Enrichments of monitoring tools to track and compare float configurations and estimate life expectancies

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Deliverable title	**Enrichments of monitoring tools to track and compare float configurations and estimate life expectancies**
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Work Package title	**Improvement of the core Argo mission**
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0.7	14/12/2020	Luca Arduini Plaisant	Final results for the European Arvor-I case study + solving all the comments. Deliverable now ready to be shared with partners.

EXECUTIVE SUMMARY

The implementation of a full-depth, multidisciplinary float array significantly increased the number of floats needed at sea and their price, naturally inducing the need to maximise floats lifetime and consequently reducing the cost per profile. This deliverable will try to provide a clear methodology to undertake life expectancy studies and list some of the main aspects of a float array to pay attention to when undergoing these types of studies.

A life expectancy study is multi-parametric and highlighting the impact of a specific parameter requires a rigorous methodology, starting with a precise sample selection, a choice of temporal units and appropriate tools to track differences in configurations. Configuration parameters dictate the behaviour of the float at sea: its number of missions, cycling time period, profile pressure, how to behave in case of grounding, etc. These parameters are defined before floats' deployment but are often changed to meet scientific specific purposes through a telecommand (available since the implementation of the Iridium technology). This deliverable will be presenting the tools developed in order to better track configuration parameters throughout a float lifetime.

Finally, these tools and methodology were put to use by conducting life expectancy studies to estimate the state of the European Arvor-I array, the impact of groundings in the Baltic Sea or the differences of survival rates according to different model types and configurations.

The survival rate of the European fleet showed poor results compared to the International one. The study presented in page **31** permitted to highlight a significantly lower survival rate for the marginal Seas deployments compared to the open Ocean ones. The proximity to shore, difficult bathymetry, numerous groundings, etc. are many parameters that could have an impact on the survival rate of the marginal Seas portion of the European array.

A case study about the impact of groundings on the battery consumption of Apex floats deployed in the Baltic was carried out. This study showed that limiting the ground contacts can save the battery. In fact, floats with fewer groundings made more cycles and covered more vertical distance than floats with numerous groundings. Even this is not without compromises, as bottom contacts can often permit a float to stay in the area of interest and provide full depth profiles.

With the help of the tools developed within this task to better monitor configuration parameters, a study was conducted on the impact of different configuration parameters (global and Arvor related) on the survival rate. The sample selected for the Arvor type is too young and did not permit to highlight if a configuration parameter value was better than the other one. This study is planned to be conducted again in the next months/years, when more floats of the sample will be dead from natural causes, hence permitting to highlight some trends in the survival rates of the different parameters considered.

After the creation of the deliverable, some additional approaches need to be explored: an audit is underway to clearly define the ending cause and recovery status of European floats. The comparison with the international array will be further refined, divided per float models, generations, etc. The creation of an energy budget tool is underway to better assess the energetic impact of each actions undertaken by the float. The study on configuration parameters will be conducted again in some time, with an older sample, hence permitting to extract more reliable trends.

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INTRODUCTION

In 2019, the Argo Program has defined its new mission that is global, full-depth and multidisciplinary (Roemmich et al., 2019. C.f. REFERENCES). Owing to technological developments over the past 20 years, Argo floats can now sample in seasonal ice zones, measure biogeochemical parameters (BGC-Argo), and make measurements throughout the water column up to 6000 m depth (Deep-Argo). Compared to the original mission of having 3000 Core-Argo floats active at any time (Argo_Steering_Team & Argo, 1998. C.f. REFERENCES), 4700 floats are now necessary to reach the objectives of this new phase, with the BGC and Deep extensions being implemented with significantly more expensive floats. Thus, the need to try to maximise floats lifetime and consequently reducing the cost per profile is now even more of paramount importance.

The number of active floats in the Argo network depends on both the number of floats deployed per year and their lifetime, which itself may depend on the way the floats are being parameterised or behave at sea. With the increased float technological capabilities (e.g. (André et al., 2020), (Riser, Swift, & Drucker, 2018)) and most particularly the massive transition of the Argo fleet towards the use of two-way satellite communication systems over the past five years (Wong et al., 2020), there presently exists a wide variety of float parameters configurations in the Argo network, that may be changed throughout float missions via remote commands.

Discussions within technical and operational Argo teams (e.g. Float and Platform Technical Workshop, 2017 Seattle, USA; Arvor/Provor floats technical Workshop, 2020 Brest, France) and among Euro-Argo deployment teams, encouraged conducting dedicated work to be able to better capture these different float configurations and investigate whether they could have an impact on float lifetimes.

The purpose of the Euro-Argo RISE task 2.1 *“Increase floats lifetime”* is to provide the means to review Argo float missions sampling, configuration parameters, shipping and deployment practices or oceanographic conditions that may have a significant impact on float reliability. The methodologies and tools developed within this task aim to bring forth valued recommendations to increase the cost-effectiveness of the Argo programme and to stretch the array’s refresh time. They will be described in the second deliverable of the task: *“D2.6: Recommendations to increase the overall life expectancy of Argo floats, based on at-sea monitoring fleet behaviour monitoring, assessment and report (including a review of metadata that impact life expectancy: specific float configurations, batteries)”*.

The first part of this deliverable will present the methodology being developed and the associated monitoring tools. The second part will expose the first results in trying to compare floats' lifetime. This work will continue in 2021 to be able to develop some recommendations in the D2.6 deliverable.

A. METHODOLOGY

1. Introduction

1.1. Rationale

The rationale behind this task is for Euro-Argo to improve our understanding, computations and monitoring of float life expectancies. Some open access tools already exist to assess Argo floats lifetimes but it might be sometimes difficult to understand or interpret the results.

A first indicator of Euro-Argo floats life expectancy is provided in OceanOPS website (Metrics > KPIs, c.f. OceanOPS Tool part).

Another indicator available on the OceanOPS website is the « Performances on target », i.e. the percentage of floats reaching a given target of profiles. It is computed for each generation or deployment year.

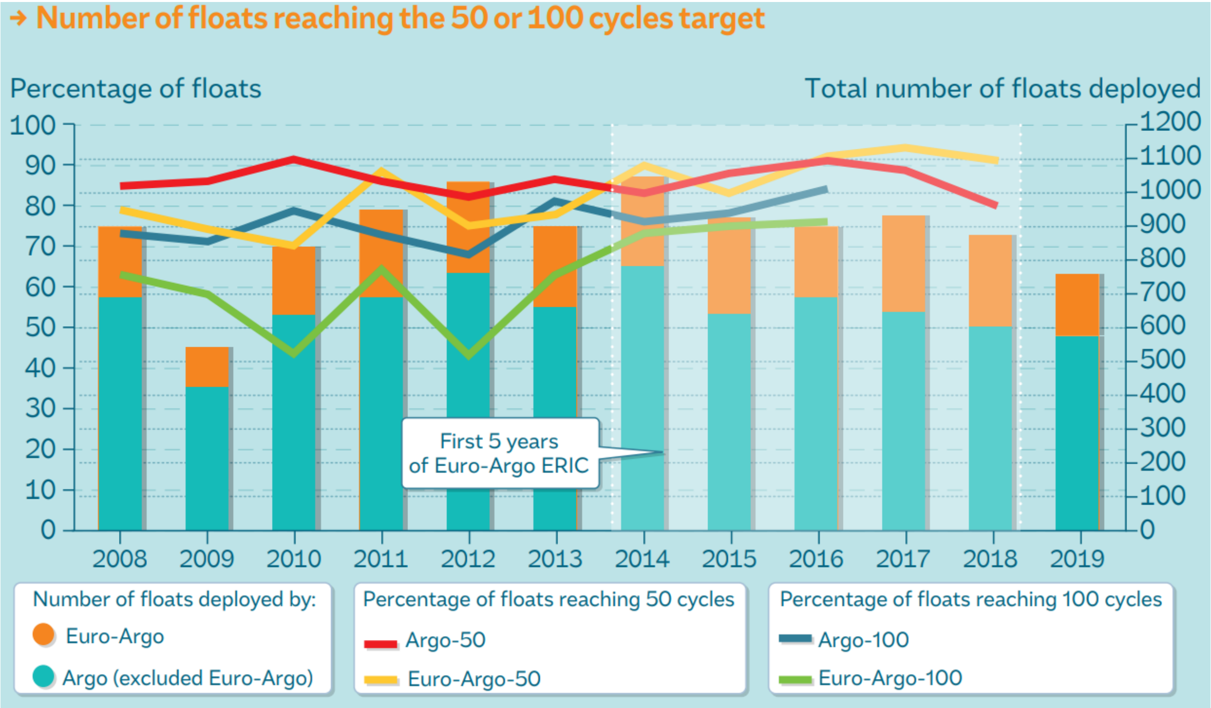


Figure 1-Percentage of floats reaching the 50 or 100 cycles target compared to the Argo fleet (coloured lines, left axis) and total number of floats deployed (right axis). © OceanOPS/AIC

On the figure above, we can see that in recent years the performance of Euro-Argo floats reaching 50 cycles (yellow curve) is higher than the global fleet (red curve). The percentage of Euro-Argo floats reaching the 100 cycles (green curve) target is progressing but still below the one of the global fleet (blue curve).

All of these reasons gave us the will to investigate if the life expectancies of the Euro-Argo fleet could be further refined, considering several aspects:

1. Approximately 17% of the Euro-Argo floats deployed since 2015 are in marginal seas, with sometimes specific configuration (e.g. shorter cycle periods) that could be taken into the survival rates computations. Configuration parameters are described from the Argo Manual as: “float settings selected by the PI (Principal Investigator), not measurements reported by the float”. Configuration parameter names are identified by the “CONFIG” prefix in the Argo data format. All parameter names

are standardized and are available in the online reference tables. Configuration parameters are separated into two types:

- **A/** Pre-deployment or launch configuration parameters that are the "configured" start settings of the float and the initial mission configuration parameters for the first cycle.
- **B/** After deployment configuration parameters define float behaviour for each mission (record of the information that changes from cycle to cycle), including all applicable mandatory and highly-desirable parameters and any other parameters that change during the life of the float are reported as mission settings.

2. Part of these floats are being recovered before having exhausted their batteries; this could be again considered.

3. Performances could be also analysed with respect to different float models. In recent years, the Euro-Argo network has seen a majority of deployments from a European manufacturer, with a technology improved since 2016. We deem it useful to analyse the latest performances of the fleet.

4. The metrics presented above provide elements to assess the implementation costs of the Euro-Argo network, that is to say the number of floats needed each year to reach a given number of operational floats at any time. But, in this Euro-Argo RISE task, we would like to further investigate and refine the analyses to review Euro-Argo float missions sampling or configuration parameters, and see whether they could have an impact on float lifetimes. In the next sections we will describe the methodology being developed, and the enrichments of monitoring tools to track and compare float configurations, and estimate life expectancies.

1.2. Challenges

When describing a global network of floats, it is difficult to draw some conclusions regarding their life expectancy or even performances for three main reasons:

- Heterogenous configuration parameters
- A reliable temporal unit
- Different "end of life causes" according to the sample

Concerning the first point, at the beginning of the Argo program, the majority of the floats had the same configuration parameters, adapted to an open ocean configuration. The development of the Iridium technology for the most recent part of the fleet permitted users to modify remotely the parameters of a float with remote controls, thus contributing to the heterogeneity of these parameters. Besides, with the expansion of the program to the marginal seas, the bathymetry and proximity to the coast are some important factors that induce a quick adaptation on the configuration parameters of the floats (see for instance Figure 3 Figure 3below), contributing to this diversity of missions during a float lifetime.

The following chart represents the number of changes of missions per float, for all the European float types (derived from the PLATFORM_TYPE field, extracted from the Argo Reference Table 23 : http://vocab.nerc.ac.uk/collection/R23/current/) and the geographical repartition of these changes. A mission is used to record the information that changes from cycle to cycle; for instance, when a float changes its mission from 3 shallow profiles to one deep one. The shallow and deep profile will have different mission numbers. The value of this mission number is recorded in the configuration file, under the variable "CONFIG_MISSION_NUMBER". Any change of a float configuration through its lifetime will induce a mission number superior to 2.

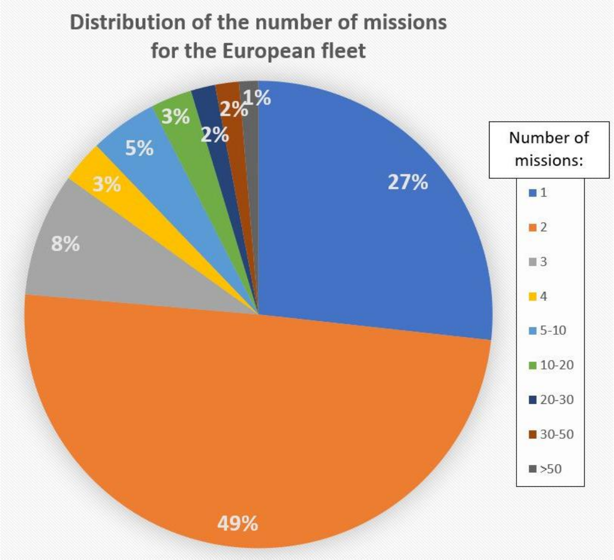


Figure 2- This diagram shows the statistical distribution of changes of mission for the European fleet since its beginning

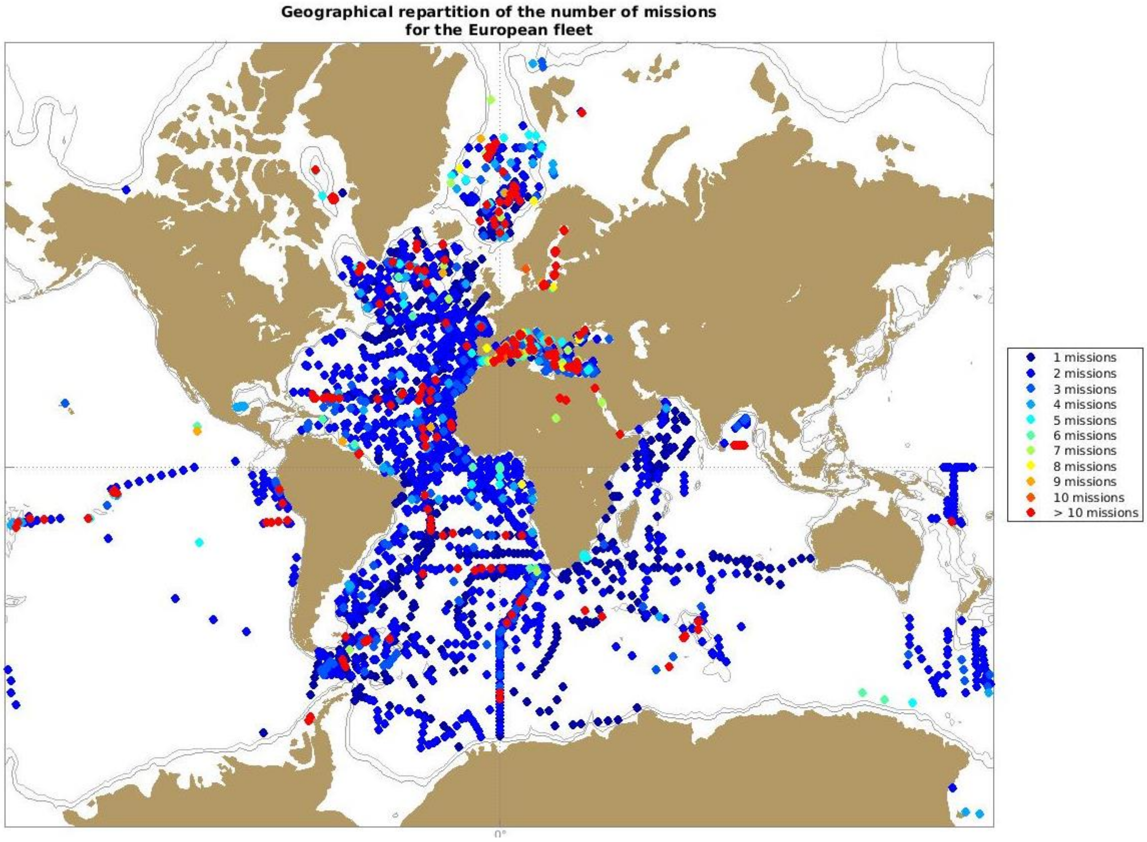


Figure 3- This map presents the geographical repartition of the changes of mission of the European fleet. Points indicate float deployment locations.

Second, there are many ways to express the lifetime of a float but some of them don't represent the same characteristics of the sample. A lifetime expressed in years is not the best indicator when comparing two samples of floats with different cycle time periods, whereas the vertical distance covered by these two floats, or the number of cycles achieved, could be more appropriate. The part

"Choice of a temporal unit" will express the differences of these temporal units and how they complement each other.

For all these different reasons, a meticulous sample selection is absolutely necessary in order to isolate a specific float configuration parameter to analyse, while minimizing the impact of the others to permit better interpretation in terms of life expectancy. It wouldn't be accurate/true to compare a float which died from drifting ashore and one which died emptying his battery pack.

Besides, a separation of samples according to their floats model and telecommunication mode (Argos or Iridium) is necessary as the technology and energy budget are different, so is their life expectancy.

Therefore, preparing representative samples and dissociating the different floats configurations and technologies in a network would bring added value for lifetime studies. For the purpose of this task, some tools have been developed permitting:

- To group and monitor floats samples according to their configuration parameters and their modifications during mission (CONFIG_fleet_status script)
- Plot a certain technical parameter on a map (these parameters are registered for each cycle performed by the float in an Argo technical file. The number and type of technical information is different from one float model to another; the list of technical parameters names may be found from the Argo Data Management website)
- Calculate a survival rate for a group of floats according to various parameters

As explained before, the necessity to discriminate to one float model to investigate the impact of a specific parameter induced us to select one. The float type selected throughout the major part of this report (when not comparing different models life expectancies) is the ARVOR - Iridium floats which represents the majority of the European fleet deployments in the last 5 years:

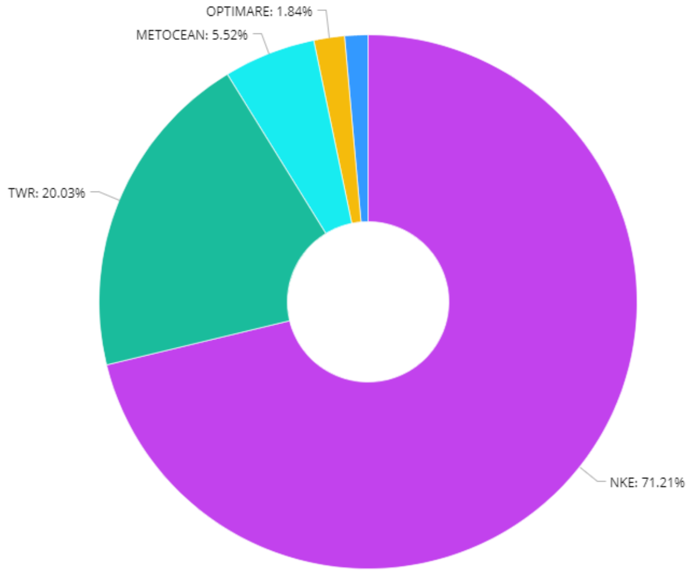


Figure 4- Repartition of Euro-Argo floats deployments since 2015 per platform_maker (1360 floats total). The dark blue portion represents SBE with 1.37% of the sample. Source OceanOPS.

NKE being the manufacturer of the ARVOR floats and its derivatives (Arvor-Light, Deep Arvor, etc), the Arvor type represents 71% of the European floats deployed since 2015.

2. Survival rate computation

The survival rate of a float sample used throughout this report is derived from the article [*Kobayashi and al., 2009.] (C.f.* REFERENCES) following a Kaplan-Meier approach (common method in medical statistics) and defined as follow:

Survival rate is defined as the percentage of floats alive for a certain cycle number (or age or vertical distance), which is the percentage of floats able to make a certain number of cycles (or age or vertical distance). As the sample considered often contains dead and alive floats, it should be considered if they are able to make *x cycles* (or vertical distance or age).

The formula of the survival rate is as follows:

$$\frac{Floats > x\ cycles}{Floats > x\ cycles + death\ floats <\ x\ cycles} \quad (1)$$

In order to better understand the meaning of this formula, it is interesting to compare it to a more basic approach when talking about survival rate. Let's assume that we define the survival rate as the portion of floats alive at x cycles, divided by the total amount of floats deployed, so:

$$\frac{Floats > x\ cycles}{Total\ floats\ deployed} \quad (2)$$

Here is what it looks like when comparing the two survival rates in a graphic:

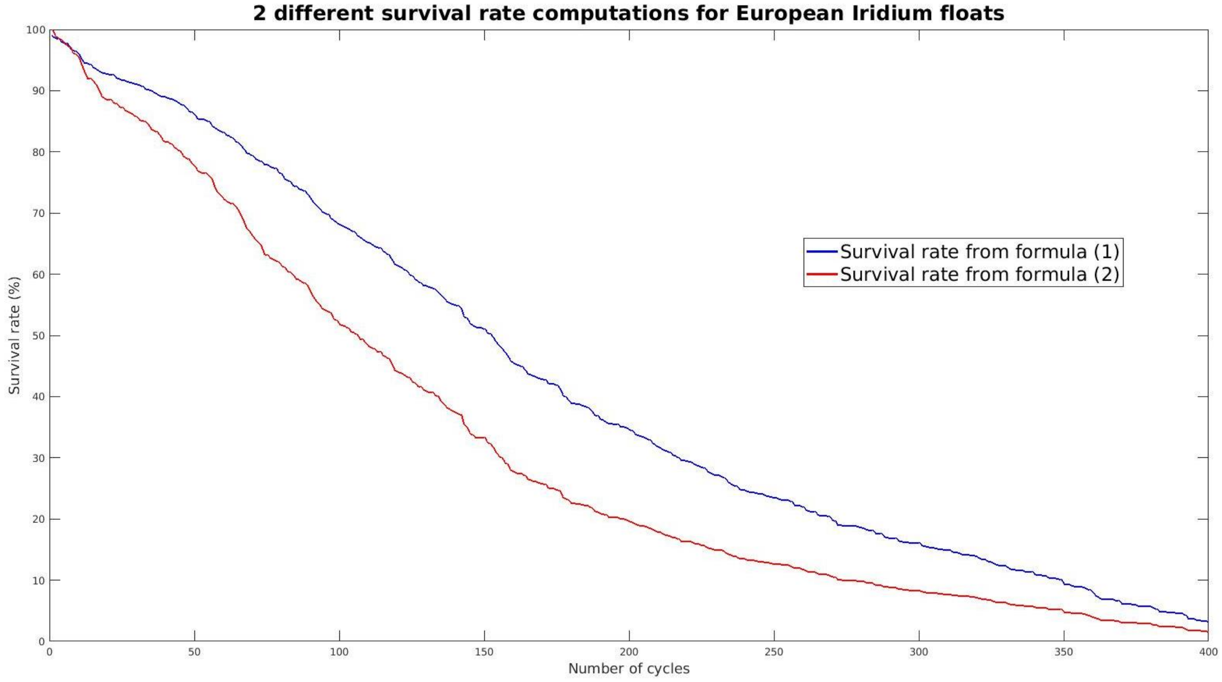


Figure 5- Survival rates computations from the same sample: all European Iridium floats deployed since 2008. The blue curve is obtained using the formula (1) when the red one uses the formula (2).

The red curve is obtained from the Formula (2) when the blue curve comes from the Formula (1). The numerators are the same, so the difference comes from the denominators. The denominator from (1) only takes in consideration the dead floats that did less than x cycles. When focusing only on dead floats before x cycles, it removes from the sample the floats still alive that did less than x cycles. These floats are still too young and did not have the time to reach the x cycle mark, when the denominator of (2) considers the whole sample, including these young floats.

One can note that at the beginning of the graph, the red and blue curves overlap because most of the floats reached at least the first 5-10 cycles (denominator (1) = denominator (2)). In the middle (cycles 10 to 300) part, the formula (2) artificially decreases the survival rate because taking in consideration floats that did not reach these amounts of cycles yet. Finally, at the end of the plot, the two curves converge because the numerators, the floats that reached this important number of cycles, are fewer and become very little compared to the denominator. Although these curves converge at the end, they will not overlap again as this substantial difference of floats too young not considered in one computation still subsist.

Here we are taking into account the cycle number time variable but it would be exactly the same for the vertical distance in Km or the age of the floats. The following part will now focus on the influence of the sample selection in life expectancy studies.

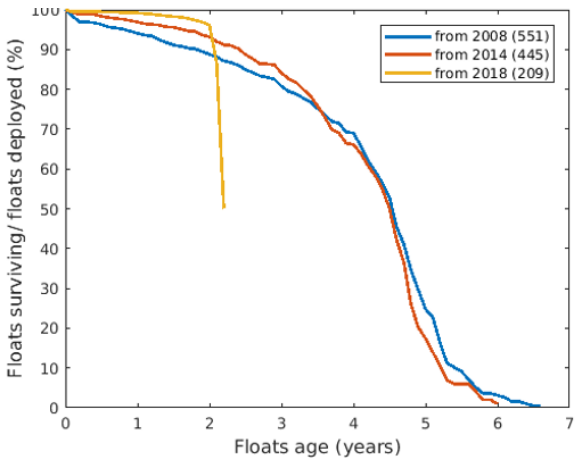
3. Sample selection

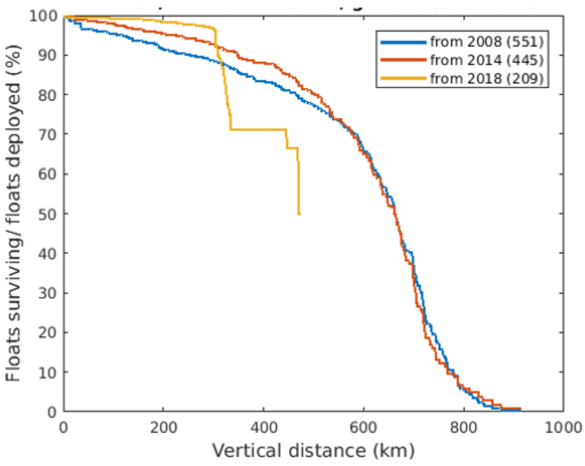
The sample selection is one of the most, if not the most, determining part of a survival rate calculation. For the comparison of life expectancies between two float samples, the fewer are the differences between samples, the more reliable will the comparison be. In fact, comparing different models to estimate the impact of a specific parameter (configuration or technical) is tricky as their technologies are different, comparing floats configured with radically different parameters also brings more complexity and grey areas to the conclusions of such a comparison. Therefore, the sample of floats considered has to be carefully chosen, in order to furnish meaningful interpretations and conclusions from the survival rate computation.

The following part will focus on the different points that this study has revealed as the most important when selecting a group of floats to compute its life expectancy.

3.1. Deployment date

The comparison between different deployment year samples permits a better understanding of the impact of the age on the survival rate computation:





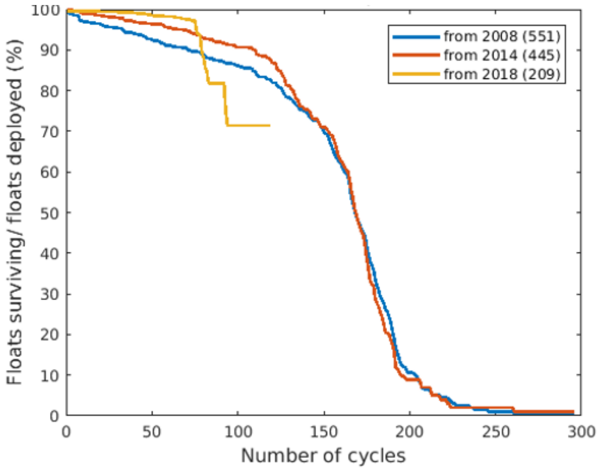


Figure 6- Survival rates computed thanks to the formula (1) for three samples: Global Arvor floats deployed with standard mission parameters in the global ocean (5 main oceans) since 2008 (blue), 2014 (red) and 2018 (orange). Both ARGOS and Iridium telecommunication systems are considered. The brutal drop of the youngest sample (orange curve) is an artificial bias and is explained hereafter.

- ❏ The first sample (blue one) is made of floats with a mean age of 2.7 years, with a 35% portion of inactive floats.
- ❏ The second sample (red one) has a mean age of 2.4 years and 22% of inactive floats.
- ❏ The third sample (orange one), made of young floats deployed since 2018, has a mean age of 1.2 years with 1% of inactive floats.

When analysing these plots, two key points have to be noted:

- The date of deployments of these floats are, for the most part, representative of their time of manufacturing. Therefore, representing in some ways, the evolution of technologies of the float. In this case, for Arvor floats, many changes and improvements of the technology (hardware & firmware) have been performed during the French NAOS project, resulting in "before 2016" and "after 2016" Arvor floats generations. The higher survival rate visible in the first part of the curves for the later batch of deployed floats reflects these improvements of the float's technology.
- The portion of inactive floats being very low for the sample deployed in 2018, most of the floats weren't able to complete enough cycles **yet** to be compared with the other samples. This specific case induces an **artificial artefact** symbolized by this huge drop in life expectancy rate for the 2018 sample, **which is not representative of the reality.** In this case (for the 2018 sample), only two floats had enough time to pass the 2 years mark, with one of them being inactive, thus decreasing the survival rate at 50% when in fact only two floats of the whole sample are taken into computations at two years.

3.2. Floats model

Floats models (derived from PLATFORM_TYPE metadata from Argo reference table 23) are an important factor when creating a sample for life expectancy calculation. Each float model is different and uses different technology (e.g. Arvor: hydraulic pump and solenoid valve, Apex: pistons) thus needing to be differentiated when comparing energy consumption and survival rate.

However, we can still compare the life expectancies of different float models for similar configuration parameters, causes of death and sensors embarked, or compare different generations of the same float model to monitor the enhancement of the technology and its impact on the life expectancy.

Such a study was carried out in the NAOS project (André et al., 2020. C.f. REFERENCES) as presented in the following figure, comparing the life expectancy of Arvor floats manufactured before 2016 and after 2016 (taking into account the NAOS related technological development of the Arvor floats):

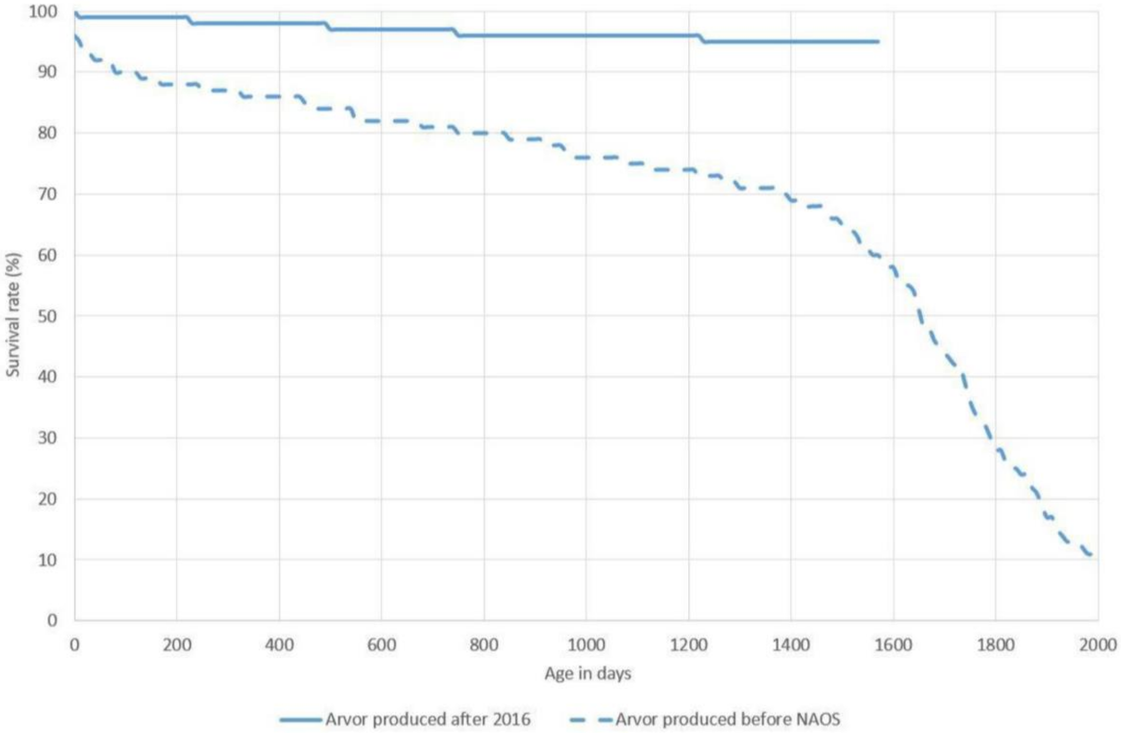


Figure 7- Survival rates of the Arvor profiling float. After 1,000 days at sea, 96% of the Arvor "after NAOS work" (i.e., produced after 2016, depending on the serial number) are still in operation, compared with 76% of the Arvor "before NAOS work" (produced and deployed from 2013 to 2016). Source: André et al., 2020

In the frame of the Euro-Argo RISE WP2 objective aiming to maintain the core Argo mission (Temperature and Salinity measurements), it would be interesting to compare the life expectancy of different float models as they carry the same type of sensors. However, we have to bear in mind that some of these floats have lithium batteries while others are alkaline, some use RUDICS telecommunication method when others use SBD, etc. Some differences will persist when comparing different float models but it is still more meaningful doing it for floats measuring the same variables (T/S (Temperature/Salinity), T/S + DO (Dissolved Oxygen), Biological parameters, etc.) in terms of sensor consumption and data transmission.

3.3. Float recovery

This aspect, as for now, affects mainly the European marginal sea regions of the Argo program than the open ocean. In fact, the proximity to the coast in some deployments in marginal seas often results in the float drifting towards the shore, due to underwater current or on surface, mainly due to wind induced currents. At an International level, for the whole Argo program, according to the OceanOps portal, a bit less than 4% of the floats are recovered when almost 6% of European floats are recovered. From a global point of view, 36% of floats recovered in the global Argo program are done by Euro-Argo. It's the case for the Baltic sea where **70%** of the floats are recovered and for the Mediterranean and Black seas where 15% of the floats are recovered. Float recovery represents a real interest for cost-saving, sensor recalibration purposes and reduction of the environmental impact. However, a float recuperation induces some non-negligible bias when computing the life expectancy of a fleet of floats if an increasing part of the floats are being recovered. The recovered floats could artificially decrease the global life expectancy of the sample especially if it is recovered at a young age.

In order to prevent this artificial bias, recovered floats before their "natural death" could be removed from the sample. The OceanOPS tool integrated a set of metadata for Argo fleet operators to fill, to inform if a float has been recovered before it reached its end of life status. This field is new in the OceanOPS AIC tool and might be unheard of for Argo fleet operators but it is a very interesting and needed tool to simplify and better assess float life expectancies in the European fleet.

In order to best use this metadata in lifetime computations, efforts have to be spent to ensure the information is correctly provided. Euro-Argo ERIC office team will work with the different European teams to complete this recovered field for the European fleet.

For this audit, we consider reviewing the floats that have the same Serial Number (FLOAT_SERIAL_NO) and/or Transmission identifier (PTT) of the float IMEI (International Mobile Equipment Identity) for different WMOs numbers. In fact, after the recovery of a float, the serial number and IMEI are still the same when re-deployed but the WMO changed because of UNESCO/WMO rules. This Audit will be conducted by the Euro-Argo ERIC Office team with the help of the OceanOps team as this field could be used in survival rate computations, depending on the objective of the analysis.

When analysing the age repartition for recovered floats, a significant part has been recovered within a month, probably due floats malfunctioning. Some floats have been recovered probably very short before having exhausted their batteries.

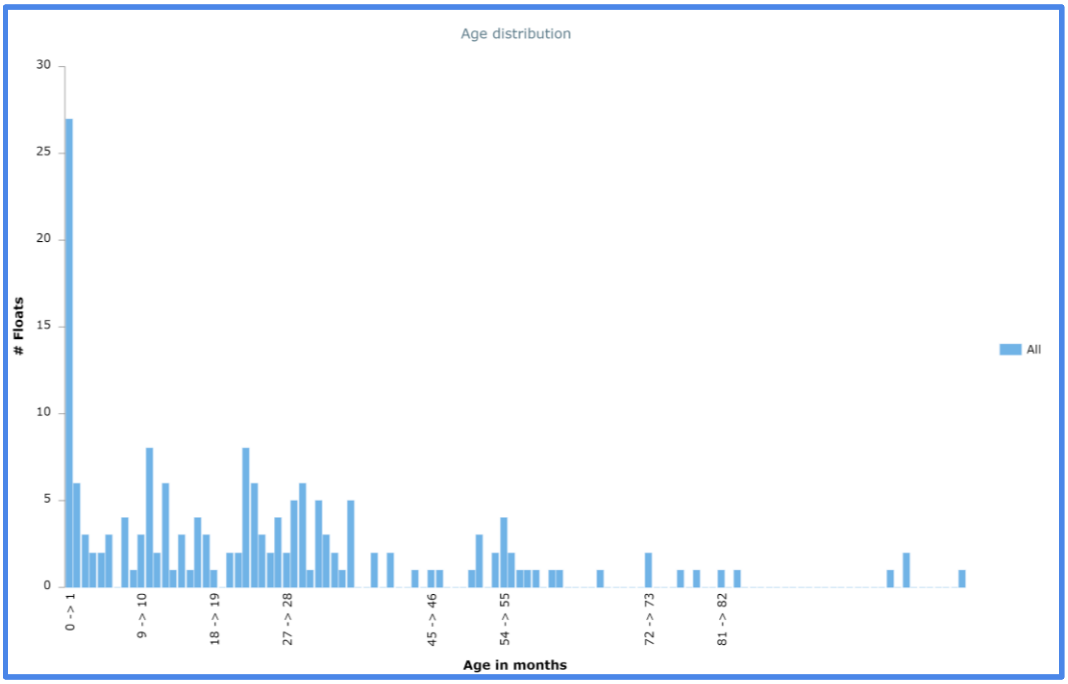


Figure 8- Age distribution of the European recovered floats (172 floats). Source: OceanOPS website

3.4. Causes of floats death

Throughout this report, we consider the "natural" death cause for a float when a float would have exhausted its batteries. When studying floats dead from natural causes, we monitor closely the battery level graphs. Hereafter is presented the example of the float WMO6902715, which triggered an alert (implemented in the [Fleet Monitoring Tool](https://fleetmonitoring.euro-argo.eu) to warn float owners if any irregular behaviour or some key thresholds are reached for the considered float) on the fleet monitoring tool [https://fleetmonitoring.euro-argo.eu/float/6902715] because of its battery level:

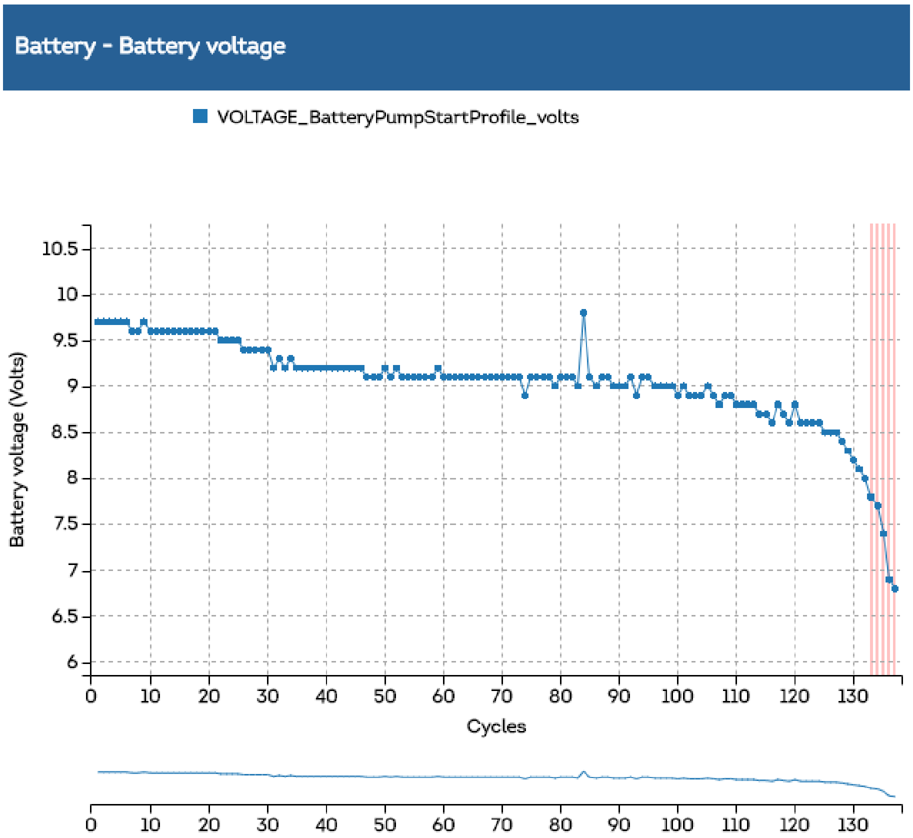


Figure 9- The red background lines on the figure correspond to the cycles where the float 6902715 battery level dropped under the 8V threshold (threshold currently defined for the Arvor float type). From this point on, the battery level dramatically decreases until the float death. Source: Euro-Argo fleet monitoring tool.

When focusing on floats dying from natural death, it is needed to select an old enough sample so some of the floats have the time to die naturally from battery consumption. It is a challenge when focusing on the most recent models of floats like explained in this part.

Floats are deployed in challenging environments where a small bump in the road could transform in a huge malfunction or worst, an anticipated death float. These elements are numerous: problems during the float deployment, ashore drifting, difficult bathymetry, unwanted groundings causing the float to be stuck in soft material, drifting on the continental slope or highly increased number of hydraulic actions to trigger the ascent, etc.

Within this task, we want to investigate how the end of life causes impact the different survival rates computations. For instance, in order to investigate the impact of a specific configuration parameter, we seek to compare the survival rates of floats that died on battery level ('natural' death) and check for any differences in performances. The OceanOPS portal made available for all users a declarative field named "ending cause" on their website. Filling this field as much as possible for float owners that already investigated the causes of death of their floats would be a huge step for a more reliable sample selection and thus life expectancy computations.

In 2021 we intend to work with Euro-Argo deployment and operational teams to try to reference this metadata in the Argo data system (most probably, in OceanOPS). Methods will be proposed to try to detect floats that exhausted their batteries or that drifted at surface.

In the Kobayashi and al., (2009) article (C.f. REFERENCES), the selection of a sample based on the death causes of the floats is the first step for a proper life expectancy computation. Are removed from a global sample all the recovered floats, the ones which drifted ashore, the sensor failures, etc. as the study aims to enlighten a global life expectancy conclusion for an Apex float working normally, without the addition of unwanted events that might impact the energy consumption budget.

Therefore, when a global life expectancy analysis is conducted, it is important to consider a sample as homogeneous as possible, regarding the time of deployment, the model, and the causes of death; yet with a significant sample size so the conclusions derived from it can be meaningful.

4. Choice of a temporal unit

As previously explained, when examining the life expectancy and performances along time of a floats network, it is important to carefully select the temporal units for these comparisons. Depending on the temporal unit selected, different characteristics of the float samples are underlined and conclusions have to be put in perspectives.

Three temporal units were examined in this task, such as: the float age (in years), the number of profiles completed and the vertical distance travelled in the water column. These last two have been examined with developments related to the Euro-Argo RISE WP2.

4.1. Age (years)

The age of the float is the most intuitive temporal unit we could get but it gives however a great understanding about the time spent since the deployment. It allows to classify floats regardless of their cycle time period and profile pressure. Let’s take a recent float, deployed in the Mediterranean Sea in 2018, with a 2-day cycle time period and an older one with a 10-day cycle time period, deployed in 2016 in the Atlantic Ocean. It would take 73 days for the Mediterranean float to accomplish the number of cycles that the Atlantic one did in one year. When comparing these two floats according to their cycle number, it will seem that the Mediterranean float is the older one as he undertook more cycles than the other. Thus, this temporal unit gives a basic understanding of the age of the float since deployment, regardless of any configuration parameters. Survival rates expressed as a function of float age are highly relevant when looking from the Argo network implementation and cost perspective. In our example, we would have to deploy five times more floats in the Mediterranean Sea than in the Atlantic Ocean to sustain the same number of floats active at any time if considering the same profiling depth.

4.2. Number of cycles

The number of cycles achieved by a float gives a different estimation of the life expectancy of floats. The number of cycles could be more reliable than the age since the deployment, regarding the hydraulic and other energy consuming actions undertaken by the float.

As a general rule of thumb, hydraulic actions performed by a float (e.g. pump actions in case of Arvor floats) require more energy at high pressure than at low pressure. Hence, a float profiling at 2000m would decrease more rapidly its energy budget than a float profiling at 200m. The number of cycles also permits to better understand how much profiles are made available by a certain float sample. Let’s take the current percentage of European operational floats among the whole Argo program: 22%. However, if the contribution of the European fleet in terms of observations available per time frame (e.g. monthly) is to be investigated, it represents a higher percentage among the whole program: 27 %. (percentages obtained from the “observations availability” in the OceanOPS dashboard). The number of cycles plays a key role in this comparison, highlighting the fact that a significant part of the European floats have a shorter cycle period compared to the rest of the International fleet, mainly due to some previous and current programs aiming to better observe European Seas, with a lower cycle time configuration, better adapted to coastal and shallow areas (C.f. Euro-Argo ERIC, (2017). REFERENCES).

4.3. Vertical distance (Km)

Ultimately, when talking about life expectancy and performances, the vertical distance travelled comes as a good compromise; as it considers the number of cycles and the profile pressure. The vertical distance travelled is calculated as twice the maximum pressure reached by the float at every cycle. A float cycling every 10 days at 2000m (standard configuration) will reach a vertical distance of 100 Km in 0.7 years, whereas a float cycling every 2 days at 200m reaches it in 1.4 years.

Thus, it is extremely important when comparing these floats in terms of energy consumption, to acknowledge the fact that the one cycling every 2 days has been at sea for 1.3 more years than the other one. As for now, we have little information about the direct link between battery consumption and life expectancy; it is a **multiparametric relationship** that we do not have entirely access to and is not 100% reliable. Recommendations to manufacturers were issued to be more transparent about the energy consumption of floats and give us more insights in the energy budgets so we can better assess the parameters to look into.

However, one could suppose that the proportion of other phenomena than hydraulic actions like data transmission or unwanted groundings, in the energy consumption budget is way more important for the float which is at sea for a longer period. If a comparison is made between an open ocean float, cycling every 10 days at 2000m and one in marginal seas cycling every 2 days at 200m, the one cycling every two days will transmit 5 times more often, but with smaller data volume than the one cycling at 2000m. Let's take the example of two floats deployed in 2017, one in the open ocean (here, Atlantic) with a standard configuration and the other in a marginal sea (here, Mediterranean).

- **6902768:** Northern Atlantic float, cycling every 10 days at 2000m depth.
    - It transmitted 133 cycles. For its last cycle, it transmitted almost 1000 CTD measurements.
- **6902767:** Mediterranean float, cycling every 5 days for most of the cycles, at either 700m or 2000m depth every 2 cycles, hence contributing to the standard Argo mission with a 2000dbar profile every 10 days.
    - It transmitted 417 cycles. For its last cycle (at a 2000m depth), it transmitted almost 500 CTD measurements.

These different temporal units, when used complementary, provide useful information and permits to highlight the differences of a sample, which at first sight seemed pretty homogenous.

B. Enhancement of monitoring tools to track appropriate parameters for life expectancy studies

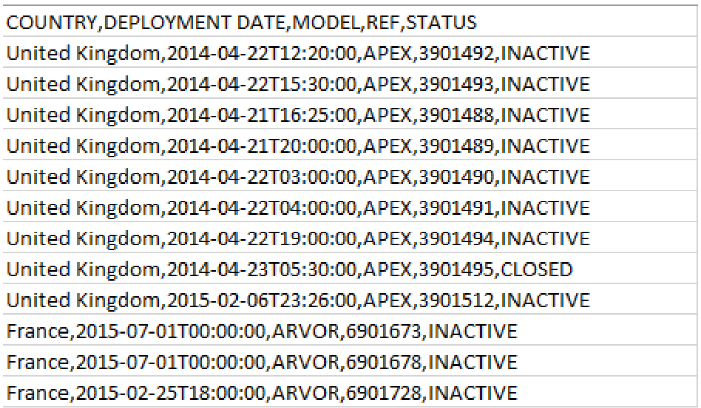
One of the main objectives of this task is to develop and enhance the tools to monitor lifetimes of various fleets. A first tool was developed in the frame of the MOCCA project, that laid the foundation for better float monitoring: the Argo Fleet Monitoring. This tool gathers all the technical data and metadata of the floats, therefore permitting users to monitor the trajectory of their floats, how the last cycle was performed, if any odd behaviour appeared during the previous cycle (alert system), the battery voltage, etc. This is a powerful help when monitoring floats, however it operates at individual float scales when the objective of this task is more oriented toward the description of a global fleet.

The configuration parameters are set for each float before deployment (cycle time period, profile pressure, number of CTD points to measure, etc.). However, thanks to the Iridium technology, scientists are able to tune the configuration parameters of a float by sending a remote control, in order to make it stay in a certain zone, measure more or less points, dodge a difficult bathymetry, etc. The post-deployment changes of configuration parameters are mainly used in marginal seas (see **Figure 3**) due to smaller basins scales, proximity to shore thus raising the needs, especially for the European fleet, to monitor the configuration parameters throughout an entire float lifetime.

1. Config fleet status

The importance of a homogeneous sample in terms of configuration parameters when it comes to performances and life expectancy analysis has been proven before. This process starts with a reliable description of a float sample in terms of configuration parameters. A dedicated MATLAB routine has been developed in Euro-Argo RISE task 2.1.

This tool takes as an input a list of floats in a csv format, with a WMO number, Country (metadata collected from the OceanOps portal), DAC path and a configuration parameter (float settings selected by the Principal Investigator, not float measurements) to be analysed. Using netCDF files available from the GDAC, it examines for each float the information contained in the netCDF files and then it returns the values for the configuration parameter given in the input.



```
COUNTRY,DEPLOYMENT DATE,MODEL,REF,STATUS
United Kingdom,2014-04-22T12:20:00,APEX,3901492,INACTIVE
United Kingdom,2014-04-22T15:30:00,APEX,3901493,INACTIVE
United Kingdom,2014-04-21T16:25:00,APEX,3901488,INACTIVE
United Kingdom,2014-04-21T20:00:00,APEX,3901489,INACTIVE
United Kingdom,2014-04-22T03:00:00,APEX,3901490,INACTIVE
United Kingdom,2014-04-22T04:00:00,APEX,3901491,INACTIVE
United Kingdom,2014-04-22T19:00:00,APEX,3901494,INACTIVE
United Kingdom,2014-04-23T05:30:00,APEX,3901495,CLOSED
United Kingdom,2015-02-06T23:26:00,APEX,3901512,INACTIVE
France,2015-07-01T00:00:00,ARVOR,6901673,INACTIVE
France,2015-07-01T00:00:00,ARVOR,6901678,INACTIVE
France,2015-02-25T18:00:00,ARVOR,6901728,INACTIVE
```

Figure 10- An example of input list for the CONFIG_fleet_status tool. The information has been extracted from the OceanOPS website. Here the sample (built from the OceanOPS query menu) is European floats deployed in the open ocean in 2008. The "ref" field corresponds to the WMO of floats (7 digits number). The status is either: Operational (at sea, transmitting data), Inactive (no data received since a certain time), Closed (no data received since a long time, the float is considered dead). The others status existing in the OceanOPS tool are not used in these analyses as they express the planning of future deployments.

It returns the different values this parameter was given and how many times it changed during the mission, grouped by the following fields extracted from the AIC of OceanOPS: country, deployment year and float model. The changes in these parameters are expressed in terms of number of changes (or percentage of floats from the sample) and number of cycles.

This tool allows a better understanding of a float sample configuration trend for a given parameter. It permits to clearly see how much the parameter was changed during the float's mission and for which value, if it was since a specific date or on a specific model, etc… It provides insight of configuration habits from different deployment teams.

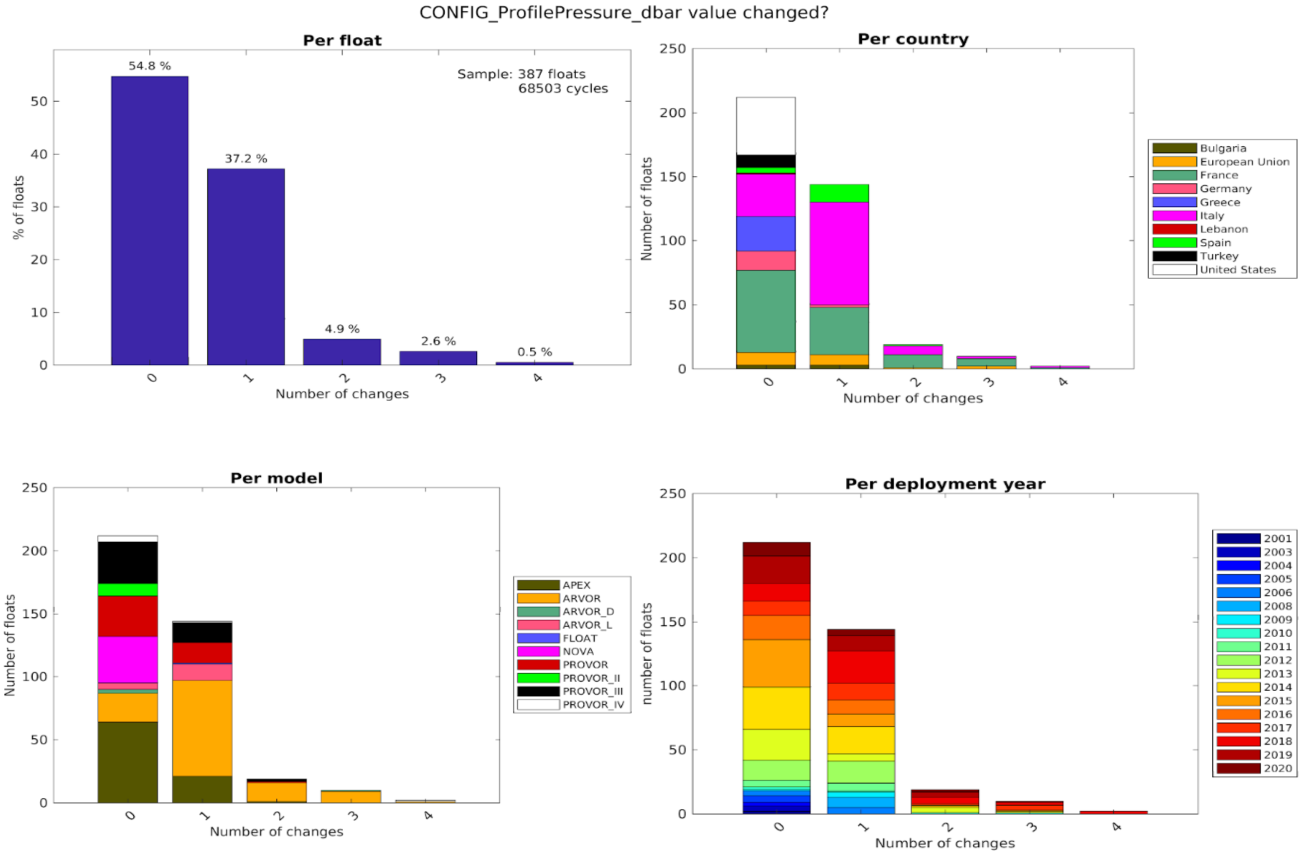


Figure 11- Sample is: floats deployed in the Mediterranean Sea, since 2008. In top left plot: the number of changes in the configuration parameters in percentage of floats to the whole sample. Top right: per country. Bottom Left: per float model and bottom right per deployment year

The number of changes in floats missions increased considerably over the time, therefore justifying the need to monitor closely these changes (C.f. **Figure 2**). The Mediterranean Sea is a particularly good example, where 45% of the floats deployed in this region (387 floats total) have seen their profile pressure parameter changed after deployment.

Majority of the floats that did change this parameter, changed it only once during its float lifetime (37% of the 45%). A clear trend emerges from these graphs regarding the country and floats model that did the most changes: France and Italy, with Arvor floats. No clear trend however for the deployments years as changes in configuration occurred during early and recent years.

For comparison, the next figure expresses the changes for the same configuration parameter but for an open ocean sample:

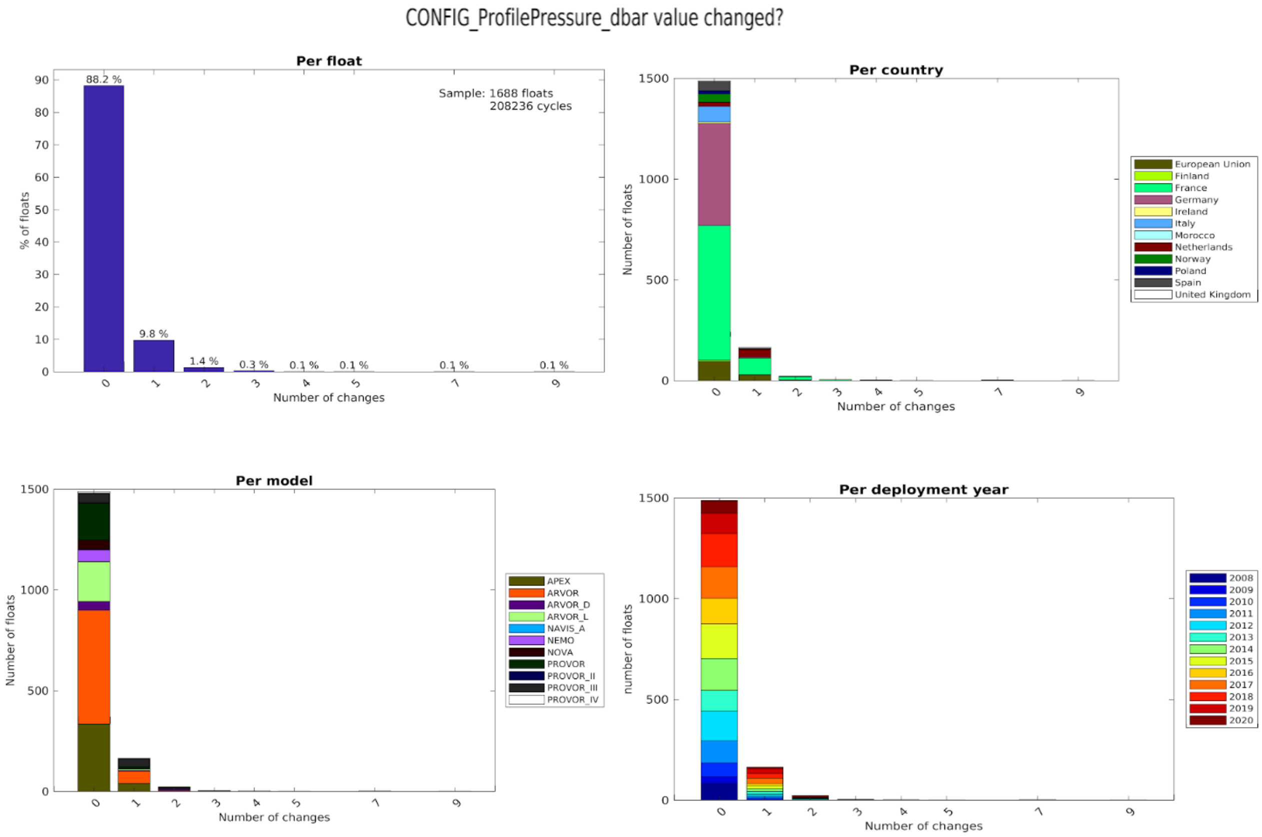


Figure 12- Changes for the config parameter “Profile Pressure”, for the following sample: European floats deployed in the open ocean since 2008.

One can observe that for the open ocean sample, 88% of the sample (1688 floats total) have not changed this configuration parameter, after deployment whereas this percentage was about 55% of unchanged configuration for the Mediterranean Sea sample (387 floats). For this configuration parameter, the percentage of unchanged configurations is about 8% for the Baltic sample (36 floats).

Another output from this tool expresses the values of the changed configuration parameters in proportion of the total cycle number. It gives complementary information about the values of the configuration parameter. In this case, most of the changed configurations occurred to put a profile pressure at either 700, 1000, 1500 and 2000 dbar, for respectively 16.5%, 17.6%, 18.8%, 33.9% of the total sample (68503 cycles). 700 and 2000 dbar configurations concern a majority of Arvor float types when the 1500 dbar concerns mainly Apex and the 1000 dbar one, the Provor_III floats.

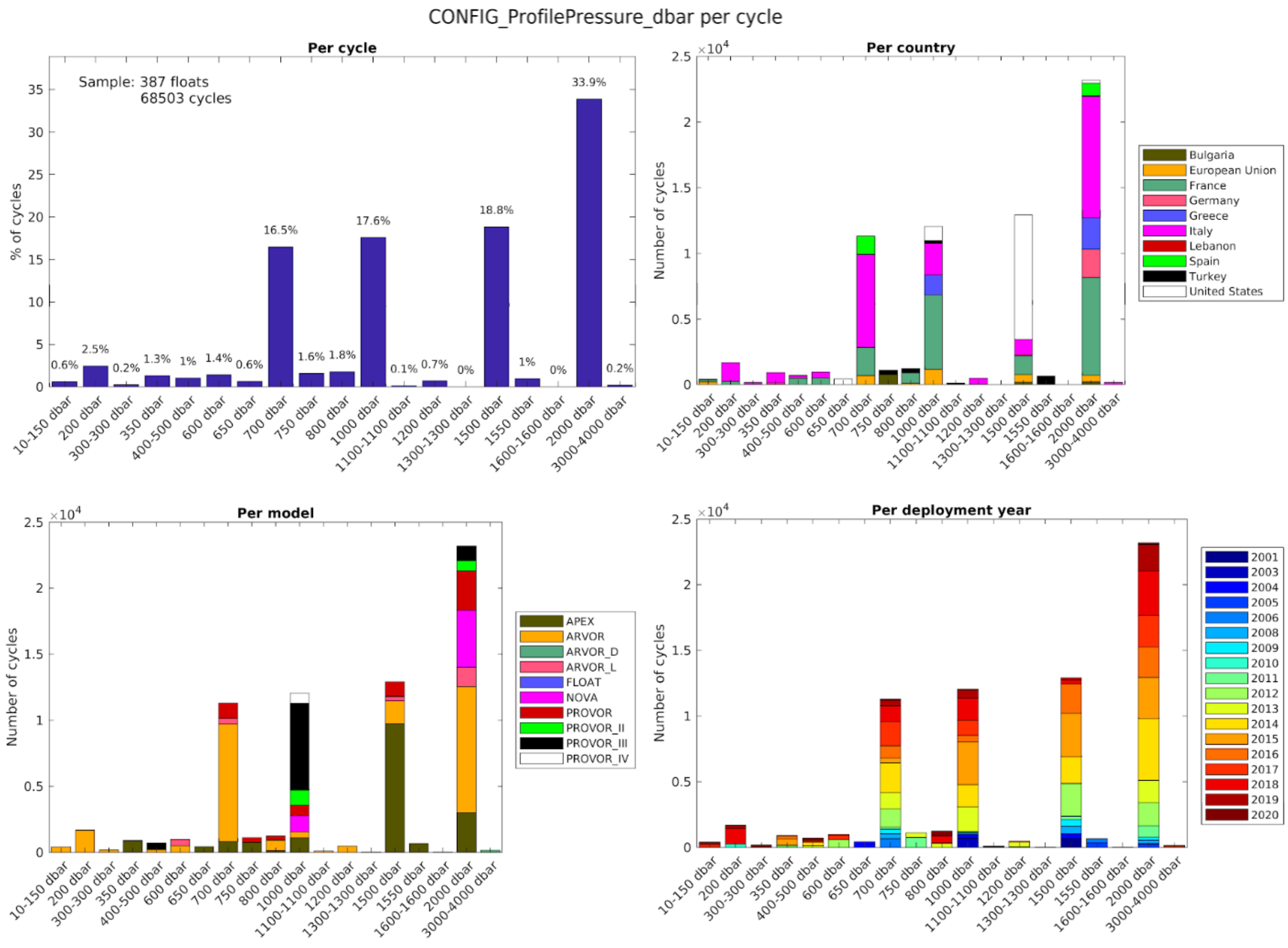


Figure 13- Values of the changed parameter (Profile pressure) for the floats deployed in the Mediterranean Sea since 2008 per cycles. In the top left in terms of percentages of the global number of cycles; top right according to the deployment countries, bottom left according to float models and bottom right, according to deployment date.

Ultimately, the last output of this tool permits to acknowledge the values taken by the floats that did NOT change their configurations throughout their lifetime:

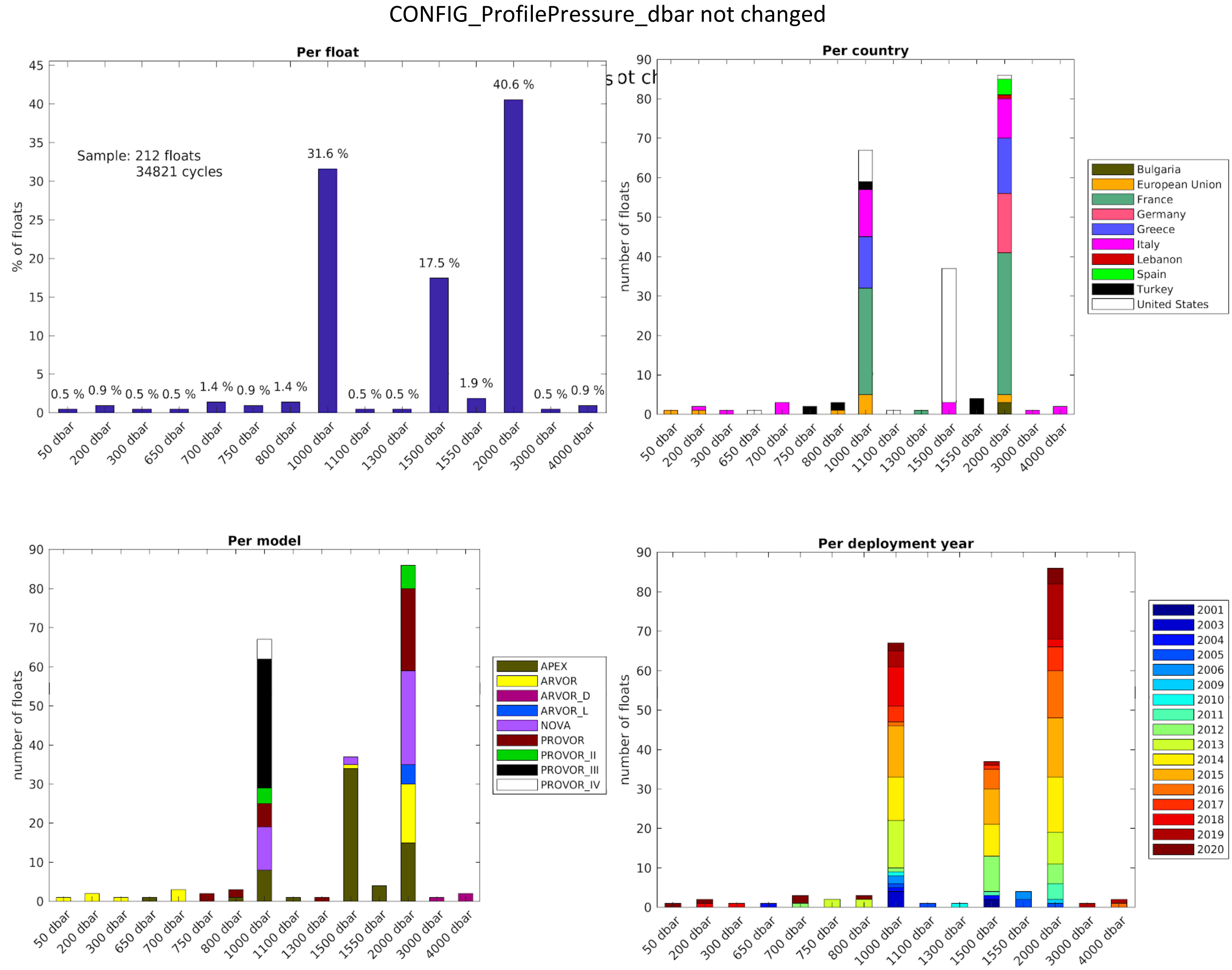


Figure 14- The sample is floats deployed in the Mediterranean Sea region, since 2008 that did not change the profile pressure parameter after deployment (212 floats)

Again, the main values taken by unchanged configuration floats are: 1000, 1500 and 2000 dbar configs. It thus appears that the 700 dbar configuration, characteristics of Arvor floats as shown in figure (two above) is a typical after deployment configuration.

The script CONFIG_fleet_status and its outputs are valuable to describe and understand the different changes and metadata values of a specific configuration parameter. It could help defining the sample selection in lifetimes studies (task 2.1 of Euro-Argo RISE), but can also be of interest for activities performed in task 2.3 (Improve Argo observation of boundary current regions) or in Work Package 6 (Extension to marginal seas) to describe the Argo sample schemes at basin scale.

The MATLAB script will be shared in a repository across the EuroArgoDev GitHub account (C.f. https://github.com/euroargodev/).

2. Technical parameters assessment

2.1. Grounded cycles

A script (map_Groudings_LUCA.m) was developed in order to provide complementary information about the technical values reported by the floats and their spatial distribution to permit a better tracking of this particular technical parameter that could have an important impact in terms of energy consumption.

The script is based on information stored in the trajectory and technical files of the float, found on the GDAC, and a mapping package for MATLAB: M_Map. As described in the Argo manual, the grounded parameter is a N-Cycle dimension, which means that each cycle data contains this parameter. Three main types of flags are associated to the "Grounded" parameters (as for now in the 2019 Argo table):

- "Y": The cycle did result in a grounding
- "B": Yes, the float touched the ground after a bathymetry check with an outside database
- "N": the cycle did not ground
- "S": Float is known to be drifting at a shallower depth than originally programmed
- "U": Unknown

Please note that the "Unknown" flag corresponds mainly to Apex floats before the firmware version *APF11*, that did not return the grounded information until then.

The script takes as input a file with the WMO numbers, DAC path, deployment date, and then returns the technical and trajectory data associated with each float in the GDAC.

The resulting outputs are the statistics computed about the repartition of the grounded floats in the sample considered (here, example for the Mediterranean Sea):

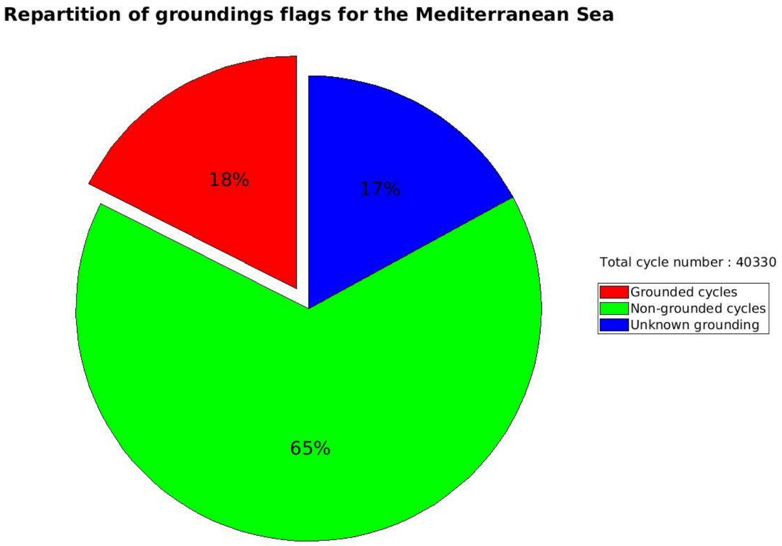


Figure 15- Repartition of the grounding flags in the Mediterranean Sea

The other output is a map that depicts the position the float cycles colour-coded according to the associated grounding flag (here example of the Mediterranean global floats fleet):

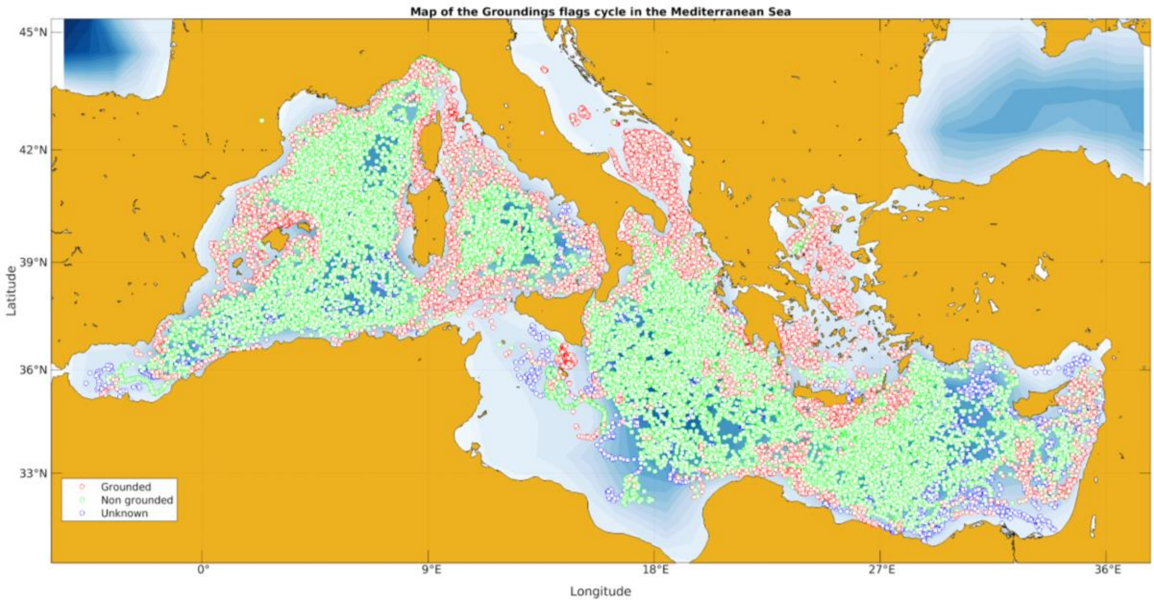


Figure 16- Repartition of the grounded flags for the European floats in the Mediterranean Sea. In order to facilitate the reading of the map, the grounded cycle layer (red markers) is shown on top, followed by the non-grounded cycles (green markers) and finally the unknown groundings (blue markers) as the bottom layer

This tool permits to evaluate the percentage of grounded cycles and their geographic repartition. If the correlation between a high percentage of grounded cycle and a decrease in the life expectancy of the float were to be confirmed (see Results - Baltic Sea use case), this tool will come handy to highlight the parts of the basin where most of the groundings append and which floats are concerned. However, it is important to keep in mind the targeted park and profile pressure of the grounded cycles, as these parameters are directly related to the energetic impact of the grounding (i.e. part Case study of the Baltic basin). The hydraulic actions related to a grounding (like any hydraulic actions) will be pressure dependent when comparing their energetic impact.

This raises the following interrogation: in which phase of the cycle the grounding happened. Was it during the descent to park or profile, or during the drifting phase? Another script was thus developed to answer this specific interrogation, using the targeted pressure, the effective pressure and the grounding phase information available for some float types (e.g. Arvor) (C.f. **Figure 17**). This method does not use the grounded flags used to make the previous map in order to find a workaround for the "Unknown" flags corresponding mainly to Apex floats. This other method relies on a pressure threshold configured for floats to determine if they are grounded or not. In fact, if the effective pressure measured by the float during a certain phase (either *PRES_DescentToParkMaxPressure_dbar* or *PRES_DescentToProfileMaxPressure_dbar*) was shallower by a 30 dbar threshold than the targeted pressure (either *CONFIG_ParkPressure_dbar* or *CONFIG_ProfilePressure_dbar*), the float could be considered as grounded.

The output of the script is a figure provided below: the red line represents the targeted pressure for the phase (descent to parking, parking, descent to profile) considered. One can observe that the majority of cycles where the floats are grounded during the descent to profile, grounded near the targeted pressure, if not at the targeted pressure when grounded cycles during the descent to park and drifting phases are way before the targeted pressure. However, it is important to remark that the majority of the cycles considered in this sample (**75%**) grounded during descent to profile phase, compared to the descent to park or drifting phases (**25%**), for a total of 197 floats / 3292 cycles considered.

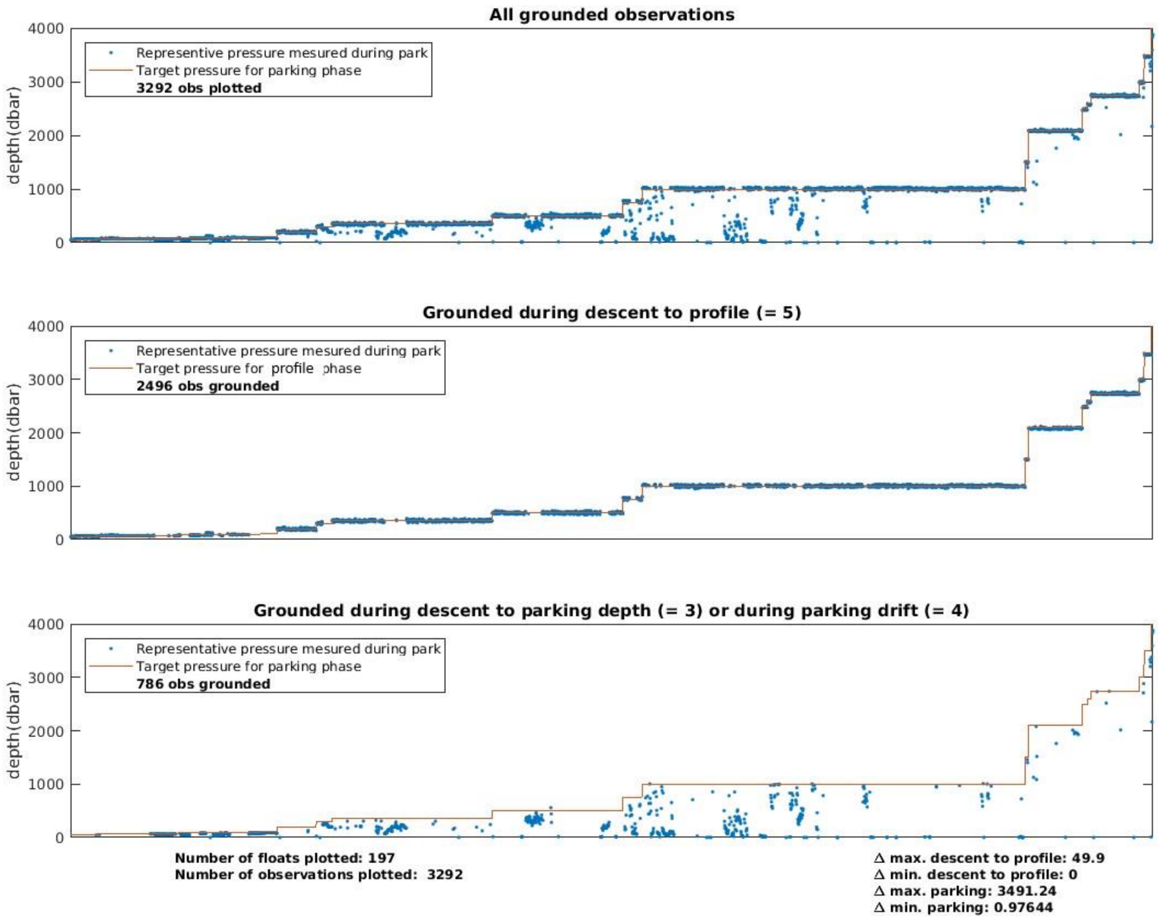


Figure 17- Repartition of floats groundings according to the cycle's phases, in comparison with their targeted pressure (red line). The sample considered here are 197 Arvor floats deployed in the last 5 years (no distinct deployment sea region).

This kind of output permits to observe the distribution of the grounded cycles in function of the cycle phase and a temporal axis. Here, the majority of the groundings happen during the descent to profile phase (more than 75% of the grounded cycles of the sample), where the maximum pressure is reached.

When combining this output with the ones from the "Config fleet status" tool, one will be able to estimate the average values for the park and profile pressure of this sample and therefore, permit a more accurate analysis of the impact of groundings from an energetic consumption standpoint. In fact, the manufacturer or float expert will know at which pressure most of the groundings happened and how much it converts into an energetic loss. The Euro-Argo ERIC Office team is planning on gathering some feedback from manufacturers on this subject in 2021.

Bear in mind that a grounding, depending on where it happens, the nature of the sea bed, the float model, etc… will have different hydraulic responses and is thus difficult to estimate. The ERIC office team will progress on having an estimation in the next months.

2.2. Map technical parameters

This tool permits to produce a map of the geographical repartition of a specific technical or configuration parameter, thus highlighting some trends in floats configurations or behaviour related to the sea region of deployment. The floats sample cycle positions are plotted and colour-coded regarding the value of the technical or configuration parameters. A colour map is used to colour-code the values above or below a user-defined threshold. The figure can also be generated for parameters values that are binaries.

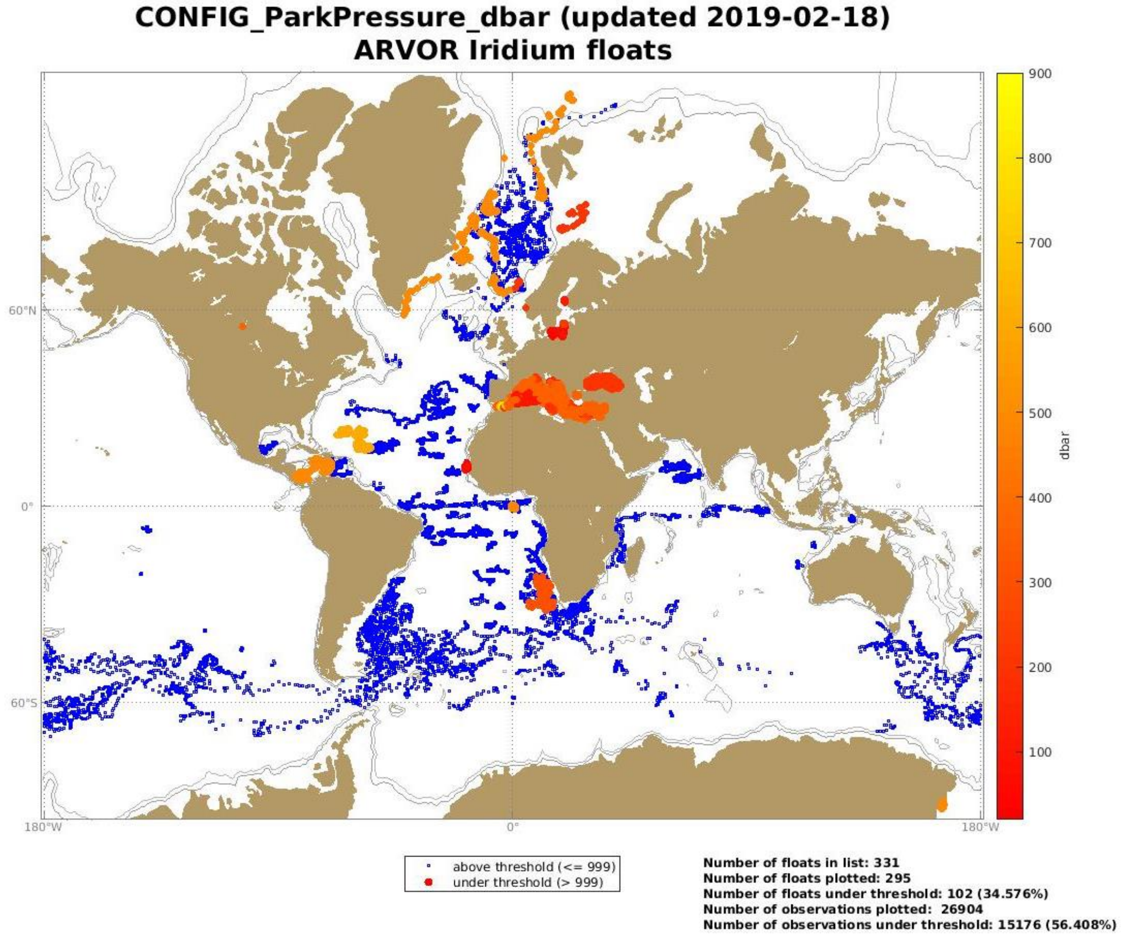


Figure 18- Geographical repartition of the parameter's values of the Park Pressure configuration parameter for Arvor Iridium floats deployed since 2008. In blue are presented all the floats with a Park Pressure value higher than 999 dbar and in red with the colorbar, all the floats having less than a 999 dbar Park Pressure configuration.

One can note that the Park pressure is significantly lower for the marginal seas, that are more shallow areas. Indeed, this parameter is often set considering the bathymetry where the float is deployed. However, this tool becomes really useful when observing the repartition of technical or configuration parameters such as: number of CTD points measured, number of repositioning during parking, etc...

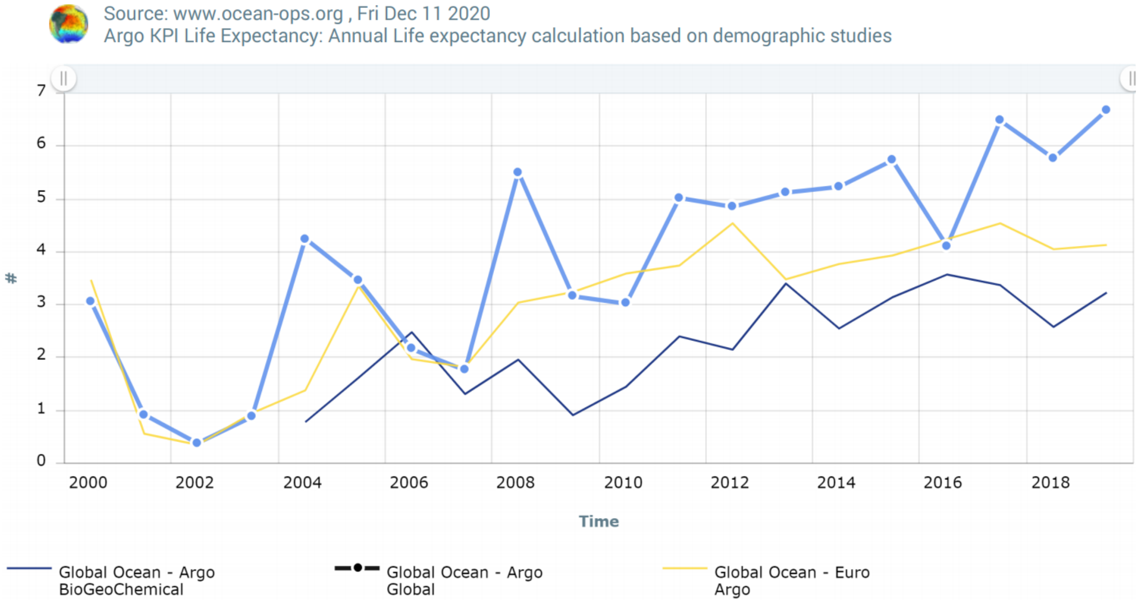
3. OceanOPS AIC tools

In order to meet the Argo community's requirements and to monitor more efficiently the global Argo array performance (and its sub-networks), OceanOPS has developed a portal integrating many interesting "on the fly" tools, monthly pre-computed indicators and fields in order to improve the fleet monitoring and simplify the end of life analyses:

- Age distribution
- Survival rates computation
- Performances on target

As well as some fields to fill that could simplify further analysis:

- **Ending cause:** this field would be interesting to determine/include/exclude values from the computed statistics. The value list lying behind that term needs consolidation, integration and governance;
- **Retrieval and post-retrieval status:** the retrieval status is used to differentiate planned retrieval/recovery from already recovered instrument. The post-retrieval status indicates what has happened to the unit after begin recovered (e.g. redeployed);
- **Deployment method:** this is a simple field indicating how the float has been thrown into the water, e.g. using a crane or thrown over.



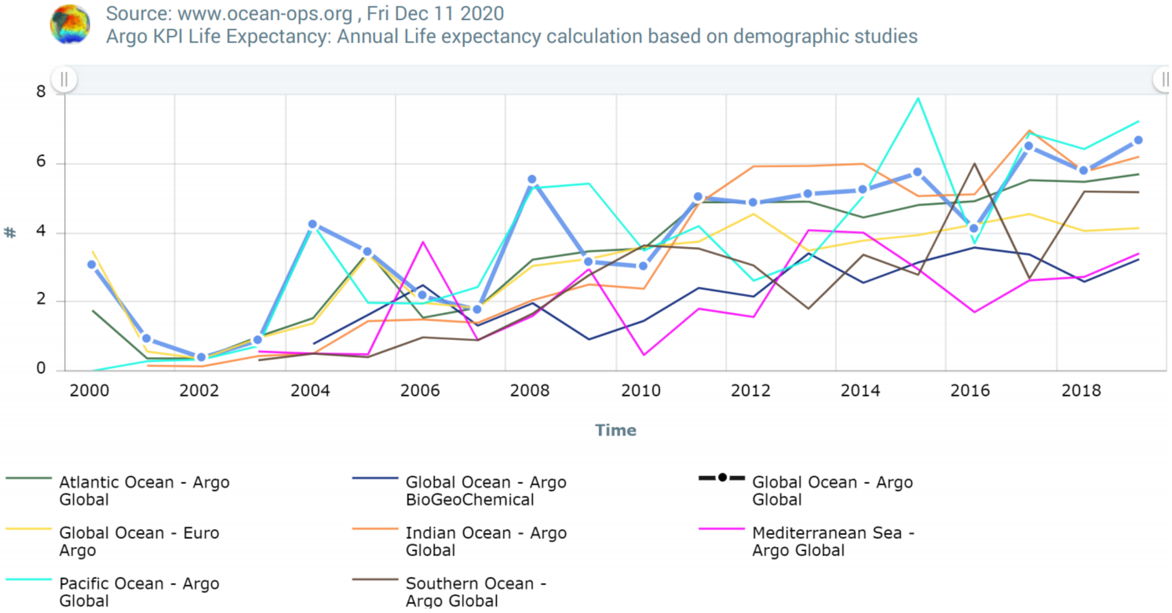


Figure 19- OceanOPS KPI on Life Expectancy. The life expectancy of a float at the time of its deployment is calculated similarly to demographic studies. This indicator represents the average age at failure of a fictional float generation on which we apply the mortality conditions of that year. This is the average number of years

that a float of a given group will operate, if the mortality rate of that group persists. Top: grouped by Networks and bottom: grouped by Basins.

One can note in the figures above (computed on the OceanOps portal), that the Euro-Argo fleet reached a life expectancy of about 4 years in the last years of deployments (**Figure 19** top). It is below the global international life expectancy, therefore pushing the needs for further investigation, as proposed in the Results part. One can also see that the life expectancy of floats deployed in the Mediterranean Sea is significantly lower than in other basins (**Figure 19** bottom).

Another metric that is presented is the survival rate. The following plot has been obtained selecting respectively all Argo fleet (yellow and grey lines) and only Euro-Argo fleet (light and dark blue lines), whatever the float's status. Two different survival rates are provided; the decay of the first one is not decreasing towards zero as there are still active floats in the sample.

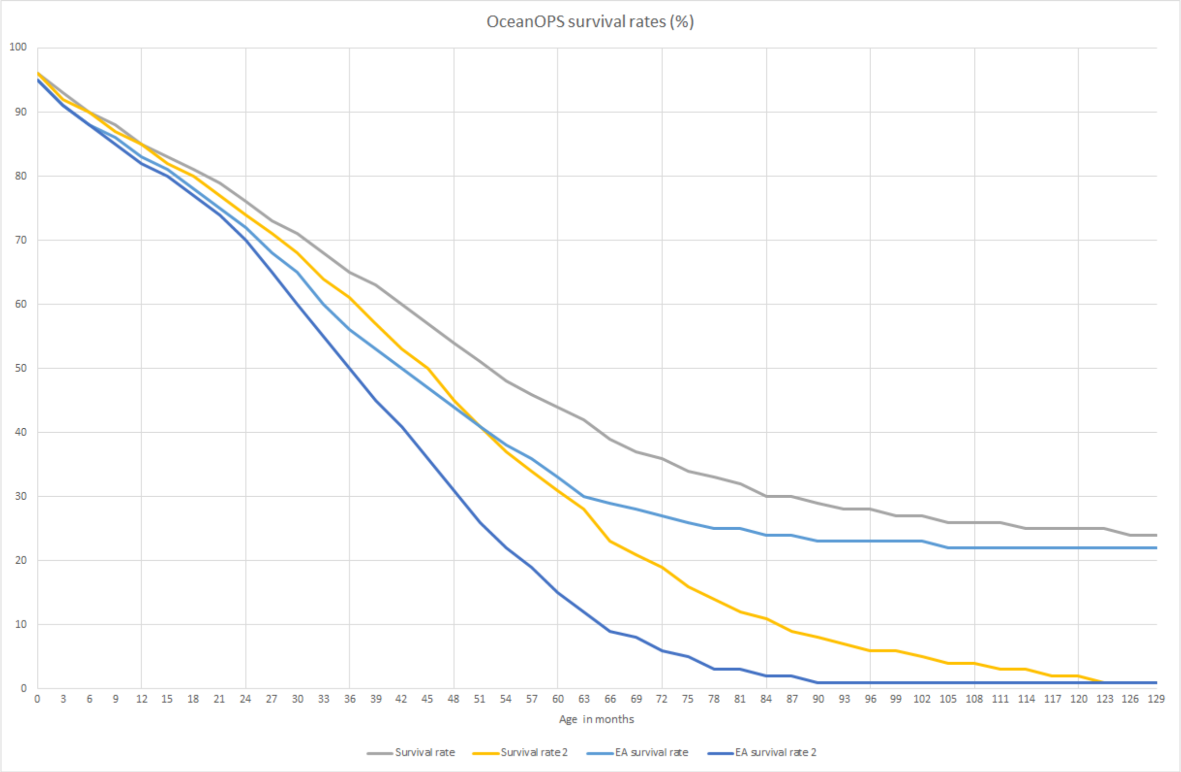


Figure 20- OceanOPS survival rates. Survival rate is defined as follows: « On each step, the survival rate gradually decreases. Each decrease represents the proportion of platforms from the group that became inactive during that step. » Survival rate 2 is defined as follows: « Survivors = Platforms older than age A; Deceased = Platforms inactive or closed before age A; Survival Rate at age A = Survivors / (Survivors + Deceased) »

Again, these indicators depict that the Euro-Argo fleet has lower survival rates than the ones of the global fleet. Performances are more or less similar for the first two years, the differences tend to emerge after 3 or 4 years.

C. RESULTS

This part will now focus on the results of different analyses undertaken with the help of the methodology and tools presented before. It will, in the first place, try to provide a life expectancy analysis for a global sample such as the European Arvor-Iridium floats, deployed in global ocean and marginal seas areas. Then, we will compare the life expectancy computations obtained from the tools developed and presented in the Methodology part with the tools integrated in the OceanOPS portal. Then, a case study of the impact of groundings on the Finnish Apex floats in the Baltic Sea will be presented. Finally, the last part of this section will elaborate on the impact of the three major configuration parameters on battery consumption (cycle time period and park and profile pressure), plus a short list of the other configuration parameters that could have a major impact on battery consumption.

Please bear in mind that these analyses are time dependent and will be carried on after this deliverable in the aim to derive more accurate and meaningful conclusions for recent samples. The further objective is to provide float owners the most adapted recommendations to increase the life expectancy of their floats, regarding the configuration parameters, model, deployment areas, etc.

1. Life expectancy for European ARVOR - Iridium floats deployed since 2008, in open Ocean and marginal Seas

The aim of this case study is to provide an overall estimation of the European life expectancy, by selecting the most deployed model, with the most recent satellite telecommunication system. Initially the study was only conducted on the open Ocean European Arvor Iridium sample because it represented the major part of European deployments. However, when comparing life expectancies of the European array with the International one, the European array tends to show lower performances in terms of survival rate, like explained in the Introduction part of the Methodology section. This trend raised interrogations concerning the overall “health” status of the European array.

By making a comparison between open ocean and marginal seas floats, we investigate the reasons that could induce the global decrease of the European survival rate mainly comes from floats deployed in marginal Seas, with more demanding conditions, “exotic” configurations, proximity to shore, etc...

This sample was selected because:

- **81%** of the total European deployments since 2008 were done in the open Ocean (either one of the 5 oceans, but with 55% of the total deployment in the Atlantic Ocean), representing roughly 2280 floats. The Arvor-I model represents **30%** of the European deployments since 2008, **43%** since 2015 and **58%** since 2019. The Arvor-I model was chosen as the most representative float of the manufacturer NKE that represent roughly 71% of European floats deployments since 2015.
- The aim of this case study being to assess an overall life expectancy study of the recent European fleet, we chose to consider only the most recent satellite communication technology, the Iridium one. In fact, Iridium telecommunication mode represents over **60%** of the European floats deployed since 2015, and this portion is still increasing (85% in 2019).
- The majority of floats deployed in the open Ocean follows the standard configuration parameters as follows (also manufacturer default): Park Pressure= 1000dbar, Profile Pressure= 2000dbar, Cycle Time Period= 10 days. As explained in the Config fleet status part, the post-deployment changes of configuration parameters for floats deployed in the open Ocean are

few (**88%** of European floats deployed in the open Ocean since 2008 haven't done any post deployment changes in configuration).

If one sample was to be selected to represent an overall estimation of the European fleet life expectancy in recent years, it should be this one. However, the necessity to split this sample in two parts: deployed in the open Ocean and deployed in marginal Seas raised from the interrogations about the impact of the marginal Seas floats in the overall life expectancy study of the European array.

Hereafter are presented the survival rates of these two samples in function of the vertical distance travelled in Kms and number of cycles reached. The survival rates in function of the age is presented in the ANNEXES and so are the histograms computed to highlight the distribution of the floats lifetime of the sample in terms of age, cycles reached and vertical distance travelled. For alive floats in the sample, the lifetime is the cycle/age/vertical distance they reached at the moment of the computation in early December 2020.

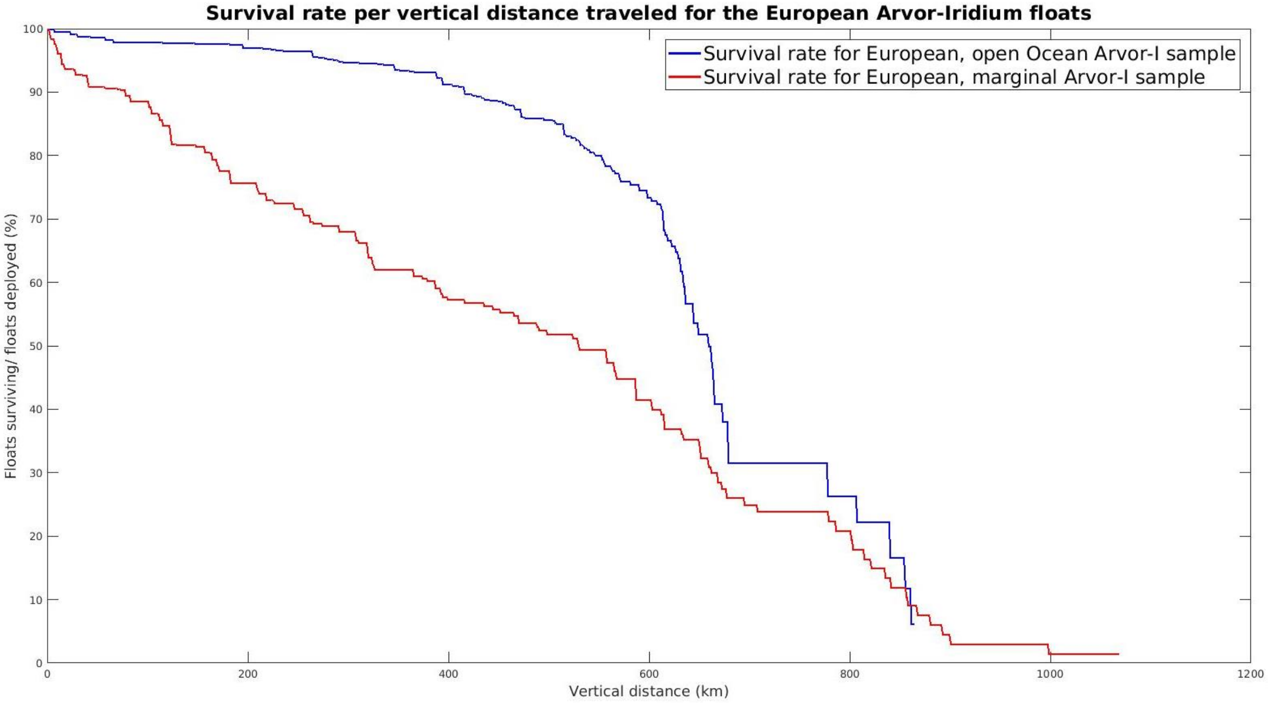


Figure 21- Survival rates per vertical distance travelled computed in Dec 2020 for European Arvor Iridium floats, with standard mission parameters in the global Ocean (blue curve), and any configurations in the marginal seas (red curve), deployed since 2008.

The first flagrant observation is that open Ocean floats have a much better survival rate computation than marginal Seas ones, especially in the first 600 Kms/150 cycles. The difference between the two survival rates reaches 40% differential at the maximum, at the 4years/650 Kms mark, then the two curves join again at the end of the plot.

At the very start of the curves, a big difference is observed as the red curve (marginal Seas floats) drops considerably fast, suggesting more early life death floats when deploying in the marginal Seas than in open Ocean. One should also note to contrast this observation that the recovered floats were considered here. In fact, an audit is planned by the Euro-Argo ERIC office team next year in order to update in a reliable manner the floats that were indeed recovered before their end of life. It will permit to delete these floats from the sample as they artificially drop the survival rate computation, and mainly the marginal Seas one as we know that floats recovery mostly happens in marginal Seas because of the proximity to the coast (ref: Float recovery).

However, float recovery is not the only reason why the survival rate is lower for floats deployed in marginal Seas. As explained throughout this report, life expectancy analyses are multi-parametric and one should consider the impact:

- Of shallower profiling depth for marginal Seas, therefore inducing a float to accomplish more cycles to reach the same amount of vertical distance travelled than a float in an open Ocean configuration. That is why the survival rates with the 3-x axis are provided (time, cycle, distance)
- Of the existence of significantly more dedicated science experiments that require special features in terms of floats configurations settings when deployed in marginal Seas (ref: Config fleet status), often making the float cycle at a higher frequency, with a shallower profile depth
- A higher number of groundings in marginal Seas and their potential impact on float battery consumption. The following case study specifically analyses the impact of bottom contacts on the energy consumption of Apex floats on the Baltic Sea (ref: Baltic case study)
- Proximity to shore could potentially increase the number of beaching and floats caught in fishermen nets.

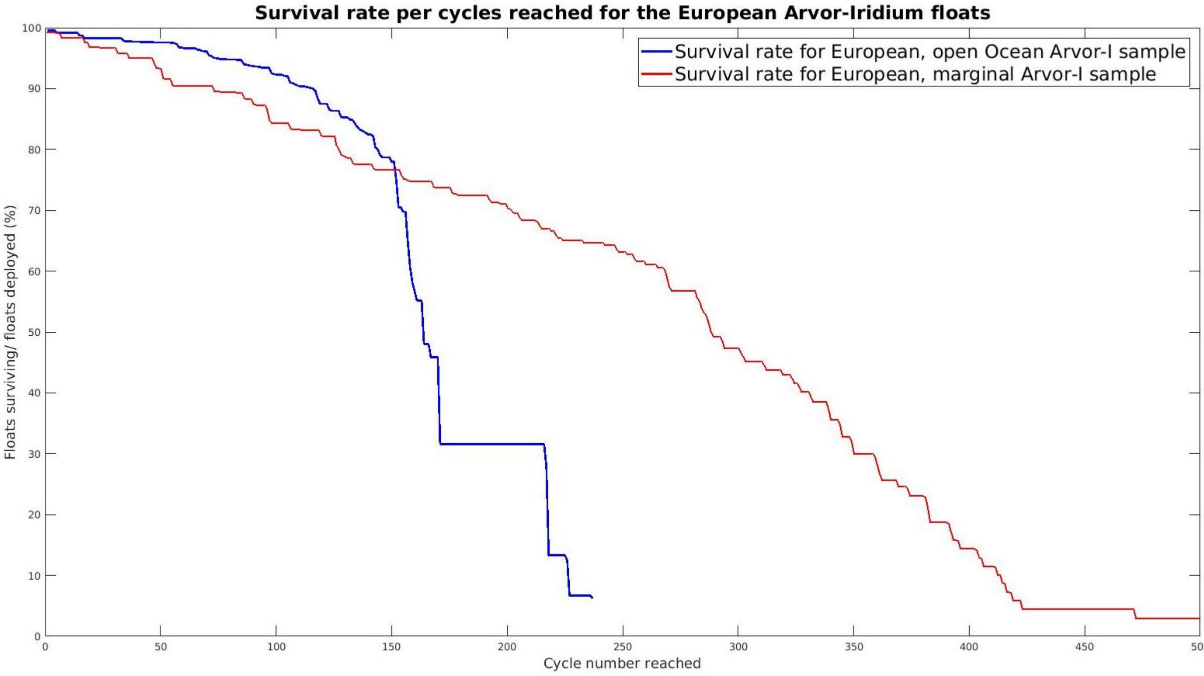


Figure 22- Survival rates per cycles number reached computed in Dec 2020 for European Arvor Iridium floats, with standard mission parameters in the global Ocean (blue curve) and any configurations in the marginal seas (red curve), deployed since 2008.

The figure above represents the same computations of the European Arvor-I samples but in regard with the number of cycles reached. One can observe a radical difference as the marginal Seas sample shows an overall better survival rate than the open Ocean one. This proves once again the importance of the context and the utility of a tool like the Config fleet status one, as it permits to underline the fact that the marginal seas sample is cycling at a shallower depth and more frequently, thus accomplishing more cycles than the open Ocean one. The trend observed here is then perfectly logical, and not so representative of the real survival rate of these samples.

However, an interesting phenomenon is observed in the first 150 cycles as the open Ocean sample (blue curve) shows a better survival rate than the marginal Seas sample. The red sample is expected to undertake more cycles than the open Ocean one (for the reasons reminded above) at any time.

This underlines once again the impact of other phenomena than cycle frequency in the marginal Seas sample, that decrease significantly the red sample survival rate to the point that even if the last one undertakes almost twice as much cycles than the blue one, its survival rate is no better than the open Ocean sample for these 150 cycles.

The next figure provides a good overall look at the main differences between life expectancies of the International and European array, and the impact of open Ocean and marginal Seas distribution on deployments.

- The international array (green curve) sample considers all the floats deployed since 2008 with Iridium technology, without any distinction of float model or deployment sea region.
- The yellow curve represents the global Iridium European array since 2008, with no distinction between float models and deployment sea region.
- The magenta curve represents the survival rate of the European Arvor-Iridium floats deployed since 2008, either in open Ocean or marginal Seas (combination of the blue and red curves).
- The blue and red curves were presented in the preceding figures and represents respectively the European open Ocean Arvor-I floats and the marginal Seas ones, like presented in the preceding figure.

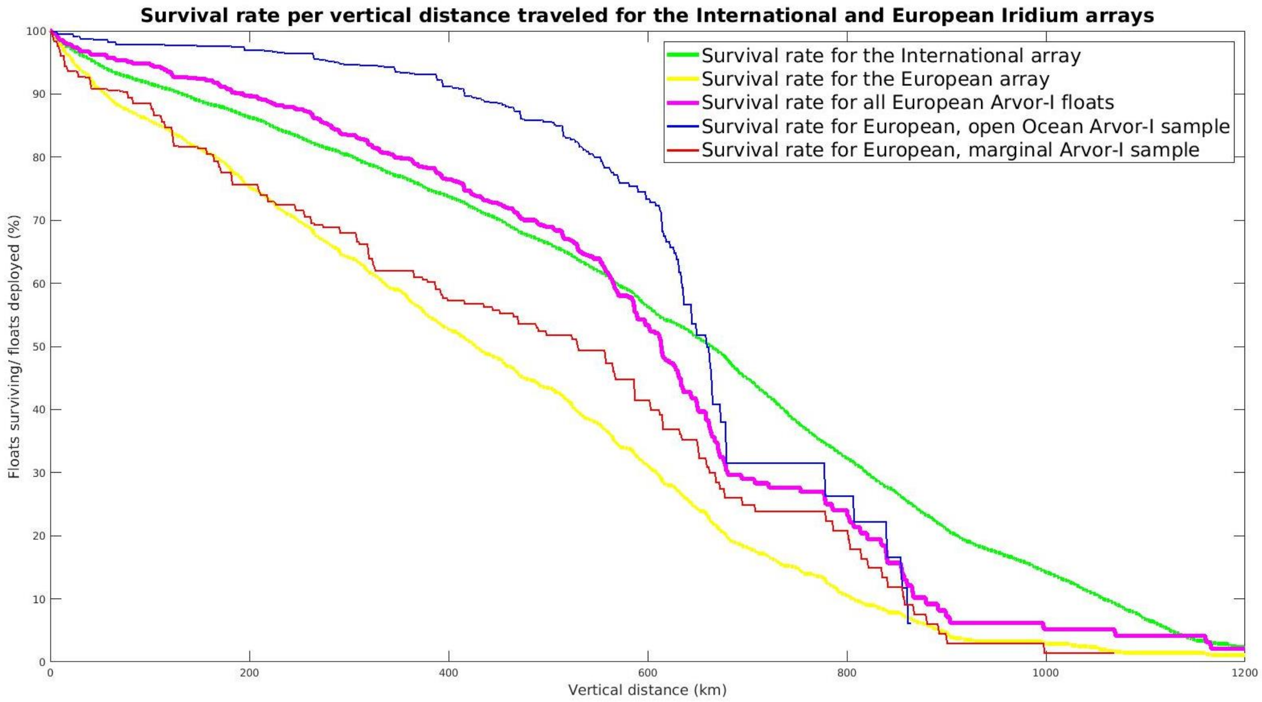


Figure 23- Survival rate curves in function of the vertical distance travelled in Kms, for the International array Iridium sample, any model type (in green), the yellow curve: overall European Iridium array, the magenta curve is the combination between the blue and red one, representing the European Arvor-Iridium sample

Multiple things can be observed in these survival graphs in function of the vertical distance travelled and cycles reached. The survival rates computations for the same samples in function of the age reached is presented in the ANNEXES.

In the graph above (in vertical km), one can note that the yellow curve coincides with the red one for the first 300Kms travelled, suggesting that the poor survival rate that present the global European Iridium array (yellow curve) for this time period is mainly due to the death of Arvor-I floats, deployed in marginal Seas (red curve). After that, the survival rate of the red sample stabilizes a little whereas the yellow one keeps decreasing suggesting that other float models than the Arvor-I mainly impact this time period (c.f. **Figure 24** below). One should also consider that the marginal Seas portion of these other floats is more likely to decrease the overall survival rate of the European Iridium array after this 300Km travelled vertically mark, than the open Ocean portion of it. This proportion of other floats than the Arvor-I model, deployed in the marginal Seas by the Euro-Argo network, represents 179 floats. On this specific sample, which is smaller than the rest, the proportion of recovered floats is about 20% and could have an important impact on the major decrease of the survival rate for the yellow sample.

The figure presented below represents the different models composing the European array with the standard configuration parameters: Cycle Time Period: 10 days, Park Pressure: 1000 dbar, Profile Pressure: 2000 dbar (mostly represented by floats deployed in the open Ocean).

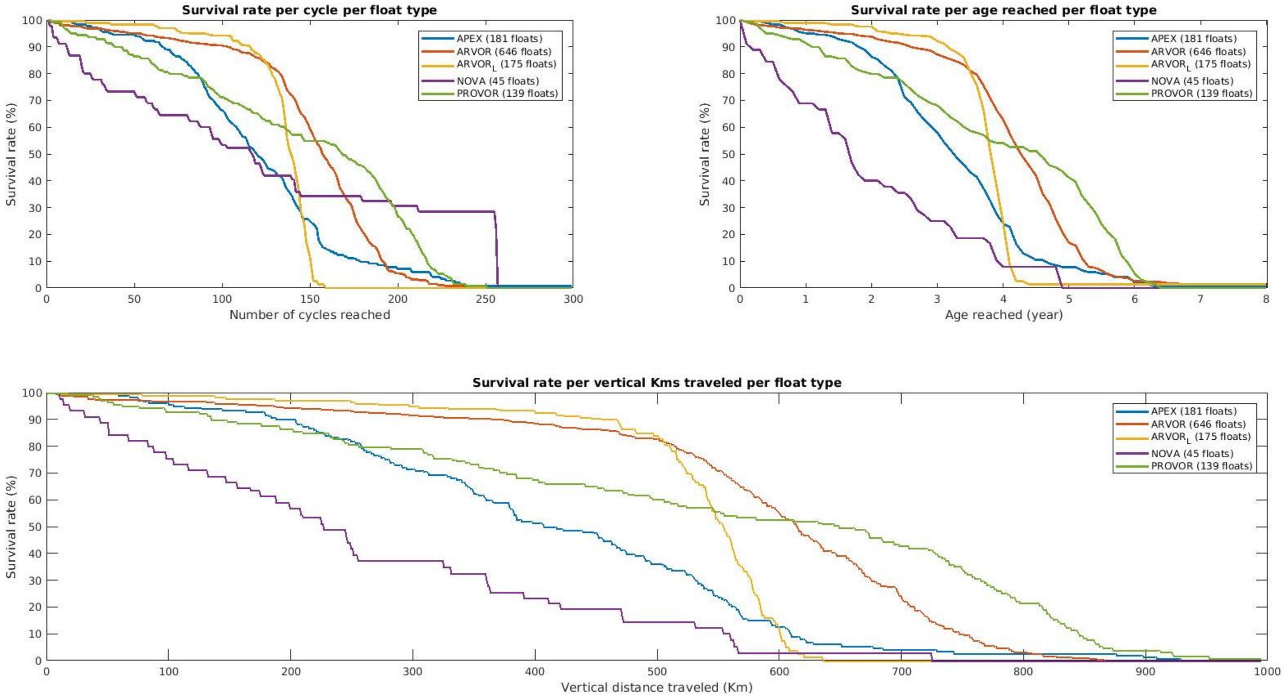


Figure 24- Survival rates computations for European floats deployed with the following configuration parameter: Park Pressure = 1000 dbar, Profile pressure: 2000dbar and Cycle Time Period: 10days. The survival rates are computed according to the three following time variables: upper-left: Cycles reached, upper-right: age reached and bottom: vertical distance travelled in Kms and grouped by float models. In the legend box are indicated how many floats were used in the computation per float models.

When the sample is too small (under 10 floats), the survival rate is not computed as it wouldn't be robust enough to accurately represent the sample.

When considering bigger float samples, the survival rate is pretty accurate. For this parameter, 4 floats types can be highlighted as presenting a good survival rate throughout the time variable considered: Arvor, Arvor_Light, Apex and Provor. However, one can observe that the two Arvor floats type present a better survival rate than the Apex and Provor one before the 600 Km mark, for this configuration. After 600 Km travelled, almost 20% of the Provor type sample lasted longer than 800 Km when no other Arvor nor Apex floats reached this mark (**Figure 24**, bottom, green curve).

It is important to bear in mind that these different float types have different technologies, different size of battery pack and number of sensors embarked.

The Arvor-L model tends to show a better survival rate for the first 3/3.5 years compared to any other floats. In fact, the Arvor-L floats are equipped with less powerful batteries, thus explaining that the curve drops after 4 years, whereas other models like Arvor-I or Apex floats with more powerful batteries show a better survival rate after this age is passed. The Provor fleet, equipped with bigger battery packs, is the one lasting longer (up to 6 years).

For these configuration parameters, NOVA floats show an overall poor survival rate compared to other float models. The Apex model presents also a lower survival rate than the three other models for these configuration parameters. The poor survival rate of NOVA floats could be one of the reasons for the poor European survival rate (yellow curve on the **Figure 25**) but it is definitely not the major reason as it represents only 45 of the 1000 floats considered.

Hereafter are computed the survival rates for the same samples according to the cycle number reached.

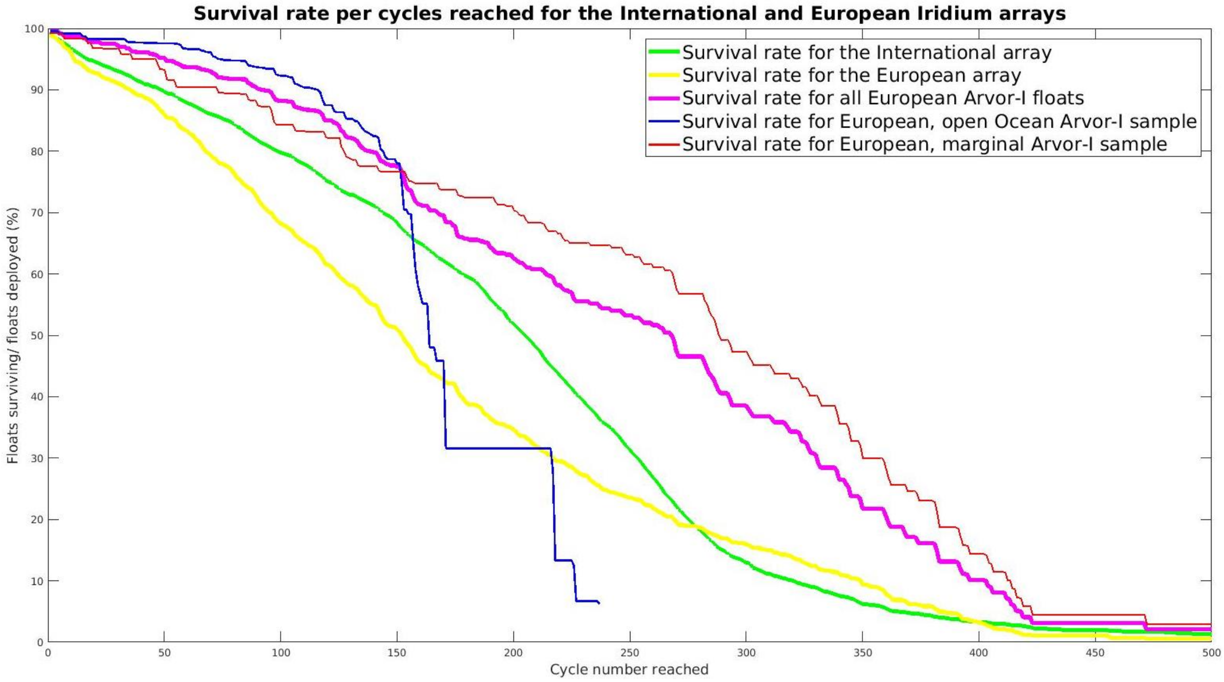


Figure 25- Survival rate curves in function of the cycles reached, for the International array Iridium sample, any model type (in green), the yellow curve: overall European Iridium array, the magenta curve is the combination between the blue and red one, representing the European Arvor-Iridium sample.

Essentially, the same trend is present when comparing the International and European Iridium arrays (yellow and green curve). The blue curve drop was explained before as this open Ocean sample underwent less cycles than the marginal Seas one and is not a reliable description of the European survival rate. However, a new phenomenon can be observed after the 270-280 cycle mark where the global European Iridium array shows a better survival rate than the International one. Before interpreting this, one should keep in mind that at this advanced stage of a float lifetime, less floats are considered than in the first part of the plot simply because less floats were able to/programmed to reach this mark. Bear in mind that the green and yellow samples include all the Iridium floats models present in their array, and all the deployment areas or configuration parameters of these floats. This means that floats manufactured with greater battery packs, that are supposed to last longer like the BGC floats are more likely to be taken into consideration in this part of the plot.

One can assume that the main reasons why the European survival rate top the International one for this period is because:

- The marginal Seas deployments being more important for the European array than the International one, European floats logically underwent more cycles thanks to higher cycling frequency and shallower depth of profiling
- The period considered is advanced enough to eliminate from the sample the floats deployed in marginal Seas that died at an early age

Another aspect of this case study consisted in comparing the tools produced to analyse life expectancies of floats array.

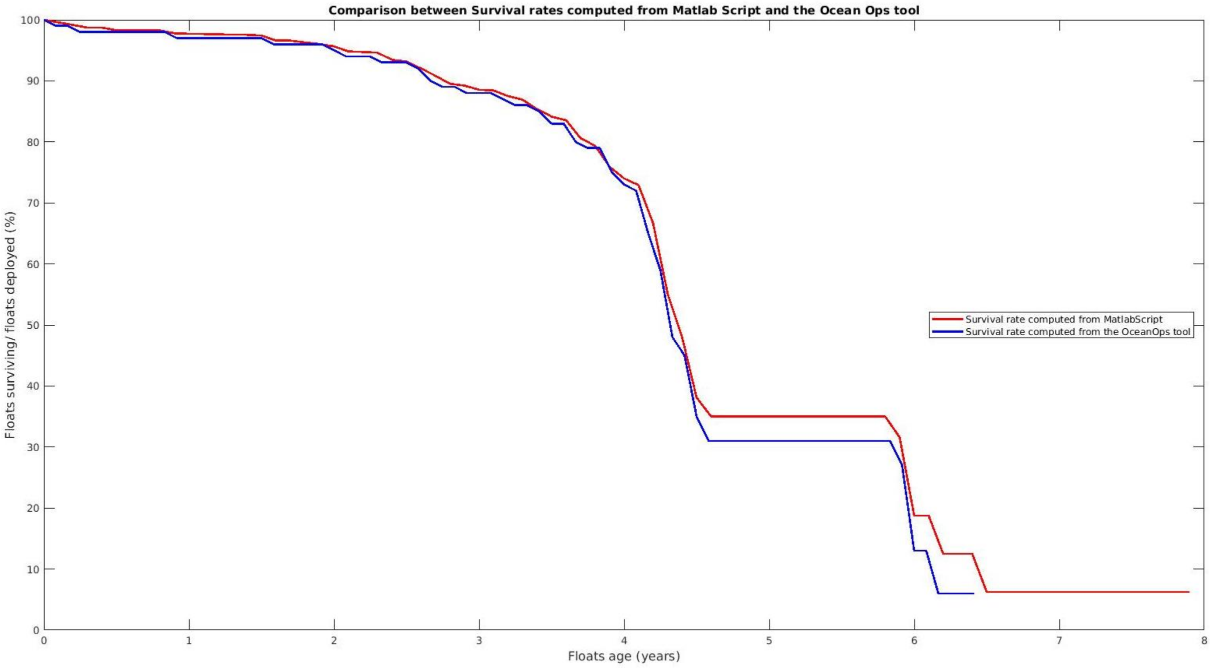


Figure 26- Survival rates computation for European Arvor-I floats deployed in the open Ocean, with standard configuration parameters since 2008. The time axis is the float age expressed in years. The blue curve represents the survival computation from the OceanOps tool and the red curve, the same computation but from the MATLAB script developed for this task.

The OceanOPS portal is a powerful web-based interface coupling a GIS (Geographic Information System) interface and the metadata filled during the float deployment. A function computing the survival rate of the sample selected according to different filters is already implemented on the website. The metadata is declarative and only depends on the fields filled by the PI of the floats at its deployment.

It is not the aim of this tool to focus on the profile data; it rather focuses on the metadata and monitoring, therefore justifying in this work package the creation of a tool computing life expectancy while integrating configuration parameters changes throughout a float lifetime.

The figure above presents the computation of the life expectancy of the precedent sample in the open Ocean, from the OceanOps AIC in blue and from the MATLAB script developed in red. One can note that globally, the two tools presented are robust and present an overall good similarity for the same sample.

2. Case study in the Baltic Sea: impact of groundings on life expectancy

Most Argo floats operated in the Baltic Sea are recovered before their batteries would render them inoperable. This makes it harder to determine exact lifetimes of the Baltic Sea floats. The expected possible operation time is still important, as the possibilities for recovery are occasional, and recoveries require planning. FMI aims to recover every float it has deployed on the Baltic Sea, so far only one has been lost. Regular float recovery has three main motivations:

- Maintaining and re-deploying the floats is more economical as the operational areas are such that we get opportunities to recover them as part of other research missions.
- Recovered floats can be further studied for their wear and condition, especially for the sensors.
- Environmentally it makes sense to pick them up rather than leave them at sea when it's possible with reasonable cost.

As of writing, most of the FMI’s Argo missions on Baltic Sea have lasted from one to two years. Majority of FMI’s floats are Apex floats (22 out of 23 floats), therefore justifying the focus of this study on Apex floats.

In general, keeping the float profile depth close to the expected bottom, tends to keep it more confined in a specific deep area. In addition to confined movement, this produces profiles starting closer to the full depth, which is interesting for science. On the other end, this produces more bottom contacts, which depending on the bottom type, risk getting stuck. In addition, when the float attempts to get deeper than the bottom, it does consume unnecessary energy trying to adjust its buoyancy which shortens the possible mission time.

Measuring direct lifetime for the Baltic Sea floats would be incomparable to open sea Argos, as the reason for mission end on the Baltic Sea is almost always float recovery rather than depletion of battery or malfunction. Battery consumption during the mission is examined as a proxy for expected lifetime. FMI missions on the Baltic Sea used on this comparison are listed on **Table 1**.

For energy consumption the voltage of the batteries was used as a proxy. For an equal amount of consumption, the period from maximum battery voltage, to the drop of 1.5 V was chosen for further comparison. This was an amount of depletion that most missions encountered before recovery, and seemed better criteria than any single voltage level, as the initial charge varied in roughly 14.8 ± 0.5 V. WMO 6902013 was later removed from analysis, as its battery level at the beginning (13.9 V) was considerably lower than on other missions, and WMO 6902018 and WMO 6902028 as the voltage didn’t drop the required 1.5 V during the mission time. Furthermore WMO 6902021 was excluded for it experienced atypical diving problems throughout its mission time, and WMO 6903704 for its voltage record was unstable within the comparison period.

Please note that the older Apex version (for example here “APF9”) did not report grounding information. Probable ground contacts for these older versions have been determined if less than a 5cm depth change was reported for a 5 hours period during mission. Control actions are any piston movement action initiated found from the command logs. One control action can consist of several control steps, indicating the amount of piston movement. The minimum step changed from older Apex versions in such a way that, in newer apx11 software, 16 steps equal one older step. In this document, the older steps are converted to match the newer ones.

WMO	Sensors	Software	Start	End	Profiles	Groundings	avg.Depth	Avg.Control actions	Area
6901901	CTD	apex9	2012-05-17	2012-12-05	309	102	49.3	11.1	Bothnian Sea
6902013	**CTD**	**apex9**	**2013-06-13**	**2013-10-02**	**117**	**1**	**78.9**	**14.3**	**Bothnian Sea**
6902014	CTD_OB	apex9	2013-08-14	2014-08-20	90	24	125.9	40.6	Baltic Proper
6902018	**CTD_OB**	**apex9**	**2014-05-30**	**2014-11-17**	**62**	**46**	**81.8**	**25.5**	**Bothnian Sea**
6902017	CTD	apex9	2014-05-30	2015-10-24	172	49	119.4	16.3	Bothnian Sea
6902019	CTD_OB	apex9	2014-08-21	2015-08-05	62	40	172.7	42.3	Baltic Proper
6902020	CTD_OB	apex9	2015-08-05	2016-08-03	68	10	210.4	43.5	Baltic Proper
6902021	**CTD_OB**	**apex9**	**2015-09-22**	**2016-05-13**	**47**	**20**	**102.3**	**17.3**	**Bothnian Sea**
6902022	CTD	apex9	2016-05-13	2016-10-11	216	109	103.6	20.4	Bothnian Sea
6902023	CTD	apex9	2016-07-13	2018-01-25	110	97	77.5	80.7	Bothnian Sea
6902024	CTD_OB	apex9	2016-08-03	2017-06-15	61	41	207.7	44.9	Baltic Proper
6902025	CTD_O	apex9	2017-05-09	2018-10-02	108	66	107.4	30.7	Bothnian Sea
6902026	CTD	apex9	2017-06-06	2019-06-02	111	89	68.3	56.2	Bay of Bothnia
6902027	CTD_OB	apex9	2017-06-16	2018-10-15	106	83	199.5	53.1	Baltic Proper
6902028	**CTD_OB**	**apex9**	**2017-08-06**	**2018-09-04**	**64**	**52**	**99.1**	**39.4**	**Bothnian Sea**
6902029	CTD	apex9	2017-08-06	2017-10-27	160	7	120.8	15.9	Bothnian Sea
6902030	CTD	apex9	2018-07-10	2019-03-04	154	24	117.8	21.8	Bothnian Sea
6903697	CTD_OB	apex9	2018-10-15	2019-08-17	63	53	213.4	40	Baltic Proper
6903699	CTD_O	apex11	2019-05-30	2020-12-01	108	54	110.8	18.5	Bothnian Sea
6903700	CTD_O	apex11	2019-06-01	2020-11-12	86	39	79.7	10.3	Bay of Bothnia
6903701	CTD_O	apex11	2019-08-17	2020-11-13	94	51	210.4	29.1	Baltic Proper
6903704	**CTD_O**	**apex11**	**2020-06-10**	**2020-11-12**	**51**	**28**	**160**	**27.5**	**N.Baltic Proper**

Table 1- FMI's APEX floats considered in this study (total of 22). The red, bold lines are the 5 floats removed from this study. Sensor legend: CTD = CORE mission, CTD_O = CORE + Dissolved Oxygen, CTD_OB = CORE + Dissolved Oxygen + Backscattering. Groundings show how many of the profiles had a bottom contact, avg. Depth indicate the mean profile depth on the mission and avg. Control actions show how many pistons action operations per profile was required.

The voltage drop of the batteries has been computed according to the three x axis units defined in the methodology part of the document. Hereafter is presented the voltage drop as a function of vertical distance travelled. The figures of the other two x-axis computations are provided in the Annexes.

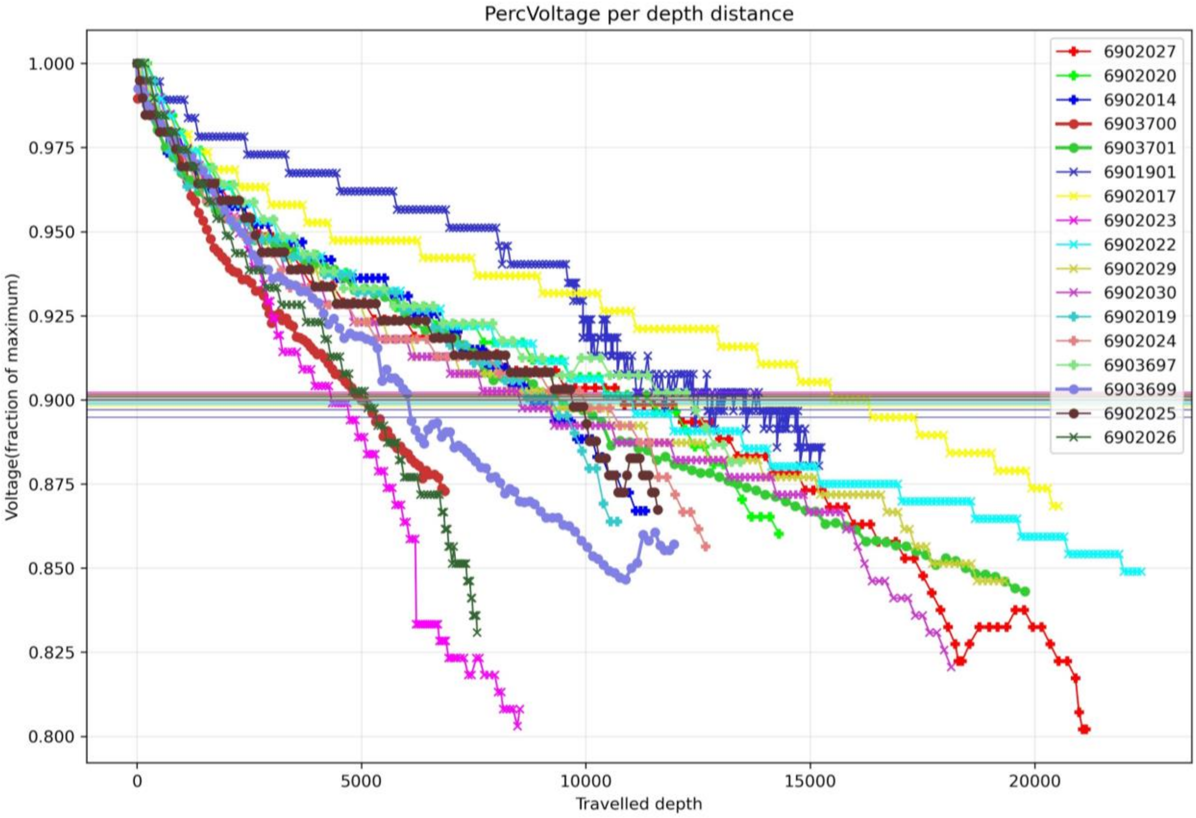


Figure 27- Voltage drop of Baltic Argo floats missions (WMO) as a function of vertical distance travelled (in meters). The level in which each mission reaches its trigger voltage is marked with a horizontal line of similar colour. Sensors are indicated with markers: x = CTD only, • = CTD and oxygen, + = CTD, oxygen and backscattering. Thicker lines indicate apx11 software.

The correlation with profiling depth, cycle period, bottom contacts and required control steps on mission length and accumulated profiles is shown on figures **Figure 28** and **Annex 15**. **Figure 29** show correlations between profiling depth, bottom contacts and cycle period on accumulated profiling distance.

From **Annex 15** it can be seen that for longer mission times, the deciding factor is cycle period. Shallow profiles do indicate longer mission time, but with much smaller effect.

Figure 28 shows that the amount of bottom contacts can impact considerably on how many profiles can be acquired with the same energy and diving depth. This is due the fact that a float stuck on the bottom will try to get deeper as programmed, and as such does unhelpful control actions consuming energy. Floats performing a high number of cycles are the one with fewer bottom contacts: WMO6901901, 6902017. Now, if one thing was highlighted throughout this report it is to always compare and put into relief the variables selected and what they mean. One quick conclusion from figure Ff could be: a float having less than 30% of its profiles with a bottom contact tends to undertake 100 more profiles than floats having more than 60% of ground contacts. Now, as we know, the number of profiles is highly dependent on the period between profiles and the depth of it. It is normal that floats cycling more frequently and at a shallower depth tends to make more profiles. In fact, when looking at **Annex 15**, one can observe that the floats making the most profiles in **Figure 28** are in fact floats with a higher cycling period and a shallower profile depth. Float 6901901 is cycling every day at an average depth of 60 meters.

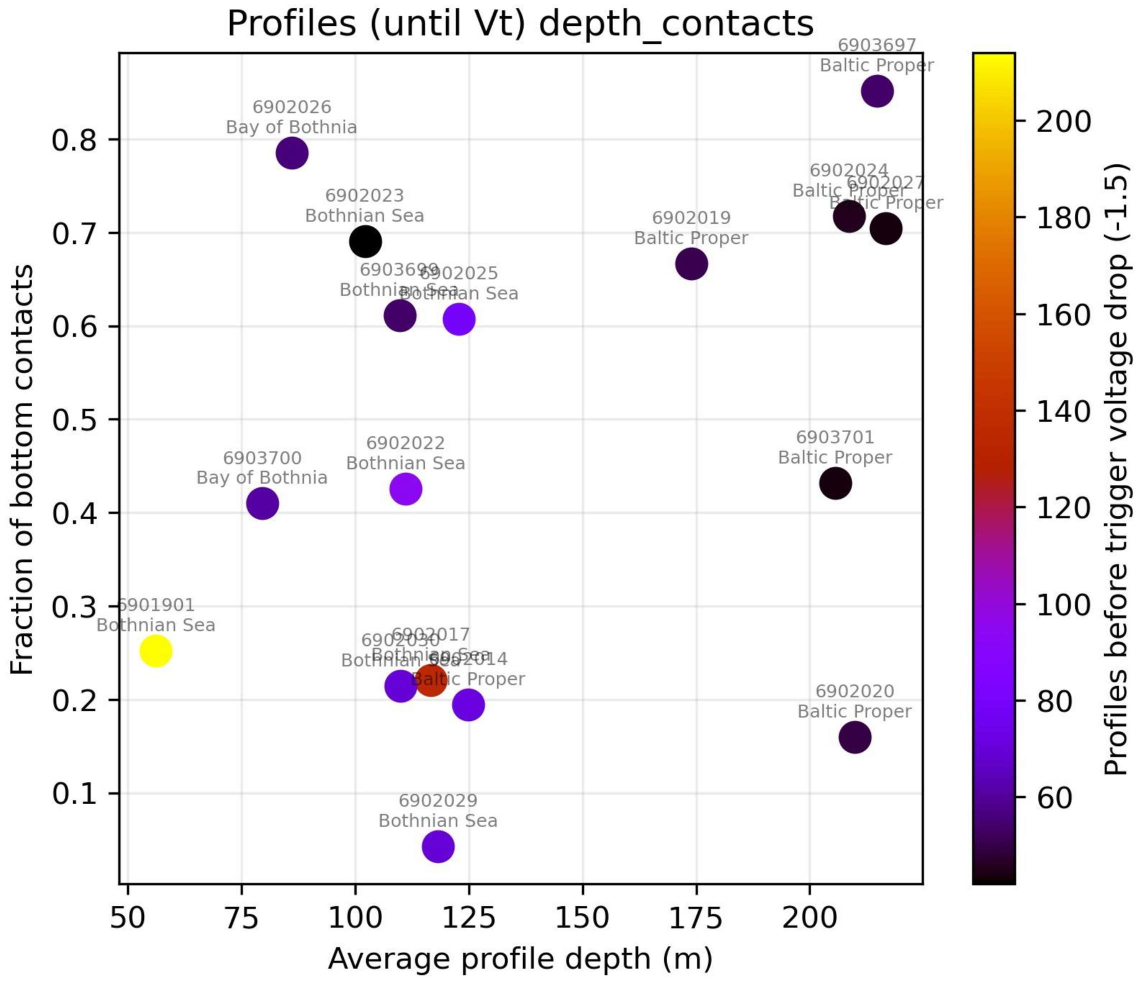


Figure 28- fF Profiles accumulated before battery voltage dropped 1.5 V. Axis shows the average profiling depth and amount of bottom contacts for each mission. Mission area and WMO plotted next to respective dot, colour indicates profiles before -1.5 V.

Figure 29 shows the impact of ground contacts in function of the vertical distance travelled, as it could be more relevant to really quantify the impact of groundings on the float's lifetime.

The **Figure 29** highlights the two main reasons for the floats to reach a smaller vertical distance:

- cycling at a shallower profile depth; more cycles are thus required to reach the same vertical distance travelled, inducing more frequent surfacing and data transmission phases maybe induce a greater energy consumption than floats diving at a higher pressure.
- Important fractions of bottom contacts. In fact, floats like WMO6902026 or WMO6902023 with a percentage of groundings about 75% are the one that reached the least vertical distance.

The correlation between the shallower profiling depths and the bottom contacts might exist but is difficult to prove. Shallower groundings might be more energy consuming because of steeper and more difficult bathymetry at shallower depth than deeper ones. Seabed geological type could be muddier at shallower depth inducing a higher energy consumption when a grounding occurs. These are hypotheses that need further investigations to be proven but that could link the energetic impact of groundings in function of the depth and sea region it occurs.

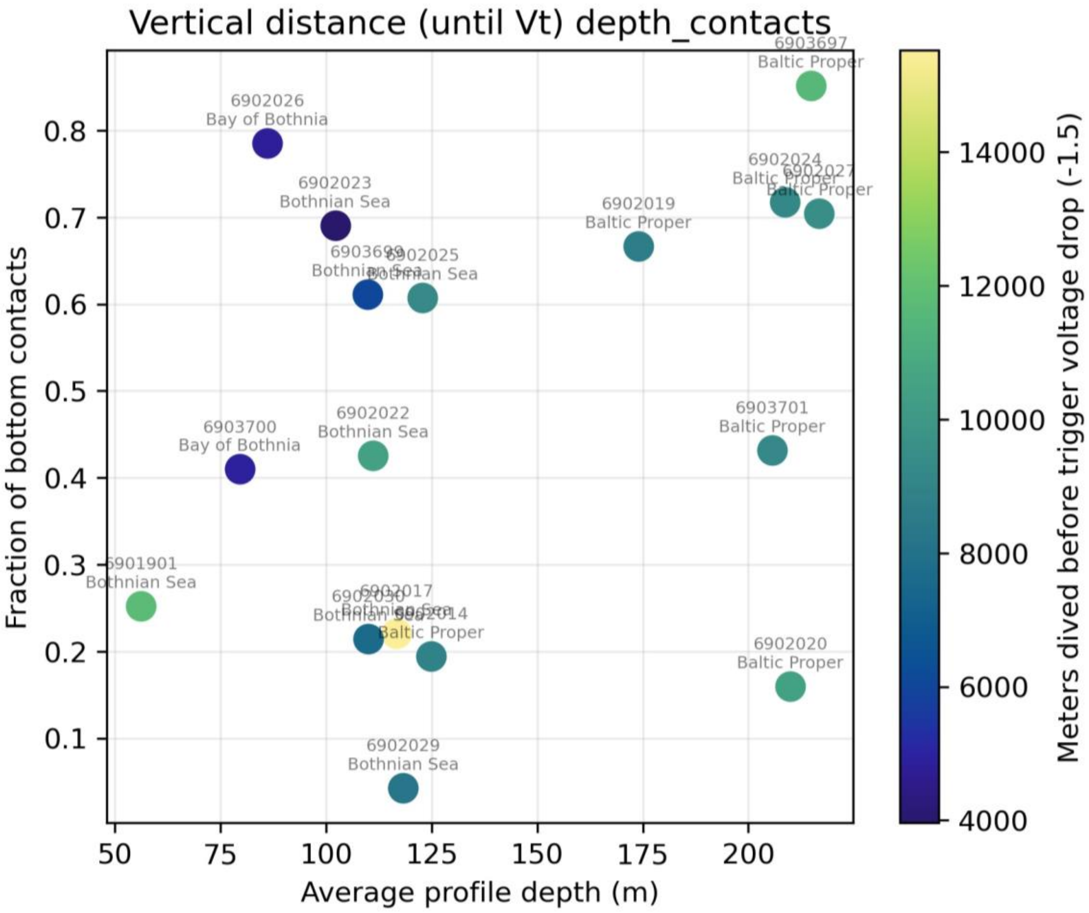


Figure 29- fH: Profiling distance accumulated before battery voltage dropped 1.5 V. Axis shows the average profiling depth and amount of bottom contacts for each mission. Mission area and WMO plotted next to respective dot, colour indicates profiling distance before -1.5 V.

Missions on Baltic Proper, e.g. WMO's 6902020 and 6902027 which have deep profiling depth and short cycle period, had high mission days but low amounts of profiles with a given amount of energy. Both managed to reach high profiling distances, WMO 6902020 higher, as it encountered fewer bottom contacts. WMO 6902017 is an interesting in-between case, which has in contrast to other examples, medium profiling frequency and diving depth. It has managed to keep its bottom contacts reasonable, and as such has a considerably higher profiling distance accumulated per given energy than any other in the comparison. It also has achieved a rather long mission time and number of profiles in comparison to the more extreme cases.

In conclusion, this case study shows that the energy consumption, and with that the expected lifetime of floats operated in conditions such as the Baltic Sea can be controlled to some degree. It should be noted that it depends on the use case whether to optimize the number of profiles or mission time. In either case, avoiding the bottom contacts can save the battery. Even this is not without compromises, as bottom contacts can often be the means to keep the float in the area of interest.

3. Configuration parameters impact on life expectancy

This part essentially focuses on the impact of a float configuration on its life expectancy. The type of question we would like to answer here is for e.g. Is a float cycling every 2 days lasting (in terms of age, and vertical Kms travelled for example) less than one cycling every 10 days? Most of the time the analysis is not that simple as the life expectancy relies on multiple parameters that need to be isolated during the process of sample selection (like explained throughout the methodology part) in order to highlight the impact of a specific parameter on the life expectancy.

Some configuration parameters are common for every float model like the cycle time period, the park and profile pressure (i.e. 3.1) when others depend on the model. Manufacturers built different floats, using different technologies, therefore inducing different configuration parameters. In the part 3.2, the study will focus on the configuration parameters of the Arvor float model as it is the most deployed float type for the European fleet (about 70% of the deployments since 2015 are Arvor floats type).

3.1. Global configuration parameters for every model

The three main parameters recognized to have a significant impact on float lifetime are the **Park and Profile pressure and cycle time period**. This is permitting to compute the life expectancies for each of these three configuration parameters and compare between different model types. The following graphs present the survival rate computations for these three parameters for the European array since 2015.

3.1.1. *Park Pressure*

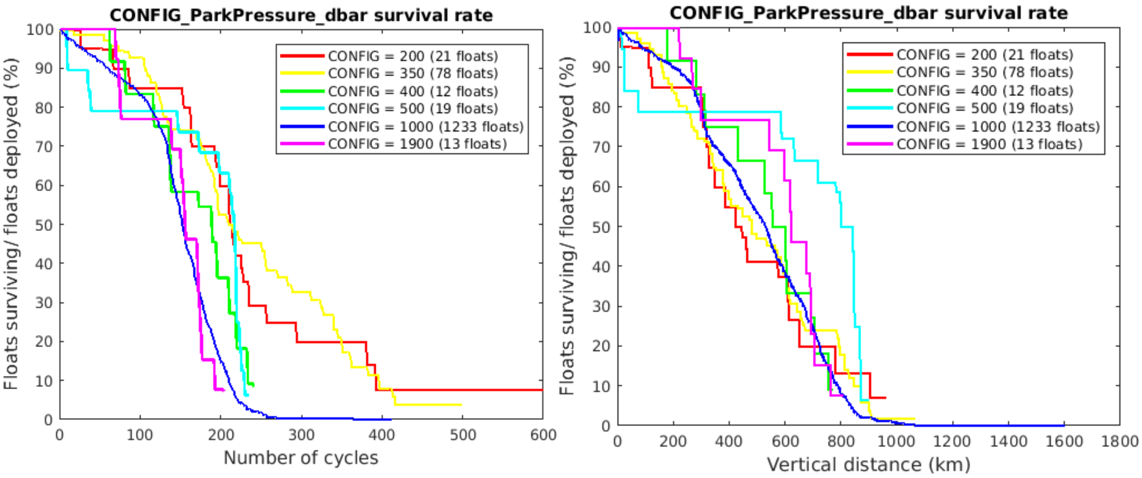


Figure 30- Survival rates computations for European floats deployed since 2015, depending on the different values for the configuration parameter: ParkPressure_dbar. The computations are expressed in function of the cycles reached (left graph) and vertical kms travelled (right graph).

When the sample is too small (under 10 floats), the survival rate is not computed as it wouldn't be robust enough to accurately represent the sample. However, one can consider that a main value is represented for this parameter: 1000 dbar, representing 89% of the sample, as it is the manufacturer default value and the standard value for open Ocean deployments. The blue curve seems to be presenting an overall good median for these different values taken by this parameter. One can note that shallower park pressure often results in floats undertaking more cycles (red and yellow curves). Hydraulic actions undertaken at higher pressure results in higher energetic consumption than actions at shallower pressures. This graph could be put in comparison with the number of repositioning during the parking phase for the different samples here to highlight the impact of the park pressure on the life expectancy of the sample.

3.1.2. Profile Pressure

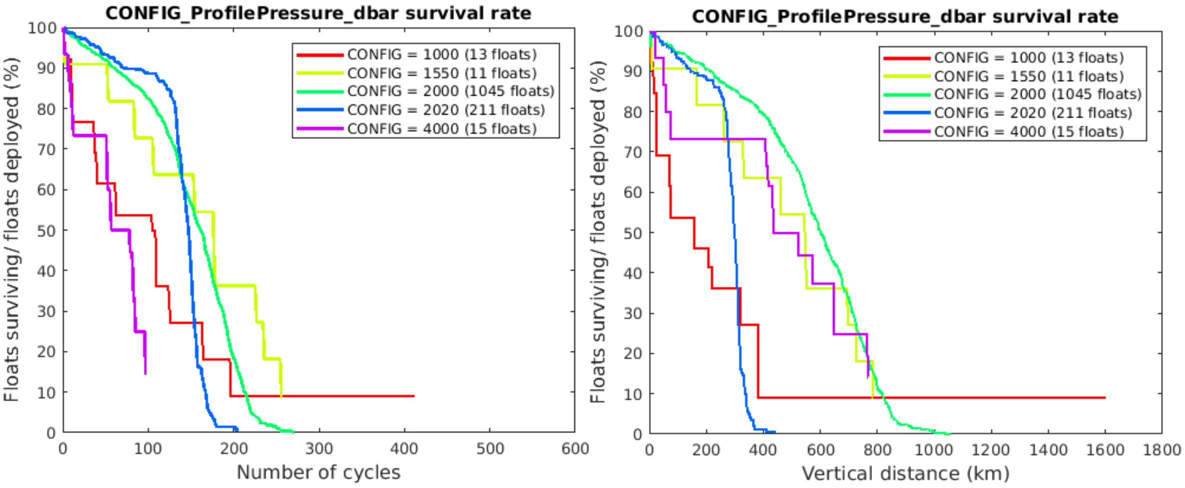


Figure 31- Survival rates computations for European floats deployed since 2015, depending on the different values for the configuration parameter: ProfilePressure_dbar. The computations are expressed in function of the cycles reached (left graph) and vertical kms travelled (right graph).

As for the Park Pressure parameter, here one value is especially represented with 75% of the sample: 2000 dbar (green curve). This value seems to present a good survival rate before the 150 cycles, so does the blue sample with a rather similar value for this parameter: 2020 dbar. Shallower profile depths present a good reliability for a high number of cycles (<200 cycles) as these shallower values are more often used in marginal seas deployments.

The floats with a 4000 dbar profiling depth value are deep floats, in the case of the European array here, Deep-Arvor floats. These floats show poor reliability in terms of survival rates at the beginning of the plots, suggesting an important part of early depth floats (-25% of floats deployed in the first 50 Kms). However, in the middle part of the plot, after the 50Km, these floats show an overall good survival rate, just below the green curve.

3.1.3. Cycle Time Period

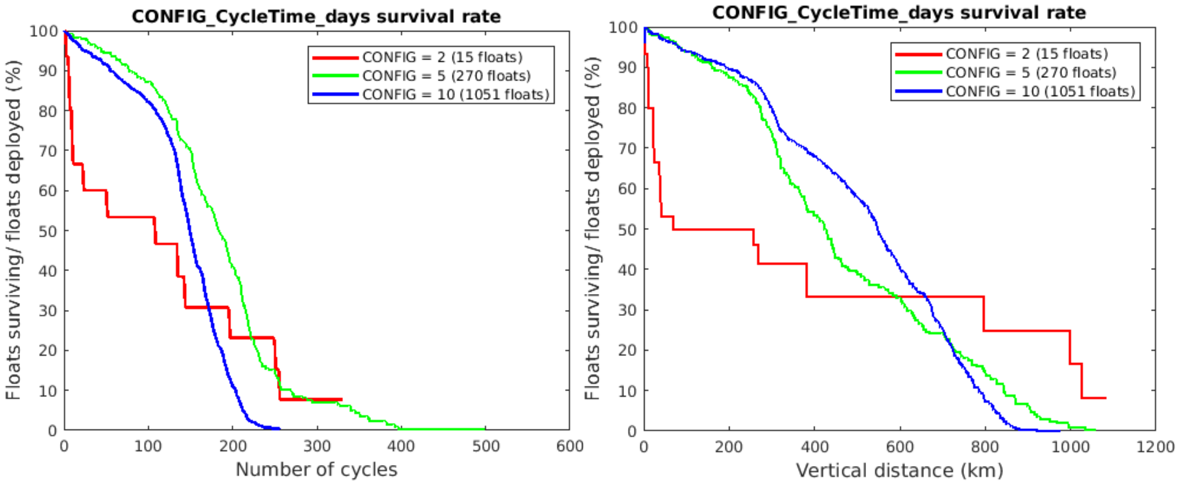


Figure 32- Survival rates computations for European floats deployed since 2015, depending on the different values for the configuration parameter: CycleTime_days. The computations are expressed in function of the cycles reached (left graph) and vertical kms travelled (right graph).

As for the other two parameters, the 10 days value is the most represented with over 75% of the sample represented by this value. The red and blue curves representing respectively a 5 and 10 days cycle time period present an overall good survival rate over the time. One can note that floats cycling at 2 days present a poor survival rate for the beginning of the plots, dropping almost at 50% before reaching 50 cycles /100Kms. However, in terms of important vertical distance travelled (<750 Km) they seem to present a better survival rate than the other two values.

The sample of floats cycling every 10 days tend to present a better survival rate in terms of vertical distance travelled between 300 Kms and 750 Kms.

3.2. Specific Arvor type configuration parameter

In this framework, the Euro Argo ERIC Office investigated in collaboration with RDT (*Technological Research and Development team at IFREMER*), engineering development team of the Arvor floats, the main configuration parameters that could have a major impact on battery consumption and thus, the float lifetime. These configuration parameters are presented in the table below and exclude the three main configuration parameters (**Cycle time, Parking and Profile pressure**) already known to have a huge impact on a float lifetime**.**

Configuration parameter	Description
CONFIG_TelemetryRepeatSessionDelay_minutes	Delay before a second Iridium session performed by the float just before diving for a new cycle (in minutes).
CONFIG_PumpActionTimeBuoyancyAcquisition_csec	Duration of the last pump action of the buoyancy acquisition phase (in centi-seconds).

CONFIG_ParkSamplingPeriod_hours	Specifies sampling period during the park phase.
CONFIG_GroundingMode_LOGICAL	Action performed by the float when a grounding is detected. 0: the float changes its drift pressure, 1: the float stays on the seabed until the next phase of the cycle.
CONFIG_CTDPoints_NUMBER	Number of CTD points measured in the profile phase. ***Parameter derived from other configuration parameters.***

Table 2- Description of the different Arvor related configuration parameters studied here

Again, we have to bear in mind that these specific configuration parameters concern **only the Arvor type floats**. Some of these may have equivalences on other floats technologies but the fundamental principle of floats movement might be substantially different, thus making any equivalence irrelevant (Arvor = Pump with ballast system, Apex = Pistons). The Arvor floats have been selected because they represent 70% of European deployments since 2015.

The script developed and explained in another part Config fleet status of this document helps to better understand and monitor the changes made throughout a float lifetime on these parameters and more importantly what are the most common values given for each float type, deployment country and year.

The sample selected for the figures below and in the ANNEXES is the Arvor Iridium floats deployed in the global ocean since 2008 with standard configuration parameter: park pressure = 1000 dbar; profile pressure = 2000 dbar; cycle time period = 10 days. The following part will present one of the five configuration parameters presented in the table above. Others are presented in the ANNEXES. Table **XX** provides a quick recap of the trends observed for all the considered parameters.

3.2.1. Pump time action Buoyancy acquisition

This parameter represents the time of action of the pump at the surfacing of the float, in order to acquire a positive buoyancy.

The majority of the floats in the sample did not change this parameter throughout their lifetime (76.2% of the sample). This configuration parameter is not meant to be changed over the float mission as it doesn’t have a scientific purpose like the target cycle period or park and profile pressure, or the vertical sampling scheme. Some Argo teams have updated this configuration since discussion emerged that it could be reduced with no impact on the data transmission performances at surface, but with a significant impact on the energy budget. Recommendations will be provided in the deliverable 2.6 to choose a definite value for this parameter. However, the ERIC office team is interested to quantify the impact of the different values taken by this parameter on floats’ lifetimes.

The next figure presents the second output of this tool, showing the distribution of the values taken by this parameter, for floats that did not change their configuration after deployment. Floats that did not change configuration had one of these three values: 27000, 28000 or 30000 csec.

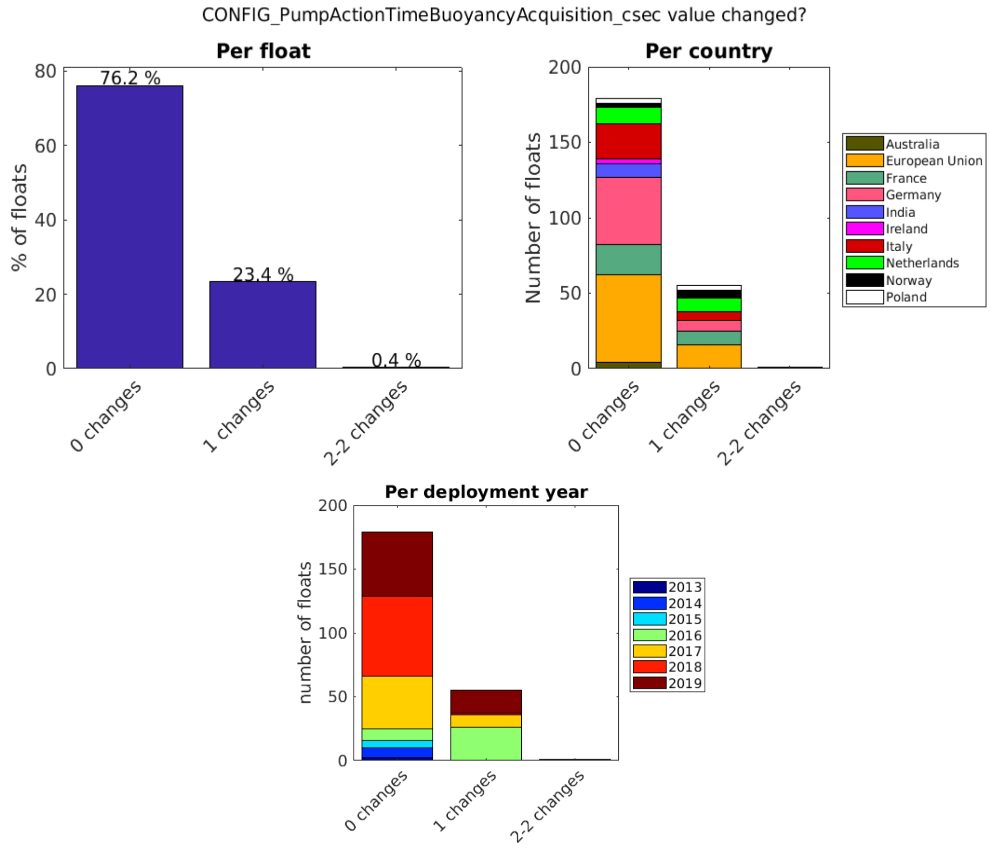


Figure 33- 1st config fleet status tool outputs for a specific configuration parameter, here the “pump action time for buoyancy acquisition (csec)”. These histograms present how much floats changed this parameter throughout their lifetime after deployment, grouped per year and countries of deployment. The sample considered is the one described above, at the end of the precedent part. Note that years before 2013 presented less than 10 floats in the sample and were not considered.

More pump time actions result in higher buoyancy, but also a greater energy consumption. According to **Figure 34**, floats that used a 30000 csec value (default NKE value) represent 37% of the sample when floats using 27000 and 28000 csec configuration respectively represent 27% and 36%. Floats using shorter pump time actions for their buoyancy acquisition (27 and 28k csec) were mostly deployed by European Union in the more recent years (2017 to 2019) because it was judged unnecessary to acquire such an important emergence to transmit data when a lower one is doing perfectly fine. This conclusion emerged after a study of the impact of oceanographic conditions on data transmission, made during the MOCCA project study (*D3.4 Impact of waves on ARVOR floats*). This study highlighted the fact that neither of the two main parameters influencing data transmission (GPS positioning and Buoyancy acquisition) were related to waves conditions. Hence, from this study emerged recommendation to decrease the time for buoyancy acquisition, which reflects in the **Figure 34** as most of a float having the less time are European floats, deployed in recent years.

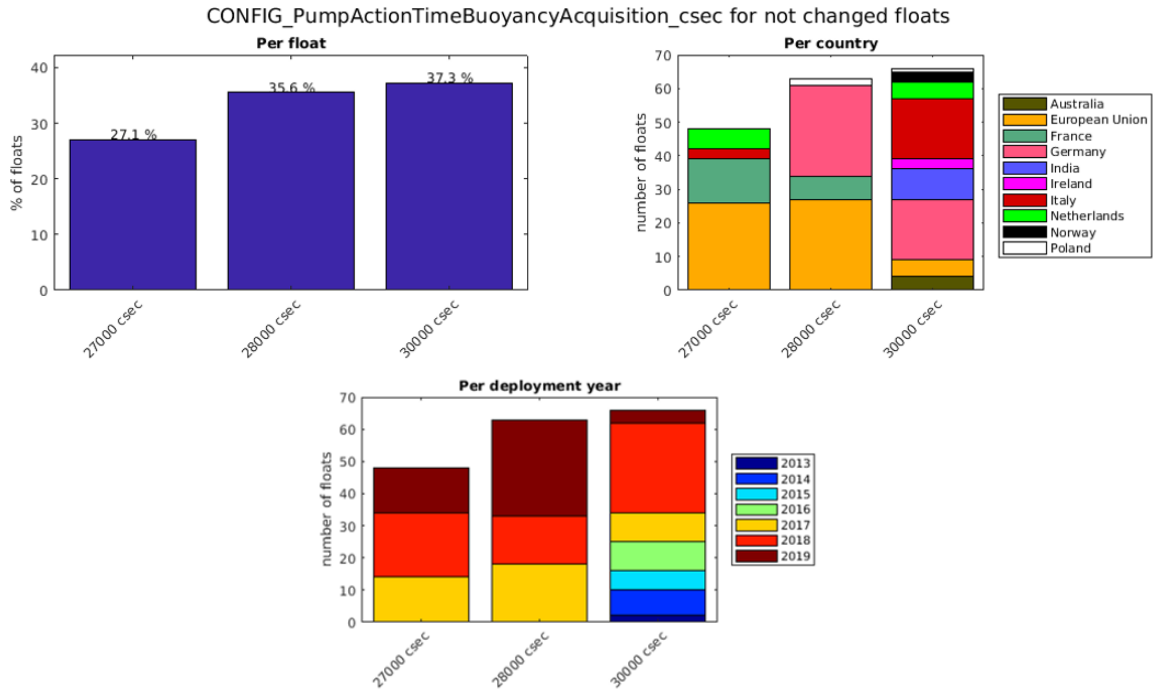


Figure 34- Second output of the "CONFIG_fleet_status" tool, providing information on the distribution of the value taken by floats that did not change this configuration parameter after their deployment.

The following **Figure 35** is presenting the survival rate computation for this configuration parameter and its three main different values in function of the number of cycles reached and the vertical distance travelled (in Kms):

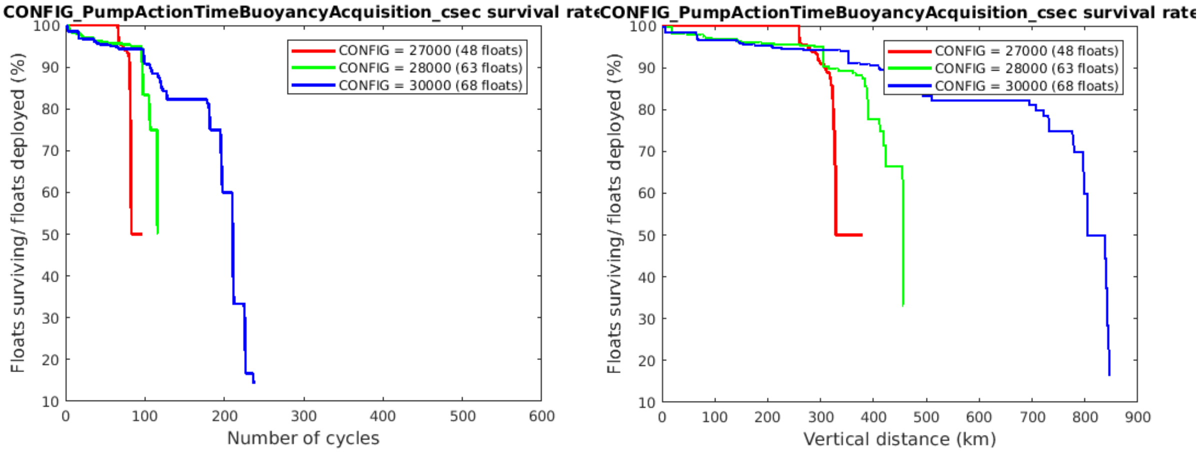


Figure 35- Survival rate computations for the different values taken by the following parameter: "CONFIG_PumpActionsTimeBouyancyAcquisition_csec". In the left graph in function of the number of cycle reached and in the right one, according to the vertical distance travelled in Kms.

A quick look at these curves will suggest that the 30000 csec value is the best in terms of survival rate performances because 80% of the float with this configuration reaches at least 200 cycles, when for the other configurations, it decreases dramatically before the 100 cycles mark. Now, we have to consider what the graphs in the precedent figures tell us: floats using a 27000 or 28000 csec value were deployed during the most recent years: 2017,2018 and 2019, thus inducing this sudden decrease in the red and green curves (like explained in the part Survival Rate computation). In fact, younger floats that were not able to reach this number of cycles or Kms yet, induce **an artificial drop** in the survival rate computations. These floats' lifetime will be computed and analysed again in the next months/years to see how the different survival rates evolve and if any value for these parameters seems to improve the life time of the floats.

3.2.2. Configuration parameters impact: Summary

The following table presents the conclusions derived from the different survival rates computations for these Arvor specific parameters. The precedent part highlighted one of these parameters but the analyses concerning other parameters can be found in this Annex.

Configuration parameter	Conclusions
CONFIG_TelemetryRepeatSessionDelay_minutes	Floats performing a second GNSS session at surface are still alive, thus not permitting to draw any meaningful conclusions on this specific parameter.
CONFIG_PumpActionTimeBuoyancyAcquisition_csec	Sample ages are very heterogeneous making it difficult to compare the different values now.
CONFIG_ParkSamplingPeriod_hours	Same as for the pump time action. The ages of floats in the sample are very heterogeneous, making it difficult to draw any conclusions.
CONFIG_GroundingMode_LOGICAL	The sample representing the grounding mode 1 is composed of 12 floats (compared to 223 floats for mode 0). The same study should be done when more floats with the mode 1 are deployed or in the marginal seas where the grounding modes sample should be more balanced.
CONFIG_CTDPoints_NUMBER	Floats measuring fewer CTD points seem to perform better. This trend should be confirmed in a few moments. The next step would be to quantify the decreased lifetime for a float measuring 101 points and one measuring 600. The ratio might be worth it when considering the 6 times multiplier of scientific measurements.

In Brief: The Arvor Iridium sample is still a bit young and this study should be repeated in some months when more of these floats will be dead of “natural cause” and more floats will be deployed. The Euro-Argo ERIC Office will then have a more precise idea of which parameters seem to impact the most the life expectancy of the floats and which values seem to perform better. Replicating this study in a few months/years will be an important step for the next deliverable of this task consisting in providing users the best recommendations to maximize their floats life expectancy.

Table 3- Summary of the survival rates for different Arvor related configuration parameters

Perspectives

The study of float life expectancies is complex. In order to draw meaningful conclusions from the different studies presented throughout this report, it is an absolute necessity to understand how complex and multiparametric this indicator is.

Throughout the METHODOLOGY part of the report, we tried to explain the different steps of this type of analyses, from the creation of the sample to the temporal units used to express the survival rate results and their different meanings. The RESULTS part of the report presented some life expectancy computation for different float samples, in function of their configuration parameters, sea region and models.

Nevertheless, there are several objectives to reach in the future in order to refine these analyses and derive some recommendations for the users in order to maximise the life expectancy of their floats.

On the methodologic part, one major update will be considered:

- **The causes of death/recovery**. In fact, this is a cornerstone in the sample creation before a life expectancy analysis. In order to put into relief, the impact of one specific parameter (technical or configuration) on the life expectancy, one must compare floats that died of the same causes. One cannot use a batch of floats with early dead floats from sensor failure or beached floats if the aim of the analysis is to highlight the impact of a long-term parameter like the park and profile pressure or the cycle time. The life expectancy would thus decrease because of external causes, inducing non-reliable conclusions about the targeted parameter.

  The OceanOPS AIC presents a declarative field “end of life causes” that would be extremely helpful for a reliable life expectancy analysis. An audit could be undertaken in order to fill this field for the major part of the European floats. Should be differentiated the following death causes: death on battery level (“natural” death as named throughout this report); recovered floats; early death floats because of sensor failure; beached; hydraulic technical difficulties preventing the float to work efficiently.

After the Arvor-Provor technical workshop hosted in January 2020 at Brest, the need of an **energy budget tool**, provided by the manufacturers of the floats, emerged in order to better understand the impact of the float actions (whether it is hydraulic, data transmission, etc…) in terms of energetic consumption. We hope to come to an agreement with the float’s manufacturers concerning the utility of such a tool, that should, in a near future, permit the ERIC office team to better assess the parameters to investigate and how much a specific configuration costs, in terms of cycles reached.

These two updates will help the ERIC office team to undergo more user-oriented analysis to provide specific recommendations to increase floats lifetime in function of the basin of deployments, variables measured, etc… The office plans on analysing the impact of technical parameters like the groundings, the number of repositioning during drift phase on the life expectancy of floats; the differences between the basins, the impact of “in-air” oxygen measurements every cycle, etc…

The use case study of battery consumption for Apex floats in the Baltic Sea should be extended to all the Baltic fleet, including Polish and European Union Arvor floats deployed in the region to reinforce the trends and the conclusions derived from it.

In addition to these future analyses, Euro-Argo will repeat the computations from this report that presented for conclusion that the sample was too young to clearly observe the trend of the life expectancy curve because not enough floats were dead yet.

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GLOSSARY

- **AIC:** Argo Information Centre
- **BGC:** BioGeoChemical
- **CORE:** Standard Argo float measuring temperature and salinity (T/S)
- **CTD:** Conductivity, Temperature, Depth
- **DAC/GDAC:** Data Assembly Centre / Global Data Assembly Centre
- **DEEP:** Argo floats diving to greater depths than 2000 meters
- **DO:** Dissolved Oxygen
- **ERIC:** European Research Infrastructure Consortium
- **EU:** European Union
- **FMI:** Finnish Meteorological Institute
- **GNSS:** Global Navigation Satellite System
- **IFREMER :** Institut Français de Recherche pour l'Exploitation de la Mer
- **IO-PAN:** Institute of Oceanology of the Polish Academy of Sciences
- **IO-BAS:** Institute of Oceanology – Bulgarian Academy of Sciences
- **IOC:** Intergovernmental Oceanographic Commission

- **ISA:** Ice Sensing Algorithm

- **JCOMMOPS:** Joint technical Commission for Oceanography and Marine Meteorology in situ Observations Programme Support Centre

- **KNMI:** Koninklijk Nederlands Meteorologisch Instituut

- **LOV :** Laboratoire d’Océanographie de Villefranche

- **MOCCA:** Monitoring the Oceans and Climate Change with Argo

- **OGS:** Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (National Institute of Oceanography and Applied Geophysics)
- **PI:** Principal Investigator

- **WMO:** World Meteorological Organization

ANNEXES

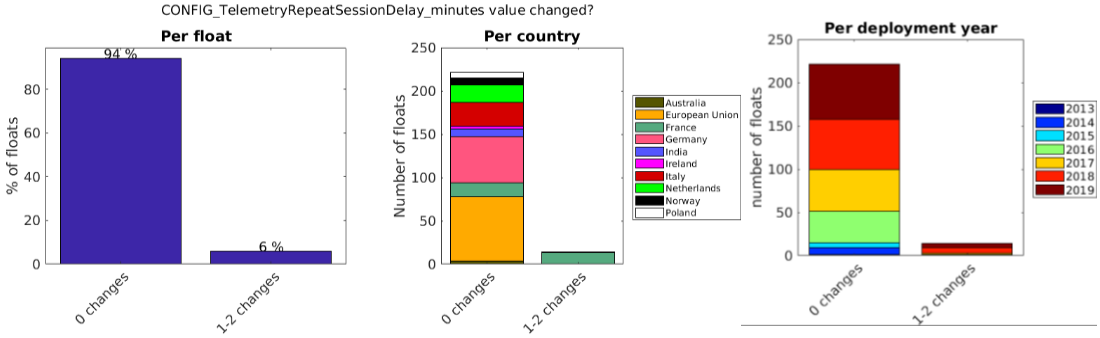
1. Config fleet status and Arvor type related life expectancy:

- Some tools were developed by Andrea Garcia permitting to group and monitor floats samples according to their configuration parameters and their modifications during mission (CONFIG_fleet_status script); plot a certain technical parameter on a map and calculate a survival rate for a group of floats. This study was essentially focused on ARVOR - Iridium floats which represents the majority of the European fleet.

1.1. Telemetry Repeat Session Delay

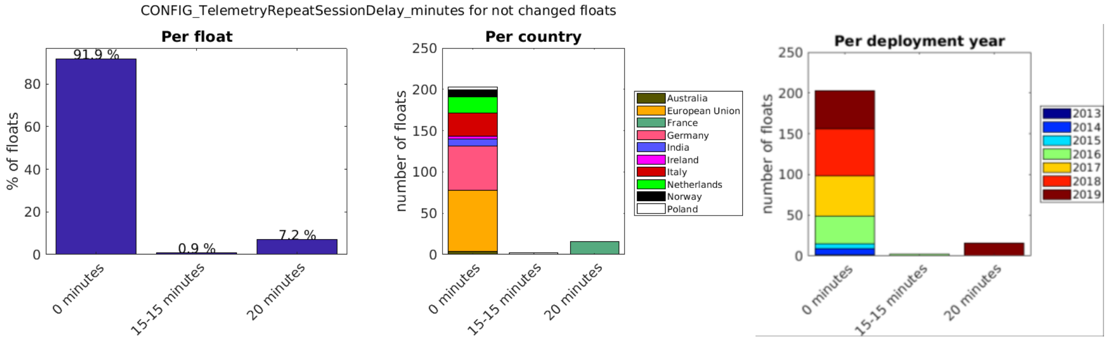
This parameter induces the float to stay longer at the surface for either one or both of these reasons:

- To make a second GPS point to improve its localization precision. Specifically used for some teams interested in floats trajectories.
- To be able to receive another iridium command from deployment teams.



Annex 1- Repartition of the changes in configuration for the parameter: "CONFIG_TelemetryRepeatSession Delay_minutes"

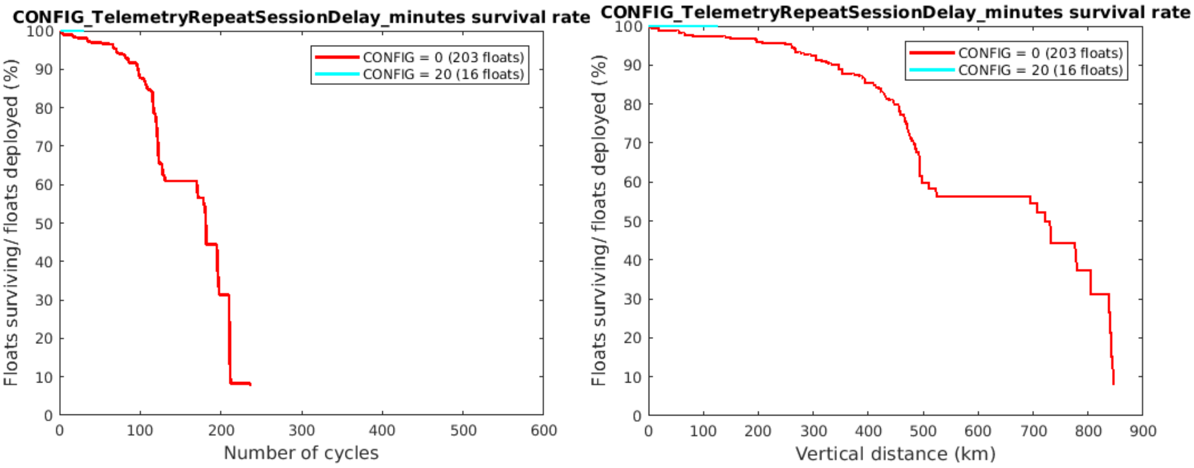
These outputs indicate that the changes of this parameter throughout the float lifetime are marginal and for the most part, changes were made by France in recent years (2018-2019).



Annex 2- Repartition of the values taken by the floats that did not change this configuration parameter after deployment: "CONFIG_TelemetryRepeatSession Delay_minutes"

For floats that did not change parameter over time (94% of the sample), the most common values are: 0, 15 and 20 minutes. A 0 minutes session means that only one GNSS point was made during float surfacing (very clearly most of the cases). The two other values mean a second GNSS point was made, inducing the float to use its Iridium modem and GNSS longer, thus consuming more energy. Floats that were configured to do a second GNSS point after 20 mins are French floats deployed in 2019, in order to increase precision of the float position and derive a more reliable trajectory computation.

When computing the survival rate of this sample according to floats with no second GNSS point and the one undertaking a second session, the following curves are obtained:



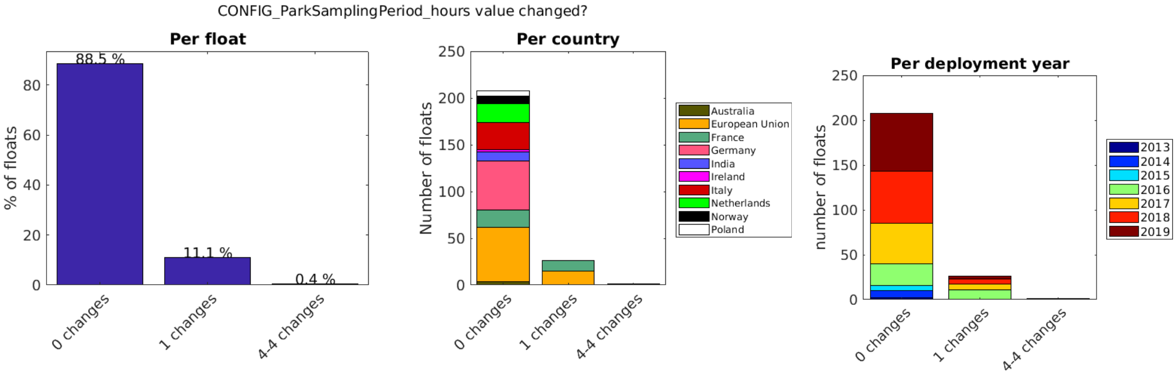
Annex 3- Survival rates computation for the different values of the parameter: "CONFIG_TelemetryRepeatSession Delay_minutes", in terms of number of cycles reached on the left and vertical distance travelled on the right

Floats using 20 minutes delay for a second GNSS session are represented by the cyan curve while the rest of the sample representing the absence of a second GNSS session is represented by the red curve. The few floats with 15 minutes values for the delay are not represented here; their proportions were marginal in comparison to the rest of the sample.

However, floats performing a second telemetry session are all still alive at this point (floats deployed in 2019), rendering impossible any reliable conclusions about this configuration parameter. The same study should be conducted in the next months/years in order to spot any specific behaviour linked with this configuration parameter.

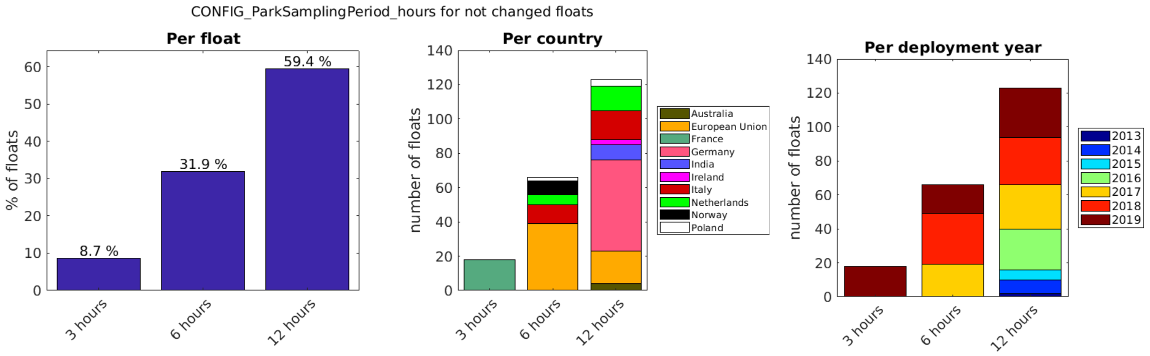
1.2. Park sampling period

This parameter defines the time interval between two samplings made during the park phase of the float cycle (in this sample taking into account the open ocean standard mission parameters: 10 days park period).



Annex 4- Repartition of the changes in configuration for the parameter: "CONFIG_ParkSamplingPeriod_hours"

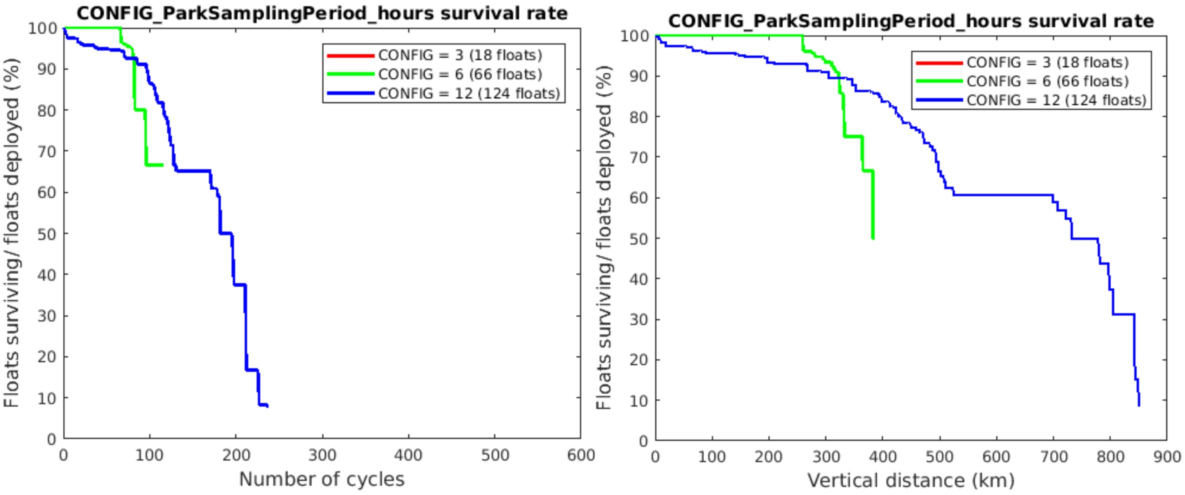
Most of the floats of this sample did not change this parameter throughout the float lifetime (88.5%).



Annex 5- Repartition of the values taken by the floats that did not change this configuration parameter after deployment: " CONFIG_ParkSamplingPeriod_hours "

The three values taken for this parameter are 3, 6 and 12 hours, respectively capitalizing 9%, 32% and 59%. The floats performing CTD measurements each 3 hours were deployed by France in 2019 for highly precise trajectories purposes and the ones performing measurements every 6 hours were mainly deployed by the European Union during the most recent years, 2017 to 2019 (standard configuration for floats bought through the ERIC). The 12 hours sampling period (manufacturer-NKE default value) seems to be the most common, capitalizing almost 60% of the sample. This value concerns floats deployed since 2013 to 2019.

The main reason why more CTD measurements were performed during the park phase recently is because it contributes to increasing the understanding of the float behavior during this specific period of the float cycle. However, it shall not be neglected that increasing the samples during this phase has a direct impact on battery consumption and is expected to decrease the float life expectancy.



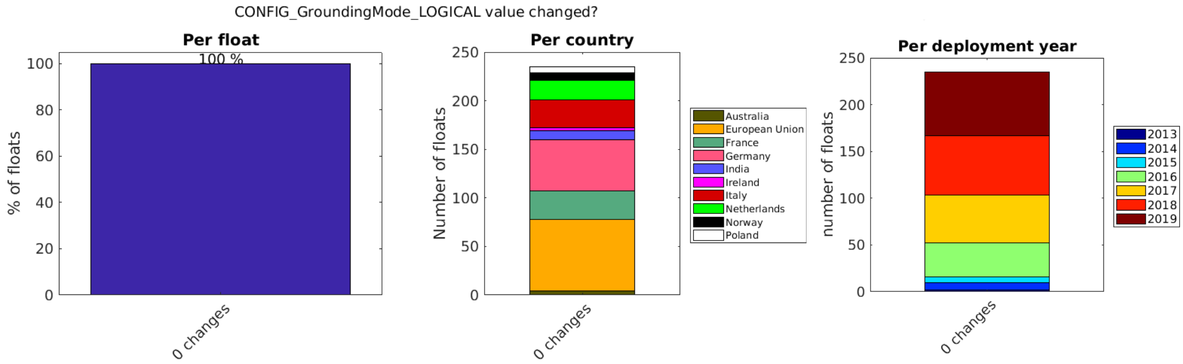
Annex 6- Survival rates computation for the different values of the parameter: " CONFIG_ParkSamplingPeriod_hours", in terms of number of cycles reached on the left and vertical distance travelled on the right

As for the pump time of action for buoyancy acquisition, higher sampling rates (3 and 6 hours) were mainly put into testing since (at the earliest) 2017. Not enough floats are dead naturally at this point and time, thus not permitting to derive meaningful conclusions. However, when focusing on the beginning of the plots, the 12 hours sampling period appears to perform better. The same study shall be reconducted in a few months/years to better assess the impact of increased measurements during this phase, on life expectancy.

1.3. Grounding mode

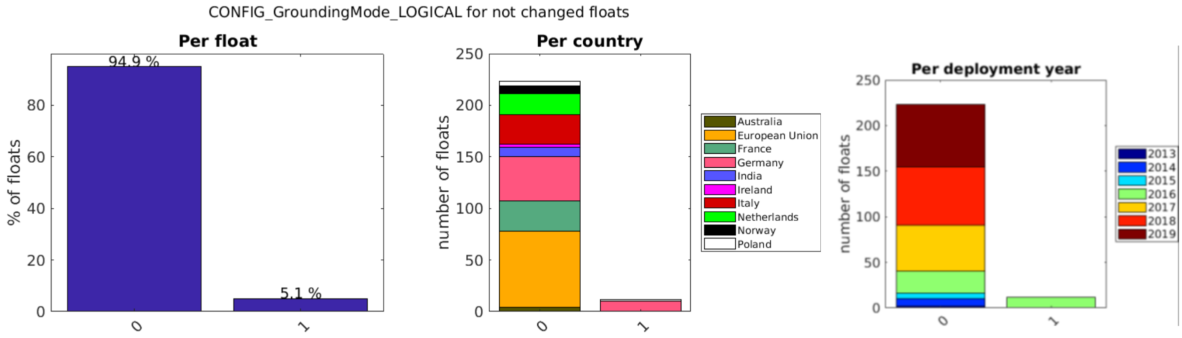
The Arvor floats have a grounding mode parameter permitting to impose a certain action for the float to take in case of grounding in the cycle. A grounding is detected when the pressure during a descent phase (descending to parking or profile pressure) does not evolve anymore for a given time interval. At some point, the float will consider itself grounded and will refer to the grounding mode configured before it descends:

- Either **mode 0**: The float changes its drift pressure given a certain threshold in order to go back to a lower depth and eventually overcome the obstacle encountered.
- Or **mode 1**: The float stays grounded until the next ascent cycle phase. This mode could be considered more “passive” and permit energy savings but in reality, it could present a real problem depending on the seabed nature. If the seabed is fine sediment, it could penetrate in the external hull protecting the external ballast and burden the float, rendering its ascent even more costly from an energetic point of view or even impossible.



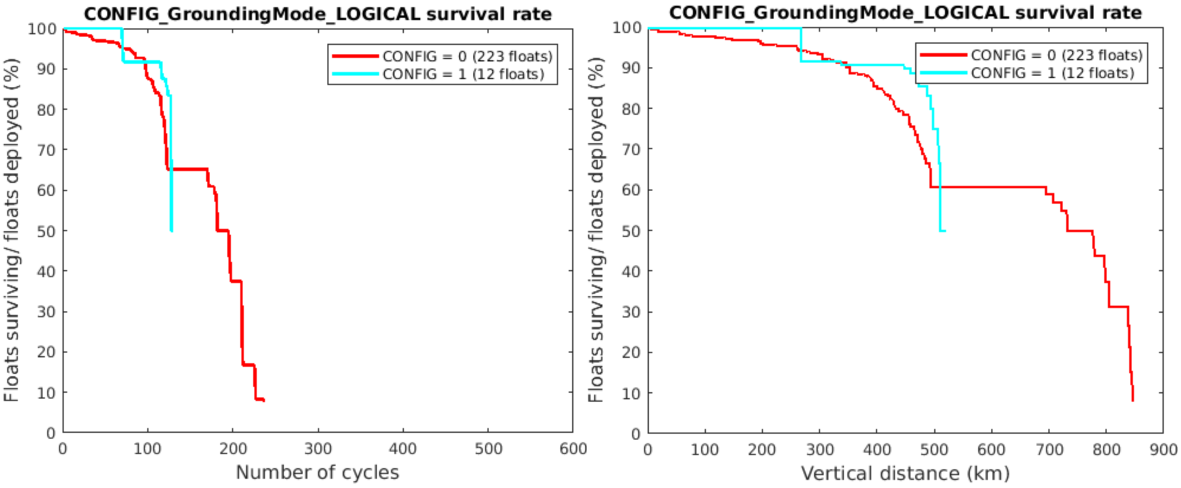
Annex 7- Repartition of the changes in configuration for the parameter: "CONFIG_GroundingMode_LOGICAL"

None of the floats considered in this sample changed this configuration parameter after their deployments at sea.



Annex 8- Repartition of the values taken by the floats that did not change this configuration parameter after deployment: "CONFIG_GroundingMode_LOGICAL "

The immense majority of the sample (95%) of the floats used the 0 configuration, implying the float to ascend back to a defined pressure threshold (usually -100 dbar) to overcome the obstacle and proceed with his drift phase. We have to bear in mind that the sample selected here is concerning floats deployed in the open ocean, with a standard mission. Floats deployed in marginal seas may have a more balanced ratio between grounding mode 0 and 1, maybe permitting a better understanding of the impact of this parameter from a life expectancy point of view. However, it is a lot more complicated to build a homogeneous enough sample in marginal seas permitting to isolate the impact of this parameter, and this parameter alone, on the life expectancy of floats.



Annex 9- Survival rates computation for the different values of the parameter: " CONFIG_GroundingMode_LOGICAL ", in terms of number of cycles reached on the left and vertical distance travelled on the right

The survival rate computations for this configuration parameter seems to present the grounding mode 0 more performant in the time in comparison to the mode 1. The sample with the grounding mode 1 are floats deployed by Germany in 2016 whereas the floats with the grounding mode 0 comes from different countries that were deployed from 2013 to 2019. The hypothesis of a prolonged grounded period (waiting for the next ascent phase) that might induce a burden of the float and in the long term, cause its early death could represent an explanation on why the mode 0 is presenting better survival rates than the mode 1. However, this hypothesis should be investigated with a greater floats sample (more than 12 floats using this mode), maybe considering the marginal seas floats networks or when the floats of this sample starts dying.

1.4. CTD measurements number

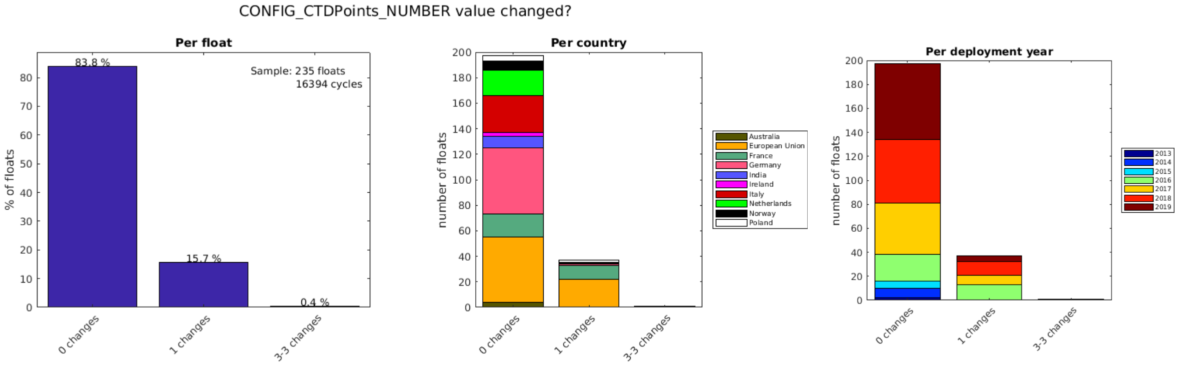
Firstly, this parameter does not exist as such and has been derived from other configuration parameters such as: Profile Surface Slices Thickness, Pressure threshold data reduction, …

These parameters define three “slices” in the profile ascent: surface, intermediate and bottom. These slices are defined in order to limit data volume and permit a more specific configuration of the number of measurements in these slices. If the scientific purpose is to better understand a deep ocean current, the number of CTD points in the bottom slice (configurable depth) could be increased significantly while reduced in the other slices. This flexibility in CTD measurements also exists for the Apex float type, where these “slices” are named “bins”, as it was a very demanded feature by the scientific community.

However, more CTD points induce bigger data volume to transmit, thus making the float stay longer at surface and using its modem and Iridium antenna to transmit the data, increasing its energy consumption per cycle.

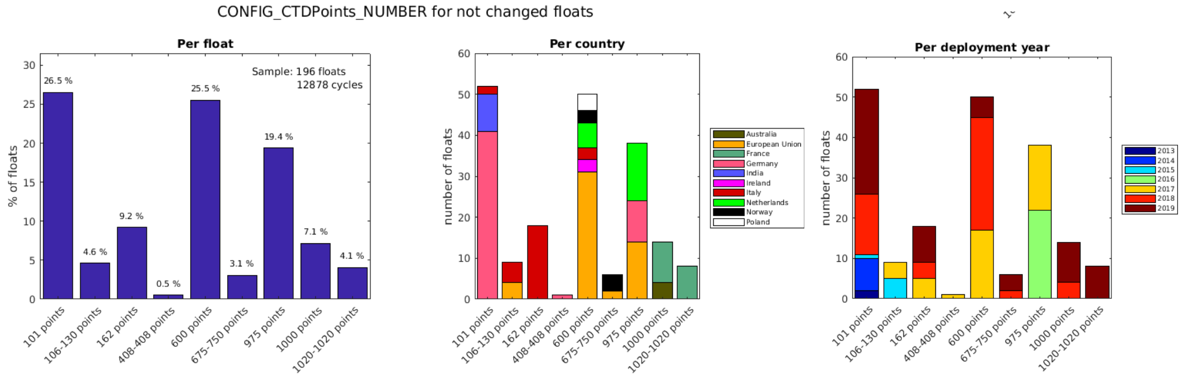
$$CONFIG\_CTDPoints\_NUMBER\ = [\frac{CONFIG\_PressureThresholdDataReductionShallowToIntermediate\_dbar}{CONFIG\_ProfileSurfaceSlicesThickness\_dbar} + \frac{(CONFIG\_PressureThresholdDataReductionIntermediateToDeep\_dbar - CONFIG\_PressureThresholdDataReductionShallowToIntermediate)}{CONFIG\_ProfileIntermediateSlicesThickness\_dbar} + \frac{(CONFIG\_ProfilePressure\_dbar\ -\ CONFIG\_PressureThresholdDataReductionIntermediateToDeep\_dbar)}{CONFIG\_ProfileBottomSlicesThickness\_dbar}]$$

The equation above permits us to understand how the number of CTD measurements is calculated according to the data reduction parameter for each slice.



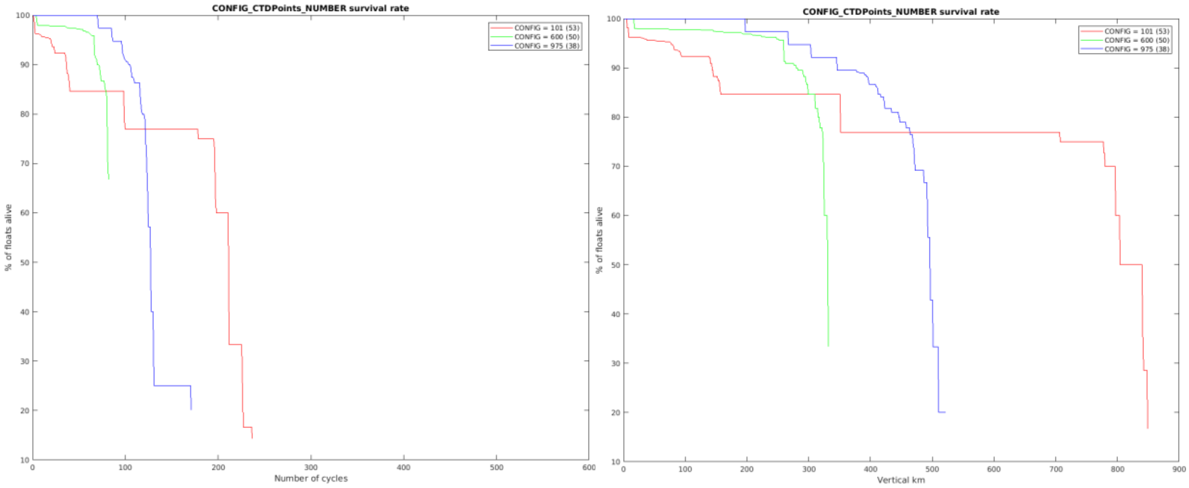
Annex 10- Repartition of the changes in configuration for the parameter: "CONFIG_CTDPoints_NUMBER"

A majority of the sample considered here did not change the number of CTD points during profile after the float deployment (83%). Contrary to other configuration parameters investigated before, the values assigned for this parameter are far more heterogeneous.



Annex 11- Repartition of the values taken by the floats that did not change this configuration parameter after deployment: " CONFIG_CTDPoints_NUMBER "

Floats performing the most of CTD measurements during profile (1000 to 1020 points) are French floats, deployed in the recent years (2018-2019). Three other values seem to be redundant: 101, 600 and 975 points, capitalizing for these three values 71% of the sample. The 101 points value corresponds mainly to floats deployed by Germany, essentially in the years 2018-2019. Floats performing 600 CTD measurements during profile are mainly deployed by the European Union, in recent years (2017 to 2019). Floats performing 975 points are from diverse countries which deployed them in 2016-2017.



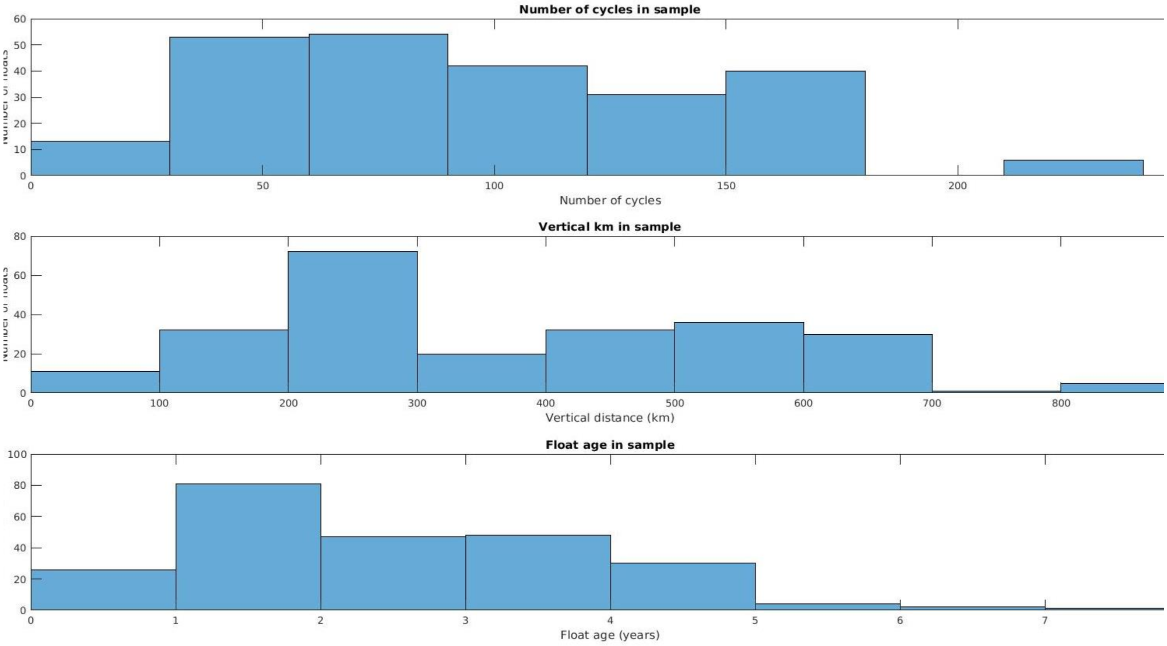
Annex 12- Survival rates computation for the different values of the parameter: " CONFIG_CTDPoints_NUMBER ", in terms of number of cycles reached on the left and vertical distance travelled on the right

The red curve represents the 101 points value, the green one, 600 points and finally the blue one, 975 points. In this case, the number of floats in each sample is relatively homogeneous as well as their age.

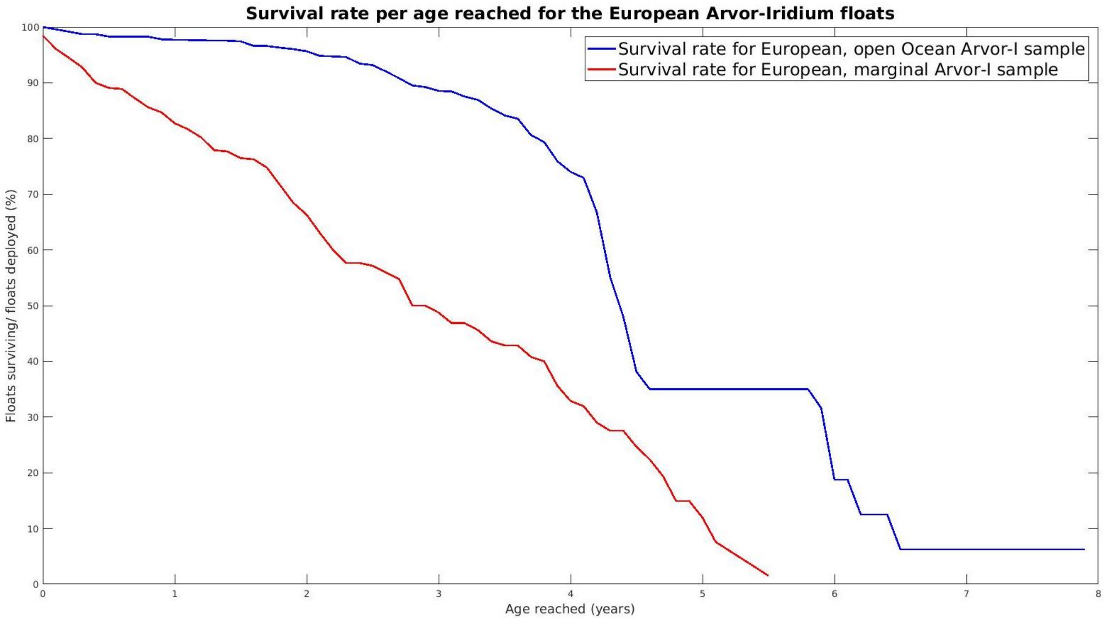
Floats performing fewer CTD measurements appear to perform better and have a greater survival rate than the other two configurations. In fact, 75% of the red sample are performing 200 cycles when none of the floats of the blue sample performed 200 cycles. The difference is even bigger when comparing with the vertical distance covered: 75% of the red sample floats travelled more than 700 Km when none of the floats from the blue sample reached more than 550 Km travelled. The green curve decreases instantly because the sample is still very young, but the curve should flatten as the time goes.

However, only a few floats died from the red and green samples, and this trend should be either confirmed or discussed by running this same analysis in a few months/years. It was expected that this parameter had a direct impact on energy consumption and thus on life expectancy of floats but the next step of this analysis would be in quantifying the decrease of the float lifetime related to this parameter. Also, it would be interesting investigating the difference between collected measurements and transmitted ones. In fact, these two numbers are expected to be different in case of shorter cycles due to an unwanted grounding for example.

2. Case study of European Arvor-I floats life expectancy

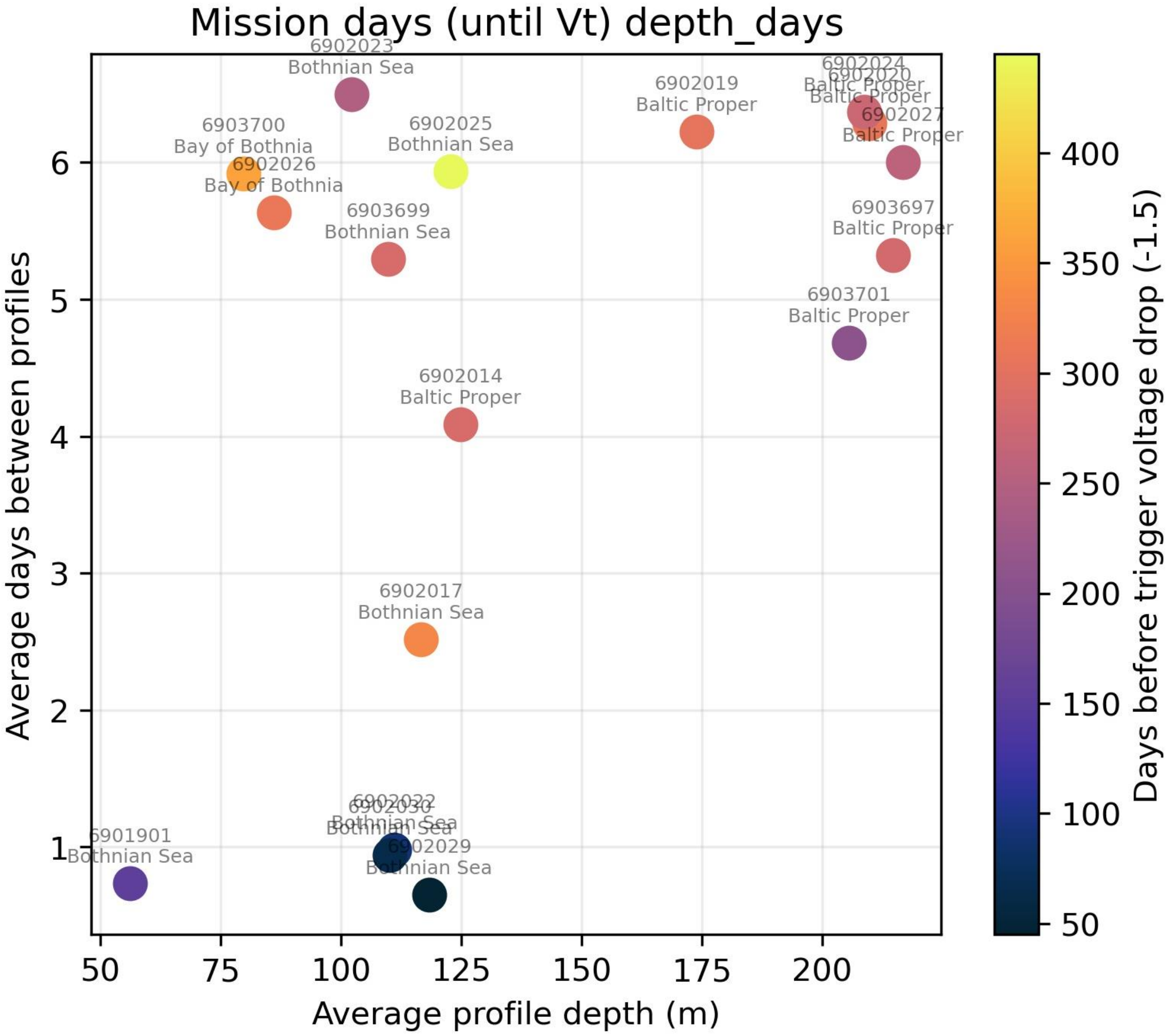


Annex 13- Distribution of floats lifetime for the European Arvor-Iridium floats deployed since 2008 in the open ocean.



Annex 14- Survival rates in function of the age reached for European Arvor-Iridium floats deployed in the open Ocean (blue) and marginal seas (red), with standard configuration since 2008

3. Case study: Baltic



Annex 15- **fD**: Mission days accumulated before battery voltage dropped 1.5 V. Axis shows the average profiling depth and frequency for each mission. Mission area and WMO plotted next to respective dot, colour indicates days before -1.5 V.