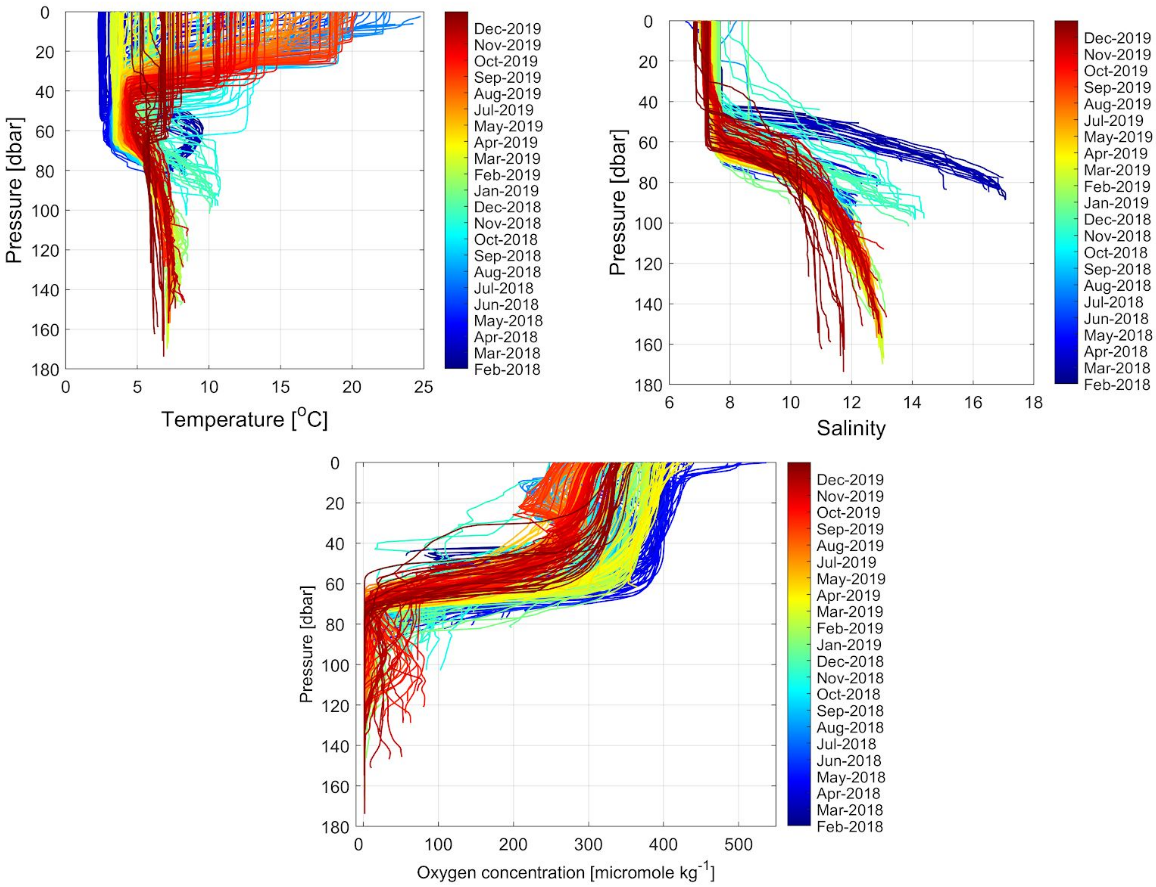

Figure 18: Temperature, salinity and dissolved oxygen concentration profiles collected by float WMO 3902101 in period February 2018 - December 2019 . (Image attribution: IOPAN)

The second Polish ARVOR BGC float (WMO 3902104) was deployed in the Bornholm Basin in May 2018. For three months it drifted eastwards (Fig. 19). In September 2019 it was recovered and redeployed back in the Bornholm Basin. As before, this operation required a change of WMO number, so that after redeployment the float was renumbered WMO 3902106. Most of the time, it remained in the Bornholm Basin, but in June 2019 it began drifting eastwards into the Gdansk Basin, northward into the Gotland Basin and next to the islands of Hiiumaa and Saaremaa. In this region float is still (September 2020) working.

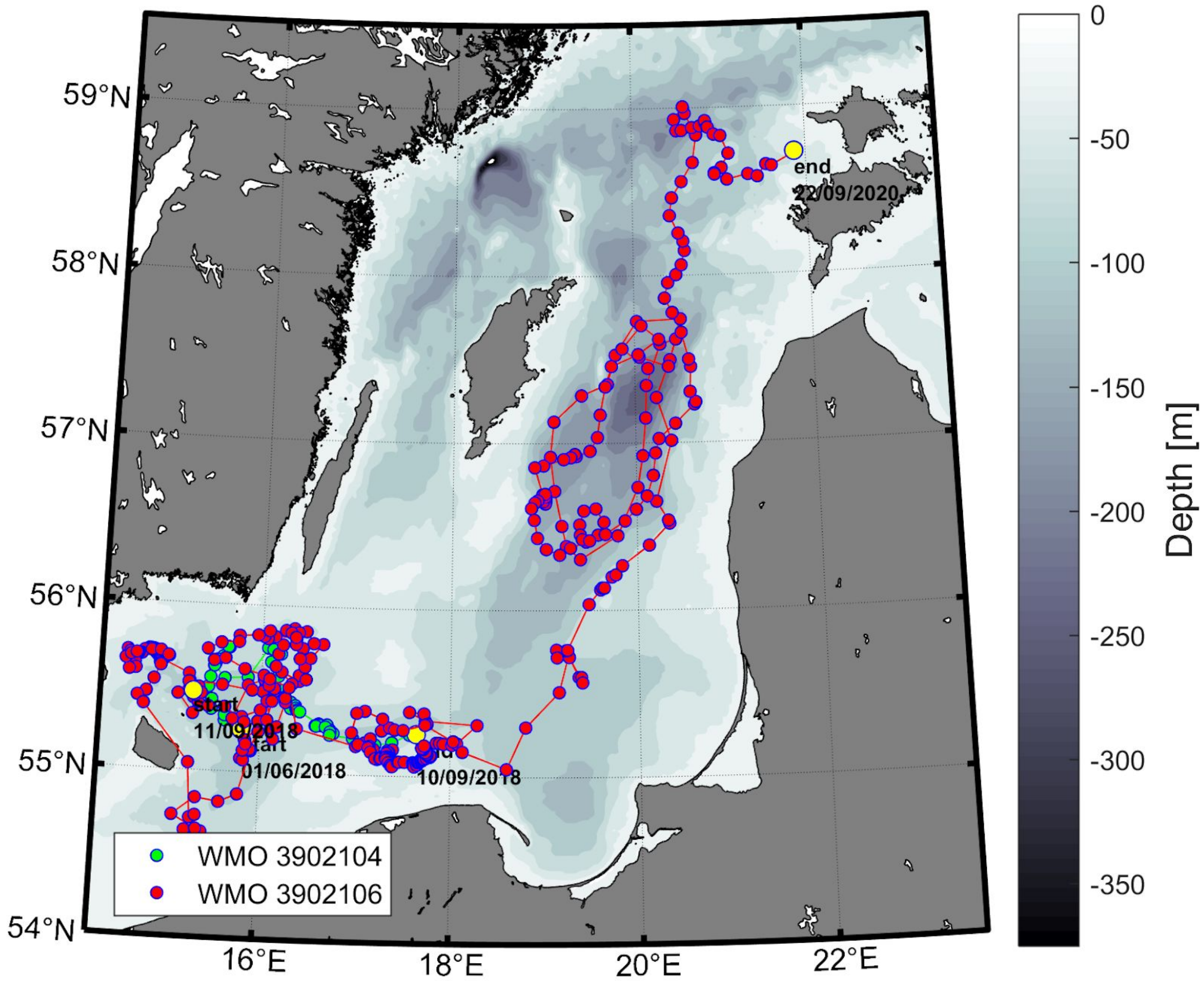

Figure 19: Pathways of the ARVOR float WMO 3902104, and after redeployment WMO 3902106. (Image attribution: IOPAN)

The third Polish ARVOR BGC float (WMO 3902110) was deployed in the Bornholm Basin in May 2020 (Fig. 20). Most of the time, it was drifting eastwards. By the end of September, the float had performed 60 CTD/O_2 profiles.

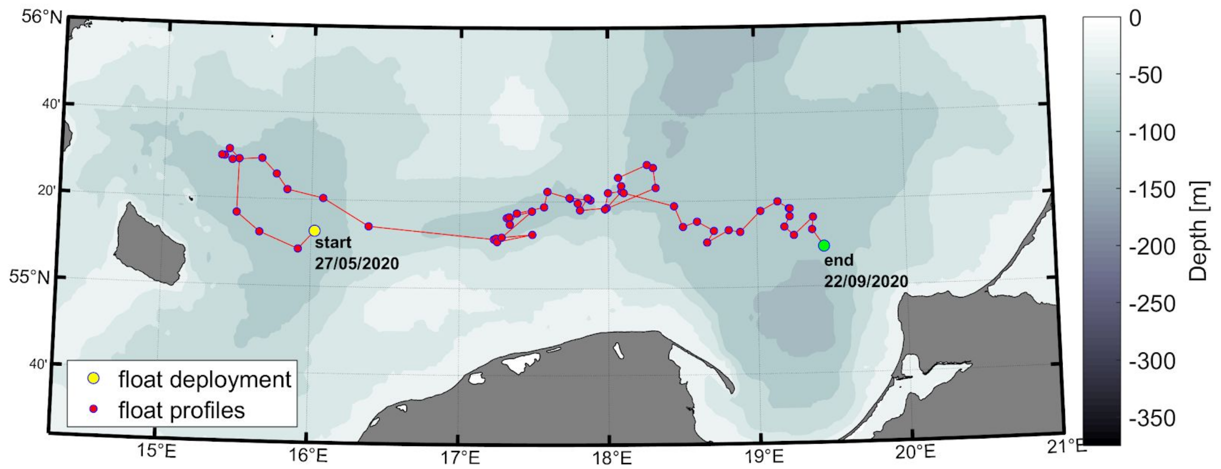

Figure 20: Pathways of the third Polish Argo ARVOR float in the Baltic Sea, WMO 3902110. (Image attribution: IOPAN)

At the beginning of June this year the CTD float within the Euro-Argo RISE project was launched in the Gulf of Gdansk (Fig. 21). Here we applied a 12-hours profiling frequency. The target of the mission is to keep the float on the shelf and use it as a virtual mooring. For this purpose, the float remains at the bottom during the parking phase. In the case of other Baltic floats used by IOPAN, the usual parking depth is 40 - 50 m. We analysed the impact of the float parking at the bottom on a distance that three floats (WMO 3902109, 3902110, 3902106) moved between 02.06 and 20.09 +-1 day (Fig. 22). During that time the float in the Gulf of Gdansk (WMO 3902109) moved much slower (109 km) than the other two floats WMO 3902110 (506 km) and WMO 3902106 (526 km). This means that parking at the bottom can have a significant impact on slowing the float's movement.

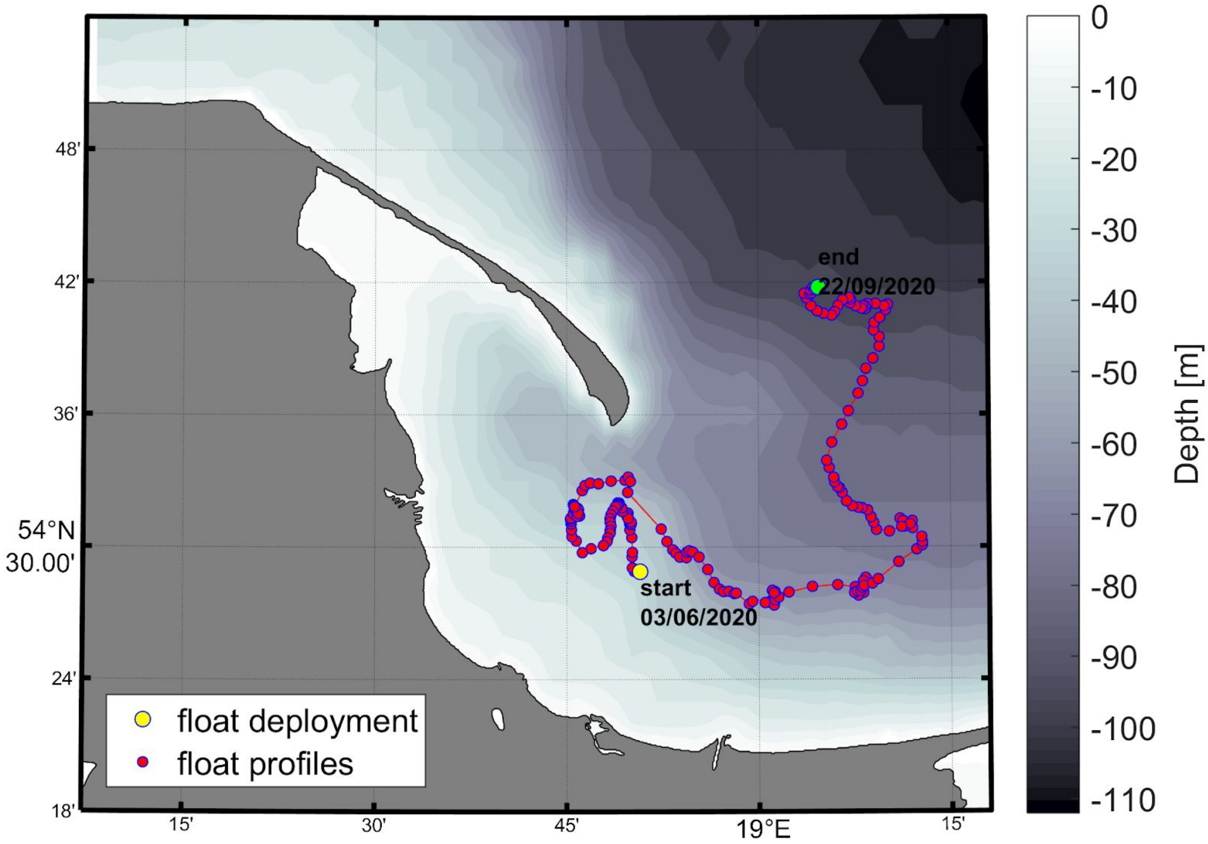

Figure 21: Pathways of the Polish Argo ARVOR float in the Baltic Sea, WMO 3902109. (Image attribution: IOPAN)

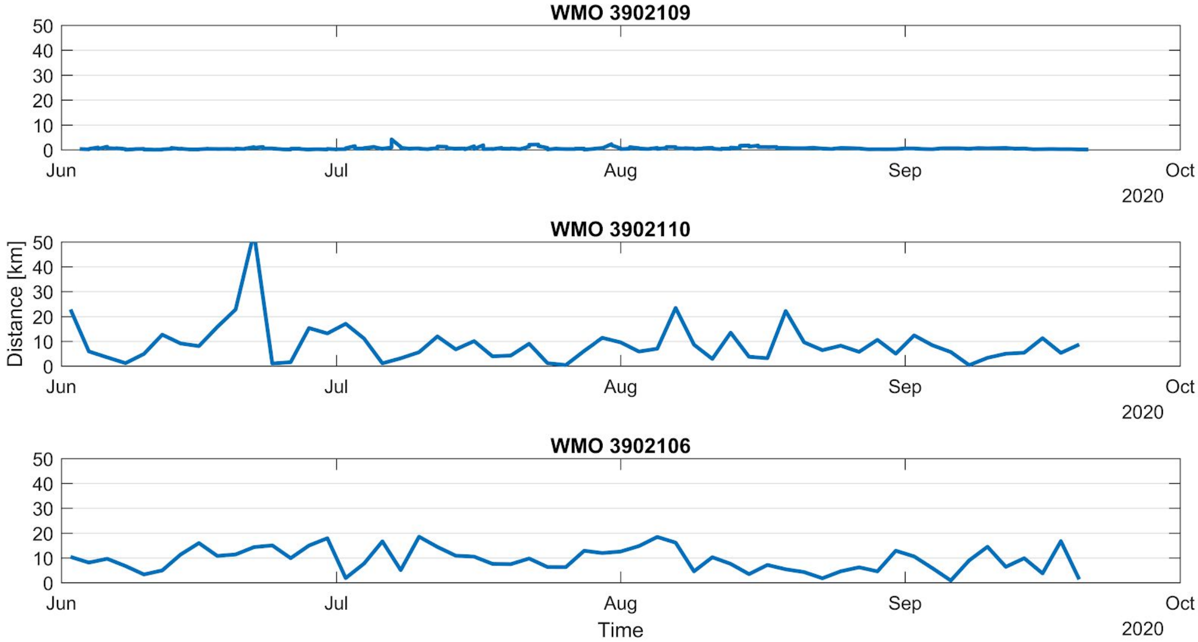

Figure 22: The distance that three floats moved between 02.06 and 20.09 +-1 day. (Image attribution: IOPAN)

Conclusions

The past experiences in the Baltic Sea from 2012 in the northern parts, and from 2017 from the Southern, have shown that shallow shelf seas can also be explored with Argo floats. The initial concerns were the low depth and small size of the Baltic Sea. However contact with the sea bed, proximity to the shore and collisions with ships are shown to be manageable problems, although there is still work to be done on determining the optimal methods of operation. This report builds upon the past experiences and expands on those with the new experiments and efforts made within the Euro-Argo RISE project. These include further developing the control parameters on known areas of operation, expansion to new areas, and experimenting with novel methods of virtual mooring.

Northern Baltic Proper is the newest expansion of the Baltic Sea Argo operations, made possible with the Euro-Argo RISE project. The preliminary results indicate that operation in the area is feasible, both with Arvor and Apex type of floats. Control methods needed to apply here do seem to require frequent bottom contacts, which so far have caused no problems in ascension.

Bay of Bothnia, being the northernmost part of the Baltic Sea is a challenging area for operations, and still in the testing phases. Ice avoiding algorithm is a mandatory feature for floats on this area, as well as constant monitoring. Even with these the area’s bathymetry makes avoiding shore contacts very difficult.

The bathymetry in the Bothnian Sea makes the control of the floats easier than in the Bay of Bothnia. In this kind of environment the floats can be kept away from shores relatively easy, however the area of operation is rather large.

Floats in the Gotland Deep have required thus far the least amount of interaction to keep them operational in a relatively confined area.

The experiments on the virtual mooring in the Gdansk Basin performed during the Euro-Argo RISE project indicate that the method succeeds in constraining the movement of the float considerably compared to other floats.

Argo floats may be used as part of a comprehensive southern Baltic monitoring system. Various sources of data, such as floats, cruises and moorings, can provide extensive, complementary data for the better monitoring of the Baltic Sea, the improvement of numerical models and validation of satellite observations. According to Euro-Argo's preliminary estimates, seven continuously working floats should be adequate for the basic monitoring of Baltic deep waters, although their recovery, redeployment and relocation may be necessary.

Additional sensors and the implementation of full BGC floats raises the value of the data. The numbers and importance of BGC floats in the Baltic Sea are set to increase. Even the use of the simplest BGC float, equipped with just an oxygen sensor, significantly enhances the opportunities for recording important processes and data interpretation. The competent, meaningful use of all the data requires the cooperation of multidisciplinary teams of scientists and technicians on the one hand and countries on the other.

Appendix 1 List of Argo missions in Baltic Sea

List of Argo missions in the Baltic Sea:

WMO number	Model	Deployment area	Mission Start	Mission end
6901901	APEX	Bothnian Sea	2012-05-17	2012-12-05
6902013	APEX	Bothnian Sea	2013-06-13	2013-10-02
6902014	APEX	Baltic Proper	2013-08-14	2014-08-21
6902017	APEX	Bothnian Sea	2014-05-30	2015-10-24
6902018	APEX	Bothnian Sea	2014-05-30	2014-11-13
6902019	APEX	Baltic Proper	2014-08-21	2015-08-05
6902020	APEX	Baltic Proper	2015-08-05	2016-08-03
6902021	APEX	Bothnian Sea	2015-09-23	2016-05-13
6902022	APEX	Bothnian Sea	2016-05-13	2016-10-11
6902023	APEX	Bothnian Sea	2016-07-13	2016-08-11
6902024	APEX	Baltic Proper	2016-08-03	2017-02-03
6902036	APEX	Bornholm Basin	2016-11-29	2017-02-01
3902100	APEX	Bornholm Basin	2017-03-15	2018-01-07
6902025	APEX	Bothnian Sea	2017-05-09	2018-10-02
6902026	APEX	Bay of Bothnia	2017-06-06	2019-01-03
6902027	APEX	Baltic Proper	2017-06-15	2018-10-15
6902029	APEX	Bothnian Sea	2017-08-06	2017-10-27
6902028	APEX	Bothnian Sea	2017-08-07	2018-09-04
3901940	ARVOR-I	Bornholm Basin	2017-09-20	2017-10-02
3901941	ARVOR-I	Bornholm Basin	2017-09-21	2019-09-10
3902133	ARVOR-I	Gdansk Basin	2017-11-06	2019-09-09
3902101	ARVOR-I	Bornholm Basin	2018-02-06	-
6902030	APEX	Bothnian Sea	2018-07-10	2019-02-18
3902106	ARVOR-I	Bornholm Basin	2018-09-11	-
3902104	ARVOR-I	Bornholm Basin	2018-05-31	2018-09-08
6903697	APEX	Baltic Proper	2018-10-15	2019-02-21
6903698	ARVOR-I	Bothnian Sea	2019-05-30	-
6903699	APEX	Bothnian Sea	2019-05-30	-
6903700	APEX	Bay of Bothnia	2019-06-01	-
6903701	APEX	Baltic Proper	2019-08-17	-
3902109	ARVOR-I	Gdansk Basin	2020-06-03	-
3902110	ARVOR-I	Bornholm Basin	2020-05-27	-
6903703	ARVOR-I	N.Baltic Proper	2020-06-10	-
6903704	APEX	N.Baltic Proper	2020-06-10	-
6903702	ARVOR-C	Bothnian Sea	2020-06-16	-

References/Further reading

- Haavisto, N. et al, 2018, Argo Floats as a Novel Part of the Monitoring the Hydrography of the hnian Sea https://doi.org/10.3389/fmars.2018.00324
- Roiha, P. et al, 2018, Estimating Currents From Argo Trajectories in the Bothnian Sea, Baltic Sea https://doi.org/10.3389/fmars.2018.00308
- Seifert, T.,Tauber, F., Kayser, B.: 2001: "A high resolution spherical grid topography of the Baltic Sea – 2nd edition", Baltic Sea Science Congress, Stockholm 25-29. November 2001, Poster #147, www.io-warnemuende.de/iowtopo.
- Siiriä, S-M. et al, 2018, Applying area-locked, shallow water Argo floats in Baltic Sea monitoring https://doi.org/10.1080/1755876X.2018.1544783
- Walczowski, W., Wieczorek, P., Goszczko, I., Merchel, M., Rak, D., Beszczynska-Möller A., Cisek, M., 2017. Monitoring the salt water inflows in the southern Baltic Sea, Proceedings of the Eighth EuroGOOS International Conference 3-5 October 2017, Bergen, Norway, pp 165-169.
- Walczowski W., Merchel M., Rak D., Wieczorek P., Goszczko I., 2020. Argo floats in the southern Baltic Sea, Oceanologia, https://doi.org/10.1016/j.oceano.2020.07.001.