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 floats configurations, batteries, etc.)

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Deliverable title	**Recommendations to increase the overall performance of Argo floats, based on at sea monitoring fleet behaviour monitoring, assessment and report (including a review of metadata that impact floats lifetime: specific floats configurations, batteries, etc.)**
Description	**This document presents multiple survival rates comparisons between different float models, deployment basins and configuration and technical parameters. From these comparisons are derived some floats performances trends and recommendations for operational teams to increase floats lifetime.**
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Lead authors	**Luca Arduini Plaisant, Romain Cancouët**
Contributors	**Simo Matti-Siiria, Mathieu Belbéoch**
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EXECUTIVE SUMMARY

The implementation of a full-depth, multidisciplinary float array significantly increased the number of floats needed at sea, naturally inducing the need to maximise their lifetime and consequently reducing the cost per profile. This deliverable bases itself on the methodology elaborated in the precedent deliverable of this task (D2.1 *Enrichments of monitoring tools to track and compare float configurations and estimate life expectancies*) in order to complete reliable and meaningful survival rate comparisons and float performance analyses.

This deliverable is articulated around three main parts:

- Float mission (CORE, DEEP and BGC), models and deployment basins (marginal Seas and open Ocean) performance analyses based on survival rates comparison.

- Analyses of the impact of configuration parameters and technical behaviour at sea, on the float lifetime (study undertook on the Arvor-A, Arvor-L and Arvor-I float models, c.f. GLOSSARY).

- Specific case study of the Baltic Sea floats, aiming to precisely estimate the optimum time of recovery for Apex floats in this region.

The first part permitted to highlight some underperforming float models when compared either to other float models performing the same mission or to their own theoretical lifetimes (HM2000, ALTO, NOVA, NINJA-D and ARVOR-D).

The comparisons between deployment basins proved that European marginal Seas floats, because of their different configuration than open Ocean one (especially on the cycle time period), complete more cycles than open Ocean ones but live for a smaller amount of time at sea. This shorter refresh rate induces the need for operational teams to deploy more floats in these regions to maintain an operational array. This study also proved, when analysing the survival rates curves in terms of vertical distance travelled (a proxy to the number of measurements collected), that marginal Seas floats tend to have a larger amount of early death failures than open Ocean ones (for many reasons related to these harsher environments). However, once this early death failure phase is passed, marginal Seas floats perform well and undertake as many measurements as the open Ocean ones (Figure 10).

Following the Deliverable D2.1 recommendations:

- An audit was performed, which aimed at updating the recovery status for all the European floats in order to have a complete and reliable list of floats recovered over the past 10 years, at a European level. This audit permitted to resolve an issue on the OceanOPS AIC metadata, wrongfully flagging hundreds of floats as recovered. The final list contains 84 European recovered floats and 27 are still pending on their PIs verification.

- A list of Arvor platform type floats (Arvor-A, Arvor-L, Arvor-I and Arvor-D) dead on battery level was created. The method used is explained at the beginning of the Chapter IV. This list was the corner stone for comparisons between theoretical lifetime and at-sea one as well as for the configuration parameter impact study.

The configuration parameter and technical impact study highlighted some critical parameters to pay attention to, that should not be changed under a certain threshold in order to optimise the floats lifetime. The number of groundings did not show to have an important impact, from an energy stand point, on the floats’ lifetime.

Eventually, the Baltic Sea study, performed by Simo Matti-Siiria from FMI, estimated the optimum timespan at sea for Apex floats in this area at 2 years with a 5 to 7-day cycling period.

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I. Introduction

The frame of this deliverable is the Work Package 2 of the Euro-Argo RISE project, aiming to improve the CORE Argo mission. This is the second deliverable of this task, after the deliverable 2.1 was submitted in December 2020. The D2.1 issued a methodology and diverse tools, in order to properly select a float sample, compute its survival rate and interpret its performances. Please refer to this deliverable if you want details on the sample selection process and the computation of its survival rate.

This deliverable D2.6 focuses on results of survival rates comparisons and key findings about European Argo floats performances. This deliverable will articulate itself around three main parts:

- Float mission (CORE, DEEP and BGC), models and deployment basins (marginal Seas and open Ocean) performance analyses based on survival rates comparison.

- Analyses of the impact of configuration parameters and technical behaviour at sea, on the float lifetime (study undertook on the Arvor-A, Arvor-L and Arvor-I float models, c.f. GLOSSARY).

- Specific case study of the Baltic Sea floats, aiming to precisely estimate the optimum time of recovery for Apex floats in this region.

This document is planned to be associated with two other related documents to be written in 2022:

- A condensed version of this D2.6, only summarising the key results and figures obtained within the different studies.

- A best practices document, gathering recommendations for operational teams, will fulfil different objectives, on different time scales:

- **Short term**: direct recommendations for operational teams, that might help improve float lifetime (conditions of storage, pre-deployment basic tests, critical configuration parameters to pay attention to, etc.).
- **Long term**: helping the “at sea” monitoring as well as the metadata filling (critical technical behaviour to pay attention to, causes of death investigation, recoveries, etc.), in order to have a better understanding of the overall “health” of the network in the future.

II. Survival rates general comparison

A. Comparison between models/manufacturer

1. All float models

For this part we aim to compare the different main Iridium float models[1], regardless of their configuration, deployment basins, etc. This will help to put into relief their overall reliability. We will work from the general list of floats (operational and dead[2]), at an international level, only omitting the "recovered floats" entries. Including also operational floats (alive), permits to consolidate the sample (adding more floats into the study) by considering floats that reached a certain target and that are still alive. This generally helps to improve the overall survival rate of a sample. Some survival rates (c.f. GLOSSARY) comparisons between a sample based on only dead floats and another one based on dead and operational floats are presented below (Figure 1).

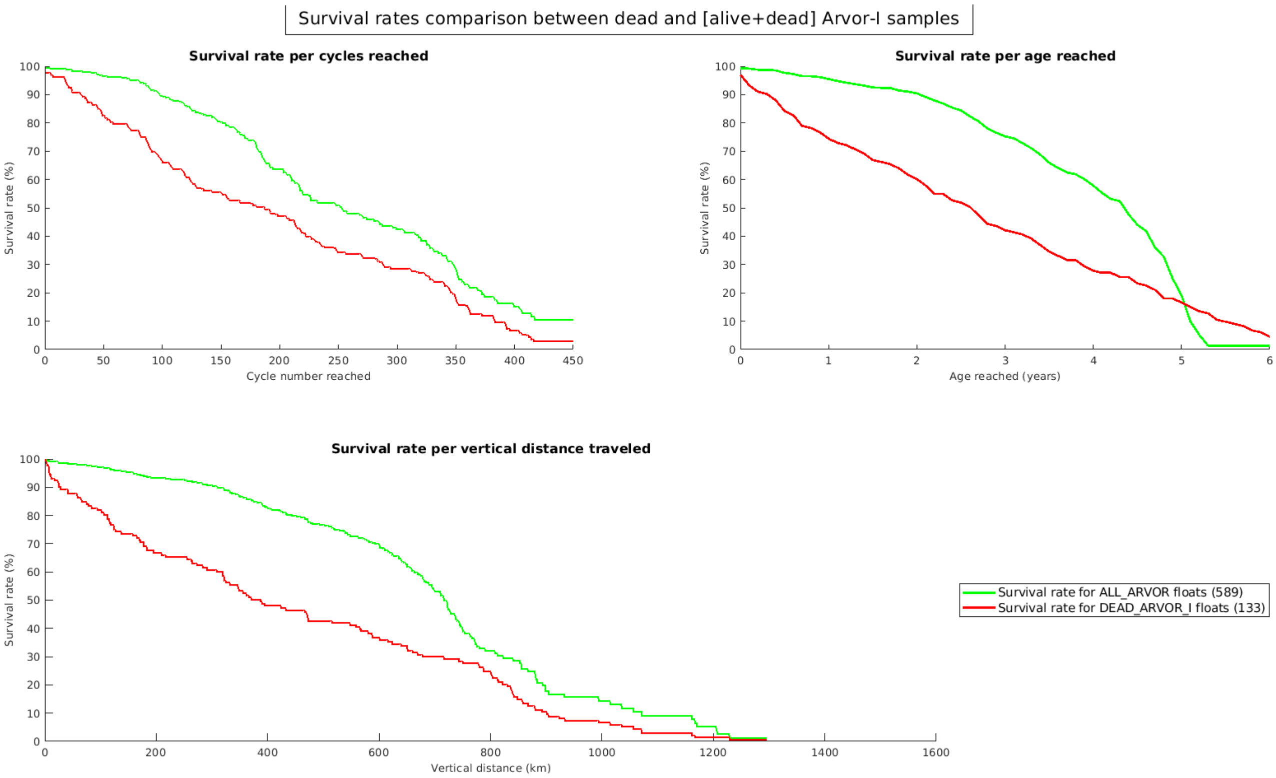

Figure 1 - Survival rates comparisons between an operational + dead floats sample (green) and only dead floats sample (red). The sample selected is CORE (c.f. GLOSSARY) Arvor-I floats deployed after 2016, not recovered.

The green curve contains dead and operational Arvor-I floats (c.f. GLOSSARY) when the red one only contains dead Arvor-I floats. Both of these survival rates curves present a relatively similar trend, however, the green one presents an overall better survival rate. As said above, including the alive floats in the sample helps considering in the computations floats that reached a certain target and that are still alive, therefore increasing the global survival rate of the sample.

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[1] In this document, "model" refers to the OceanOPS model metadata field and corresponds to the PLATFORM_TYPE (https://vocab.nerc.ac.uk/search_nvs/R23/) metadata in Argo netCDF files.

[2] These two statuses are defined according to the OceanOPS AIC, following the status of a float. "Operational" = alive float, "Closed + Inactive" = dead float.

The interest of only focusing on Iridium technology from its appearance in 2006 to now is because the Iridium telecommunication type is the most popular telecommunications technology adopted on most of the recent floats. Compared to the Argos telecommunication type, the Iridium one permits to transmit more data in a shorter period of time. Since the objective for this document is to present recommendations for the future, it seems coherent to reduce the sample to Iridium telecom type only. For the same reasons, we decided to only consider floats deployed after 2016 since the different float's technologies evolved with the time and the partners will only get to buy the newest generation of each float model. This is particularly true for the Arvor-I (representing about 50% of all Euro-Argo deployments since 2016) that saw some major changes in its technology with the NAOS project in 2016 (André et al., 2021).

We eventually set a sample size minimum[3] for survival rate plots, meaning that only samples with enough floats will be considered reliable. In fact, a low number of floats in a sample gives too much weight in the survival rate computation for a single float, possibly introducing a bias in survival rate estimations of this very sample.

Recovered floats artificially decrease a sample survival rate computation with an anticipated "death" and were therefore, withdrawn from all the samples in the following computations. That is why, for example, very few floats will be analysed in the Baltic Sea because they are almost all recovered in this area thanks to the conjoint efforts of the Institutes in this region (FMI, IOW, IOPAN, etc.).

Following the deliverable D2.1, conducted within this task of the Euro-Argo RISE project, an audit on the recovered floats was carried by the Euro-Argo ERIC Office, based on an initial list of 590 floats flagged as recovered on the OceanOPS AIC. This high number of recovered floats seemed doubtful and motivated this audit. Some additional floats were identified as recovered following the CTDs duplicate method. This method bases itself on an analysis of the GDAC data (c.f. GLOSSARY), comparing the duplicates of CTDs serial number (for each CTD model) between different float models. This method permitted to highlight 80 recovered floats that were not flagged as such on the AIC.

From this initial list of supposedly recovered floats, 246 were European. All these European floats were checked thanks to the European PIs, resulting in **only 84 floats that were in fact recovered** (11 are still waiting to be checked by the PIs). This audit permitted to highlight a bug in the OceanOPS automatic flagging routine. The OceanOPS team found the source of the bug, corrected it and eventually updated the metadata of the concerned floats.

As a result of the work performed within this task 2.1, a list of recovered floats extracted from the AIC now only contains 134 floats. Non-European countries (39 floats) should base themselves on this list to perform the same kind of audit, asking PIs to confirm the state of the recovery of the floats. This way, the metadata field of the recoveries will be up to date for the global Argo program.

Based on the samples selection defined above, the graphs below present the survival rates computations for all the Argo float models samples containing more than 10 floats, equipped with Iridium technology, deployed since 2016 (Figure 2).

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[3] The sample size minimum chosen for the whole report is **10 floats**. With that many floats, a survival rate curve become reliable enough to show the overall sample performances. This sample size minimum was not set too high in order to be able to make comparisons in the Chapter IV.

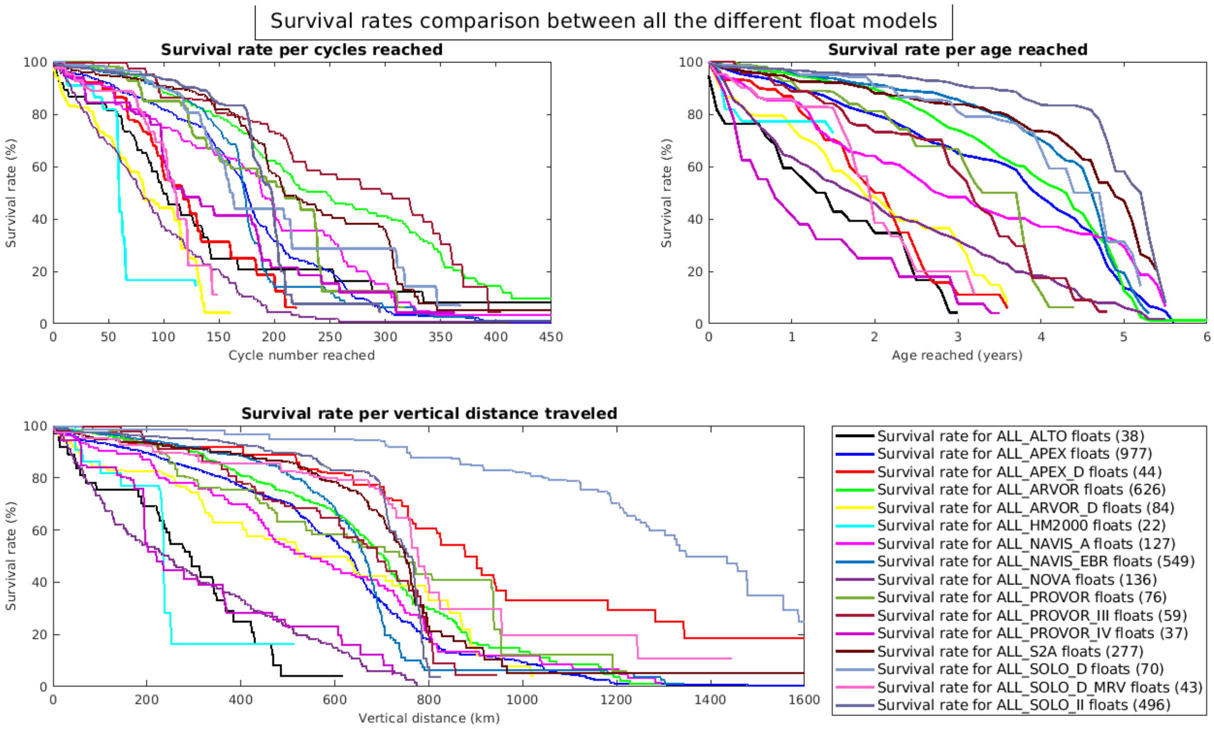

Figure 2 - Survival rates comparisons between float models equipped with Iridium technology, deployed since 2016, not recovered and containing more than 10 floats each. The number of floats in every sample is indicated within bracket on the right part of the legend.

Even though models are different in terms of technology, battery capacity, sensors embarked and configurations, some models can still be highlighted showing a poor reliability on the long term. In the graph above, the survival rate (y-axis) is computed for float models, alongside three different x-axes: cycles made, age reached (years) and vertical distance travelled (Kms)[4].

A clear trend could be underlined for the following float models: ALTO, HM2000, NOVA, PROVOR_IV, Arvor-Deep and Apex-Deep; showing an overall poor reliability. Two of these floats' models are Deep float versions, three are CORE and one is a BGC version.

However, it's difficult to draw general conclusions from such plots. In fact, results need to be more detailed, mitigated and discussed before judging a general reliability of a float technology. In the case of the two Deep float models, since they're diving at a 4000m depth (6000m for SOLO-Deep), for a certain given time, they will travel more kilometres than their CORE versions. However, the CORE versions generally (not true for every model, i.e. S2A and SOLO_II) undertake more cycles than the Deep ones (see analysis below). Therefore, reliability of a float model needs to be discussed and compared with other float models undertaking the same mission (CORE, DEEP or BGC), according to their theoretical lifetime (usually given by the manufacturer in number of cycles for a given "standard" configuration).

That also applies to the PROVOR_IV float model. Looking quickly might throw us off and one could easily think that this technology is not reliable over time. But it turns out that the PROVOR_IV floats considered here were mostly deployed in difficult basins, more particularly the Arctic one, often inducing early death failure because of the ice coverage. This will be more detailed in the BGC part (Part IV.A.5).

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[4] The vertical distance travelled is computed for the descent and ascent of the floats, in kms.

2. CORE float models

Hereafter are presented the survival rates curves for the different CORE (c.f. GLOSSARY) float models equipped with Iridium technology, deployed after 2016 with more than 10 floats in each sample. Floats that carried any additional sensors than a CTD (oxygen optode, dual CTDs, etc.) were omitted from the sample selection.

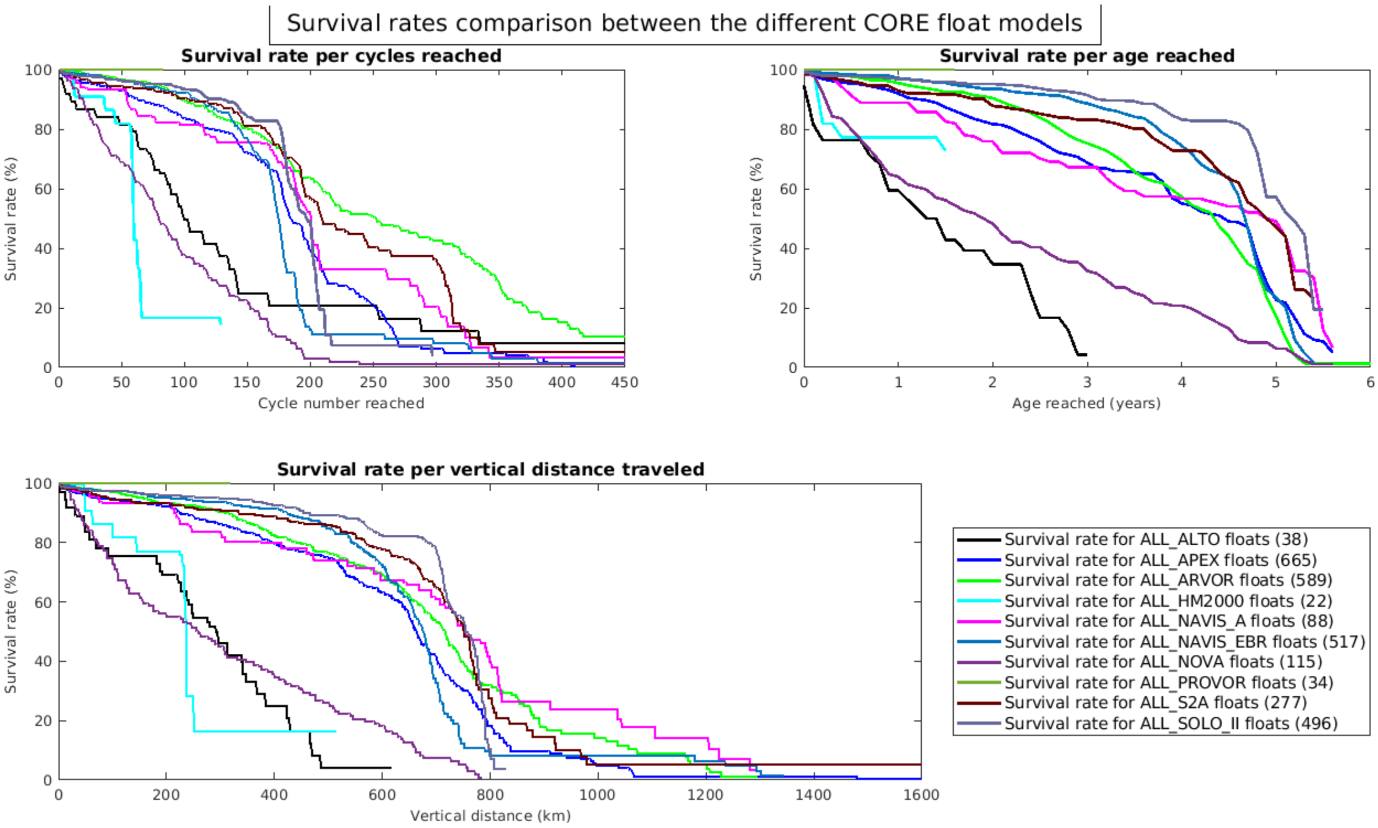

Figure 3 - Survival rates comparisons between CORE float models.

Three float models stand out, presenting some poor survival rate results, with more than 50% of the sample not reaching the 110 cycles/3 years mark: HM2000, ALTO and NOVA floats.

On the other side, the SOLO-II and SOLO-II enhanced version (S2A) floats present an overall very good survival rate, in terms of vertical distance travelled and age reached. When analysing the top-left plot, these two models are second and fourth in terms of the number of cycles reached. This can be explained because they are essentially deployed in open Ocean, most of the time with a cycling time period at 10 days following the Argo standard configuration recommendations.

On the other end, Arvor-I floats are often deployed in marginal Seas with a 5-day cycling period allowing them to perform more cycles (bump in the light green survival rate curve in terms of cycles).

To our best knowledge, the theoretical lifetime announced by the manufacturer for S2A floats is 250 cycles with 10 days cycling period. As it for now, 40% of the S2A sample considered here (total of 277 floats: 37 dead & 240 operational) reached this target. More than 85% of the sample is still alive and only the future will tell us if this survival rate curve adjusts closer to its target.

However, these two float models slightly stand out of the pack with an overall very good reliable life expectancy.

The rest of the models; the two NAVIS (A and EBR), the Arvor and Apex floats present some similar survival rate curves, with a good overall reliability according to their survival rates.

The theoretical lifetime provided by the manufacturer for the two NAVIS floats is 300 CTD profiles at a 2000m depth and 10 days cycling period. If we consider the graph presented in the Figure 3, less than 10% of NAVIS-EBR (most deployed) and about 20% of NAVIS-A reached that target. The NAVIS-A survival rate curve reflects some early death failures (before cycle 60); an observation already pointed out during the Float Technical Workshop in 2017. Again, one should consider the number of floats alive in this sample (87%, 453 floats), with the opportunity for this float model to reach its target in the future. The average number of cycles done for a NAVIS-EBR float at this moment is 104 cycles, 2.7 years at sea and 398 vertical Kms travelled (vkms).

For the reasons explained above, the Arvor-I model present a better curve in terms of the number of cycles made because of its numerous deployments in Marginal Seas.

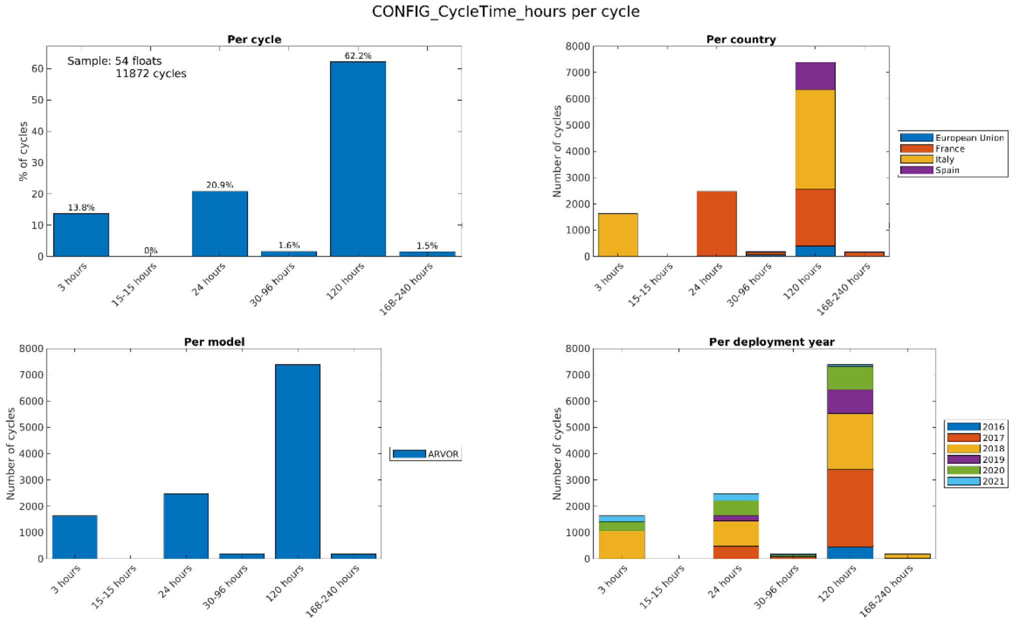

Figure 4 – Distribution of the cycle time period values in terms of the number of cycles (from the fleet status tool), for Arvor-I floats in the Mediterranean Sea.

In the Figure 4 above, one can observe that the cycle time period for a float deployed in a Marginal Sea varies between a 5-day cycling period (62% of the sample) and other shorter periods.

The theoretical lifetime of an Arvor-I float for an open Ocean standard configuration (10 days, 1000/2000m – roughly 110 CTD points acquired) provided by the manufacturer is:

- **equipped with a SBE41CP CTD sensor: 270 cycles. | With an additional DO sensor: 230 cycles**

For a Marginal Sea standard configuration like in the Mediterranean basin (5 days, drift at 350m and alternate profile at 700/2000m), the theoretical lifetime of the float was computed for each profile depth and then averaged:

- For a profile at 700 m: 600 cycles | With an additional DO sensor: 517 cycles

- For a profile at 2000 m: 360 cycles | With an additional DO sensor: 285 cycles

- For an alternating profile depth between 700 and 2000m, we obtain the following theoretical lifetime: **480 cycles | With an additional DO sensor: 400 cycles**

However, it is important to bear in mind that this float model is very young and that the survival rates metrics are likely to change in the future since 87% of this sample is still alive and might increase the overall survival rate of this model.

Further analyses comparing different float models' performances between an open Ocean and a marginal Seas basin will be conducted in the Chapter III.B. Survival rates comparisons between a standard Arvor-I float and one equipped with a DOXY sensor are presented in the Chapter III.A.4.

Apex floats, represented by the dark blue curve in the (Figure 3), present a slightly lower survival rate in terms of the number of cycles and vertical distance travelled than the rest of the floats compared above. 205 Apex CORE floats were deployed at a European level since 2016, mostly by the UK (129 floats) and Germany (52 floats), representing almost 16% of the overall European deployments. Apex floats were mainly deployed in the Open Ocean, only 5 were deployed in the Mediterranean basin and 8 in the Baltic Sea (that were recovered, therefore not included in the graphs).

The theoretical lifetime of a CORE Apex float, not embarking any DO sensor, and cycling every 10 days at a 2000m depth is: **250 cycles**.

Arvor-I floats representing almost the majority (≈48%) of the European deployments since 2016, we studied in detail the 10 better performing Arvor-I and the 10 worst in order to possibly highlight a common point between these floats (areas of deployment, consecutive serial numbers, causes of death, etc.).

Two of the worst performing Arvor-I floats were equipped with RBR CTD sensors and experienced early death failures at the 1st and the 18th cycle. The implementation of a new sensor always come with a prototype phase, testing the viability of the implementation, etc. These two floats were the first implementation of RBR sensors on Arvor-I and should not represent the performances of such a float model. Besides, the manufacturers estimate a theoretical lifetime for an Arvor-I equipped with an RBR sensor at 400 cycles, 130 more cycles than the SBE41CP version. The design of the RBR CTD permits the water flow to go through the CTD cell without any pumping, therefore saving energy when compared to the SBE41 CTDs. It is definitely worth continuing the tests for integration of this CTD model on Arvor floats.

The other 8 worst performing Arvor-I floats were lost at sea before reaching the cycle 30, with an unknown cause of death. No specific common point between this point was highlighted. Same for the 10 best performing Arvor-I floats, no real common point was highlighted.

Conclusion:

Survival rates, computed as of September 2021, across Argo CORE float models were examined following the methodology defined in this study (Iridium floats deployed after 2016, not recovered).

HM2000, ALTO and NOVA floats present an overall poor reliability.

SOLO-II and S2A floats have the best overall survival rates observed at sea, followed by ARVOR, NAVIS and APEX float models.

3. DEEP float models

The Argo DEEP mission was created in order to sample the deep-water masses up to 6000m (SOLO-Deep and Apex-D), in order to complete our knowledge of the full volume Ocean.

The Argo DEEP mission is particularly challenging and still in its pilot phase. The development of DEEP technologies continues, choice of designs differs between manufacturers (Annexe 3) and some technologies are still not completely mature.

The two floats models profiling at a 6000m depth are equipped with a specifically designed CTD, the SBE61CP when the two others profiling at a 4000m depth are equipped with usual SBE41CP CTD.

At a European level, Arvor-Deep are mostly deployed (81% of the European Deep array deployments) and the rest are Apex-Deep deployed by the UK.

Before comparing these two models, one should bear in mind that these floats have different technologies and mission types:

- Apex-D floats only embark a CTD and profile up to a 6000dbar depth

- Arvor-D floats only profile at a 4000dbar depth but systematically embark a DOXY (Dissolved OXYgen) sensor and acquire CTD measurements in continuous pumping. The manufacturer estimates the impact of DO measurements to be -15% and continuous pumping about -25% of the global life expectancy. Therefore, an Arvor-D with a standard European configuration (DOXY and continuous pumping) is expected to reach 120 cycles.

- Most of the Arvor-D floats were European deployments. In fact, the international array of Arvor-D floats deployed after 2016 only contains 5 more Chinese floats.

- It is not quite the same for the Apex-D where the European deployments only represent 38% of the overall deployment. In addition to the UK, the United States (2 floats) and mostly the Japan (29 floats) deployed other Apex-D floats since 2016. The survival rate of the Apex-D at an international level is way better than at a European level and one should consider that the Japanese Apex-D floats are going through an entire process of reconditioning and tests once delivered at JAMSTEC, therefore permitting to avoid deployments of fragile/abnormal floats.

However, in the last couple of years, the number of Apex-D floats deployed significantly decreased. At a European level, many early deaths (before the 50th cycle) of Arvor-D floats were experienced, therefore decreasing the overall survival rates and reliability of the technology, as seen in the Figure 5.

The graphs in the Figure 5 presents the survival rates comparison for different types of DEEP models (considering our original sample: Iridium floats, deployed since 2016, at an international level).

The SOLO-Deep floats, on another hand, show a better overall survival rate compared to all the other floats, traducing a solid float model performance.

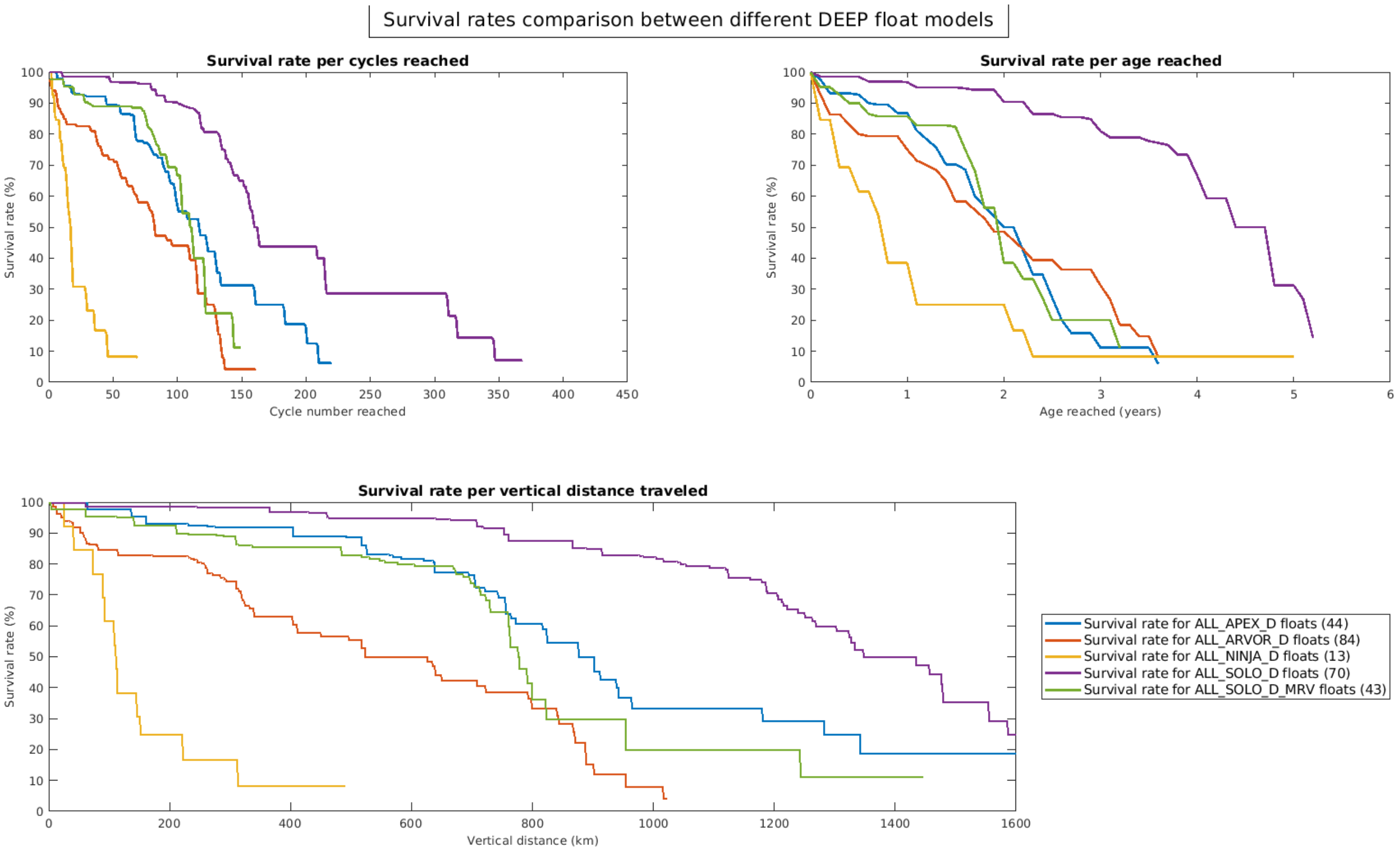

Figure 5 - Survival rates comparison between different Deep float models.

The SOLO and APEX-Deep, present a good overall longevity, with more than 75% of the sample reaching 400Km travelled vertically. However, when comparing survival rates in terms of vertical distance travelled (or “vkms”), it is an absolute necessity to differentiate models cycling at 6000dbar (SOLO-D and Apex-D) and others at 4000dbar (Arvor-D, Ninja-D). The SOLO-Deep comes out with the best survival rate of all the models, in all the x-axes considered here, proving its overall reliability.

The Apex-D shows the 2nd better survival rate in terms of vkms and cycles made (20% of the sample reached 175 cycles), but has a quick decreasing survival rate curve in terms of age, suggesting maybe a quicker cycling period.

The NINJA_D presents the worst survival rate curve of them all, with only 25% of the sample reaching the 200Km travelled vertically.

On the other hand, one can note the **quick decrease in the ARVOR_D curve in the first 50 cycles**, revealing some unexpected early deaths for a certain proportion of the sample (only 60% of the sample reaching 50 cycles). This early death trend is a common point for the two less reliable models (NINJA_D and ARVOR_D).

The performances of these floats compared to their theoretical lifetimes, the proportion of floats dead on battery level, and other metrics are summarised in the Table 2. When analysing in detail the performances of the Arvor-D model, one can observe that this model is underperforming at sea from its theoretical lifetime expectations.

30% of the Arvor-Deep floats are dead (representing 26 floats). Considering these dead floats, their average lifetime at sea in terms of number of cycles is 53 cycles. The theoretical lifetime provided by the manufacturer is 120 cycles, meaning that as of today, this model is underperforming by almost 60%.

When reducing the dead floats to the one dead of battery exhaustion[5], 35% of the sample is concerned, constituting a total of 9 floats. Meaning, that 17 floats died from another cause than the natural one, and almost 70% of these unknown dead floats, died before the cycle 15.

However, when considering the 9 floats dead on battery level, the average lifetime reached at sea is of 100 cycles, which is significantly better than before, “only” representing an underperformance of 17% compared to the theoretical lifetime provided by the manufacturer.

To conclude on this float model, we can say that the floats working well and completely exhausting their battery are close to the theoretical lifetime estimated (-20 cycles in average), but the main concern of this model comes from the anticipated deaths. In fact, more than 45% of the dead floats did not reach 15 cycles, which is a real problem and traduce a technology that is not mature enough and encountering too many early failures. Now, 70% of the Arvor-D floats deployed are still active, this model is still pretty young and these metrics should be recomputed in a couple of years to confirm or infirm the observations made here.

Conclusion:

SOLO_D and SOLO_D_MRV clearly account for the best reliability of Deep float models.

The ARVOR-D and NINJA-D both present a significant number of early failures, and a shorter amount of cycles achieved for the floats that worked until battery exhaustion.

The APEX-D presents the 3rd best reliability in terms of Deep float models. However, when considering non-Japanese floats (that went through a verification process once received at JAMSTEC), they tend to show a lot of early failures, like the ARVOR-D and NINJA-D.

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[5] The death of a float because of a battery exhaustion is what comes the closest to a “natural death”. Such floats performed until the exhaustion of their overall energetic budget, not dying because of a sensor, deployment issue, an unknown cause, etc. The method of selection of floats dead on battery exhaustion is explained at the beginning of the Chapter IV.

4. Arvor-I and Arvor-I + DOXY comparison

As explained before in the Chapter III.A.3, the integration of an additional sensor on a float decreases its overall theoretical energy budget.

In the case of a DOXY sensor, in addition to the measurements (extra energy consumption) made by the sensor itself, the float needs to undertake some in air measurements in order to be able to correct in post-processing, possible optode measurements drift (Johnson et al., 2015). It is recommended for this sensor to make at least two in-air measurements a month (Bittig and al., 2019), one every two cycles for a float cycling every 10 days. In order to make a measurement in-air, the float (in this case Arvor float), will increase its buoyancy to assure a complete emergence of the optode (recommendations are at least 20cm above water level), therefore using more energy than a standard cycle.

The graphs in the Figure 6 represent the survival rates comparison between Arvor-I floats standard version (green curve) and Arvor-I equipped with DOXY sensor (red curve). The sample is the same since the beginning of this document: operational and dead Iridium floats deployed since 2016, recoveries excluded.

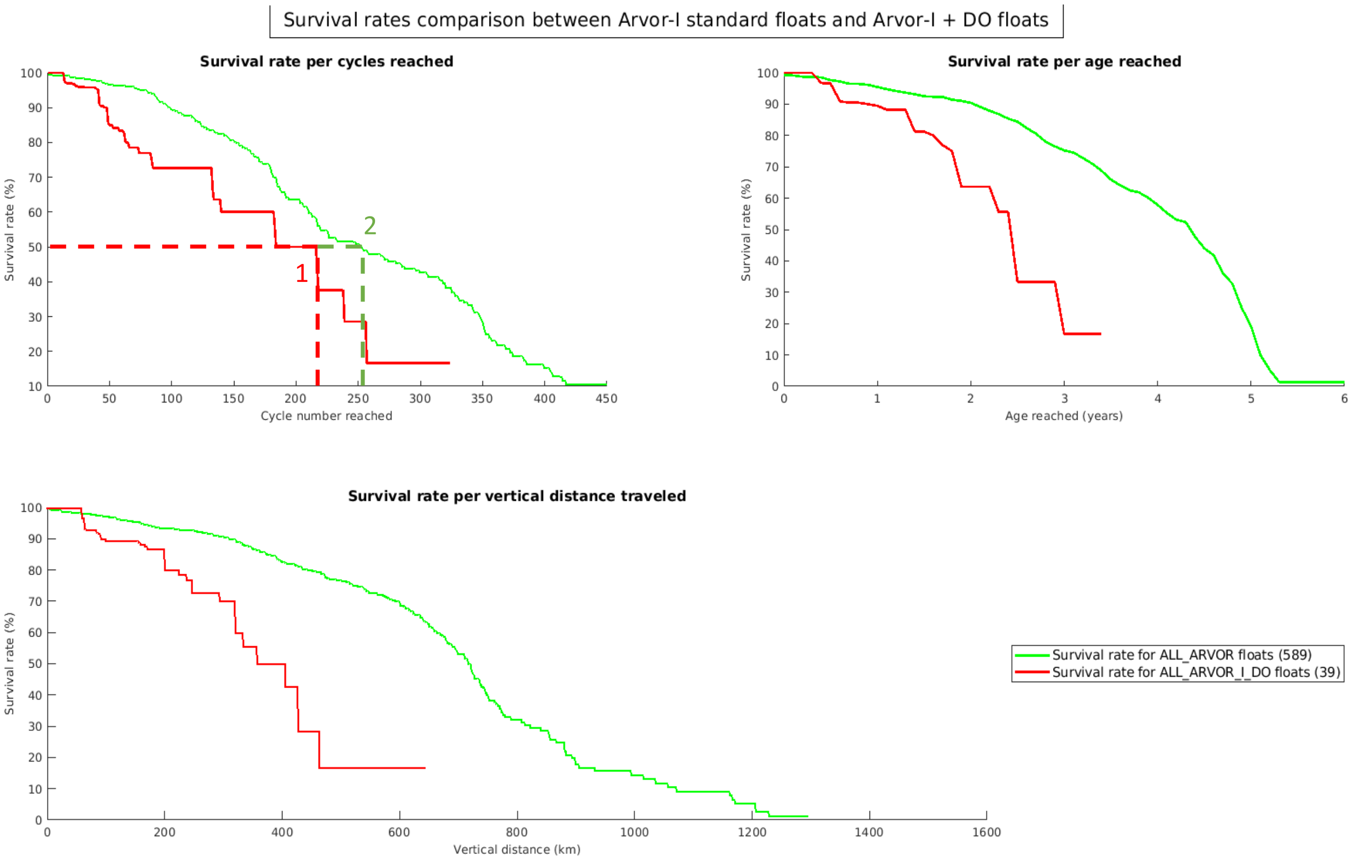

Figure 6 - Survival rate comparison between Arvor-I and Arvor-I DO

First of all, one should note the difference in sample size, between the CORE floats (589 floats) and the ones equipped with a DOXY sensor (39). The smaller the sample is, the greater the impact of a single failure can have on the overall survival rate of the sample.

There is a clear difference between the curves in terms of age and vertical distance travelled, with the Arvor-I standard model presenting a better survival rate than the same model equipped with an additional DOXY sensor.

In terms of the number of cycles reached, the curves show relatively the same trend, with an important difference**: 50% of the Arvor-I + DO sample reached 216 cycles against 254 cycles for the standard Arvor-I one**. Therefore, we have:

- (216/254)*100 = 85.04% | 100-85.04 = **14.96%**

With the floats **at sea**, we find an almost 15% decrease in terms of cycles made between an Arvor-I equipped with a DOXY sensor and its CORE version, which is compliant with the manufacturer theoretical lifetime provided for these two float versions.

In terms of age reached, the difference is flagrant with 50% of the red curve (Arvor-I + DO) sample reaching 2.4 years whereas the green curve sample reaches at 50% 4.4 years. In terms of vertical kms travelled, 50% of the red curve travelled 404 kms and 50% of the green curve travelled 715 kms. There is a 1.75 factor between, these two samples in terms of age reached and vertical kilometres travelled but not in terms of cycles completed.

The differences in terms of survival rates and other metrics between Arvor-I and Arvor-I + DO floats are summarised in the Table 2. According to the manufacturer, for a standard configuration 1000/2000 dbar and 10 days cycling period, the estimated lifetime is:

- for an Arvor-I: **270 cycles** (reached by 24% of our sample)

- for an Arvor-I + DOXY: **230 cycles**

A decrease of 15% is therefore expected between these two floats models, strictly considering the energetic consumption differences due to the DOXY sensor.

Another element to keep in mind when explaining the differences of survival rates between these two models is the areas of deployment. In fact, half of the Arvor-I + DO floats are deployed either in Marginal Seas (Mediterranean, Baltic, Black Seas) or in complex basins such as the Arctic and Southern Oceans, that are, as explained in the following Chapter III.B, complex basins who tend to decrease the overall life expectancy of a sample for many reasons.

Ultimately, on the 39 Arvor-I + DO floats considered here, only 5 are dead (none of battery exhaustion) and the rest of the sample is still very young, at a median of 40 cycles and an average of 70 cycles reached for now. It is still very soon to conclude on the overall performances of such a float model, but as if for now, the manufacturer's estimations on the theoretical lifetime of such a float seems pretty accurate.

Conclusion:

The theoretical lifetime provided by the manufacturer showed a 15% decrease of cycles with the integration of a DOXY sensor on the ARVOR-I model.

From the sample of floats at sea, we find a 14,96% decrease in cycles made between these two versions, hence in compliance with the manufacturer's estimations.

5. BGC float models

There are fewer BGC floats models than CORE ones in the International Iridium array. In this part, our sample will consist in BGC Iridium floats, measuring at least 4 variables and deployed since 2016. In Europe, the main models used are the PROVOR_III (45% of European BGC deployments), Apex (23%) and PROVOR_IV floats (20%). At an international level, 58% of the BGC deployments are Apex platforms and the two NAVIS-BGC models combines for 15%. Note that the PROVOR_V sample only represented 9 floats, was therefore removed from this comparison (not enough floats to consider the computations reliable).

The BGC array is a “relatively” new array and its implementation really started with the SOCCOM and NAOS project, respectively in 2014 and 2016. The BGC array is still, up to this date, often tuned to respond to specific scientific requirements and questions in certain areas of the globe. A bunch of different sensors were tested and implemented on floats in order to gather various bio-geochemical variables (pH, Nitrates, Chlorophyll, Irradiance, Backscatter, Oxygen, etc.).

The BGC floats are the most expensive float type in the Argo program and are often deployed to respond to a specific scientific demand in a defined basin. Their configuration and sampling strategy are highly dependent on their scientific mission and could vary a lot through their lifetime and obviously from a float to another. The number of sensors embarked on the platforms and their sampling rates have a very important impact on the overall float’s energetic budget (especially true for the Nitrate sensor). Following tests and figures from Riser et al. (2018), the Nitrate sensor (18%[6]) is the second most consuming function of a BGC float, after its buoyancy pump (32%). These tests were done on UW-build SOCCOM Apex BGC floats but could be supposedly extended to other float models.

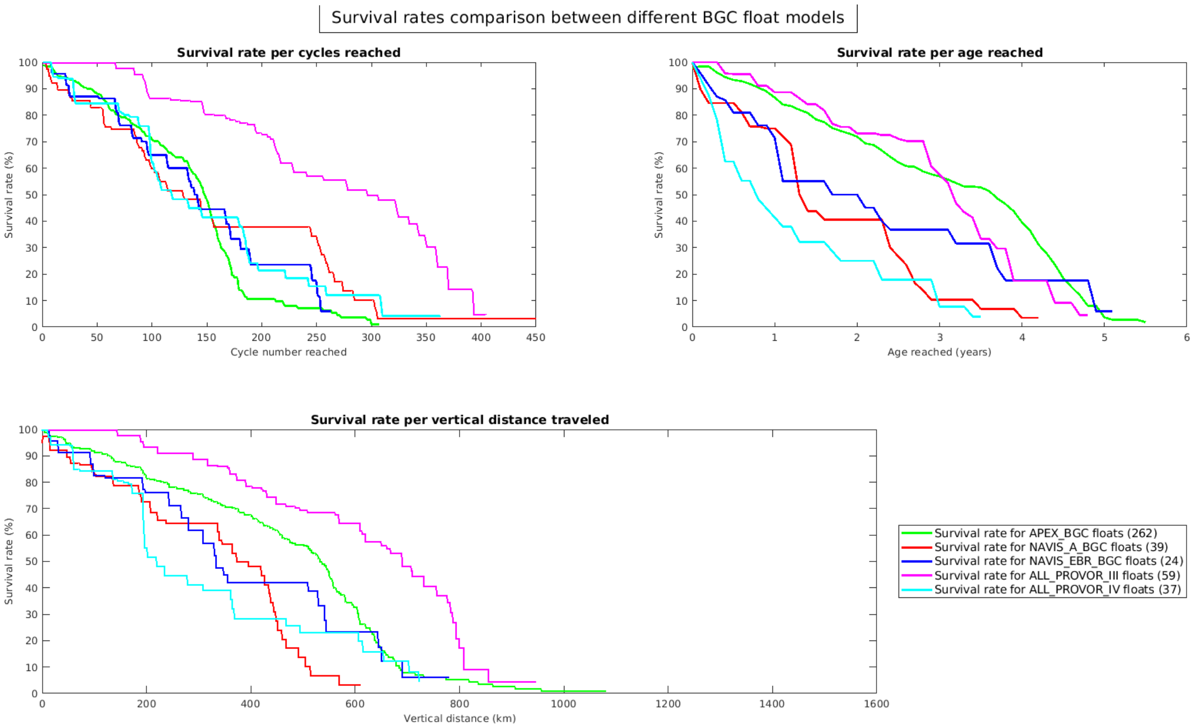

Figure 7 - Survival rates comparison between different BGC float models.

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[6] The energetic consumption is expressed as the total percentage of the energetic budget of an UW-build SOCCOM Apex BGC floats. This “rating”, of the two most consuming functions in a BGC float could be extended to the other BGC float models.

In the graphs presented above (Figure 7), the PROVOR_III model (magenta curve, corresponding to NKE Dual board PROVOR CTS4 product) stands out of the pack, presenting an overall very strong reliability, with good survival rates in terms of cycles completed, vertical Kms travelled and age reached. A majority of the PROVOR_III floats cycled at a 5-day frequency or lower (24 to 48 hours) when Apex floats cycles more at a 10-day frequency. The profile depth is generally at 2000m except for 6 PROVOR_III that profiled at a 1000m depth (Annexes 1 & 2).

In conclusion, the PROVOR_III float is in majority cycling quicker than the Apex ones but at the same profile depth, thus completing more cycles and travelling more vertical distance for the same time spent at sea.

In terms of age, however, until the 3 years mark, the PROVOR_III presents the best survival rate of all models. Past this 3-year mark, these floats last less than Apex ones because of the quick cycling frequency. The proportion of floats cycling under 5 days having a huge impact on the time spent at sea here. One can note the flat trend at the beginning of the magenta curve, traducing a good reliability in the early stages for PROVOR_III floats until the 66th cycle.

The Apex-BGC floats are just behind the PROVOR_III in terms of performances, with a good overall reliability and traducing a “mature” technology with no early death failures as well.

The two Navis BGC models have a fairly similar survival rate curve, presenting an overall good reliability. The Navis-EBR model has a little advantage over the Navis-A one, with better survival rates in age reached and vertical Kms travelled.

Looking at the PROVOR_IV survival rate (cyan curve), one might think that this model is not reliable over time with 40% of the sample reaching 1 year at sea. A little context is needed here, especially in terms of areas of deployment.

In fact, PROVOR_IV, those are first NKE CTS5 BGC floats, are often deployed in some complex basins such as the Arctic (40% of the sample) or Mediterranean ones (8%) to observe precise and limited bio-geo chemical processes.

As said before, recovered floats were taken out of the sample selection. Float deployed in the Arctic are difficult, if not almost impossible to recover depending on the ice conditions and the time spent by the float at sea. If the float goes under ice for a long time (>1year), it is very difficult for it to surface again and plan a quick recovery. It is often considered dead after a certain amount of time without communication.

When taking a look at the NAOS project (Le Traon et al., 2020 and André et al., 2020) deployments of PROVOR_IV floats in the Arctic since 2016, 16 were deployed and only one is still alive to this date. For the 15 dead floats, only one float was recovered because of the complexity of this area. When comparing with PROVOR_IV floats deployed in the Mediterranean since 2016 (6 floats), 50% were recovered thanks to the Institutes in the region, the proximity to the coast and the overall easier conditions for recovery in this basin compared to the Arctic Ocean.

On the Figure 8 below, the low survival rate associated with deployment in the Arctic is directly observable (black curve). Most of the other curves stops before reaching the 0% survival rate mark because the floats are still alive. Recovered floats were withdrawn from the sample, that is why the Mediterranean sample only contains 3 floats.

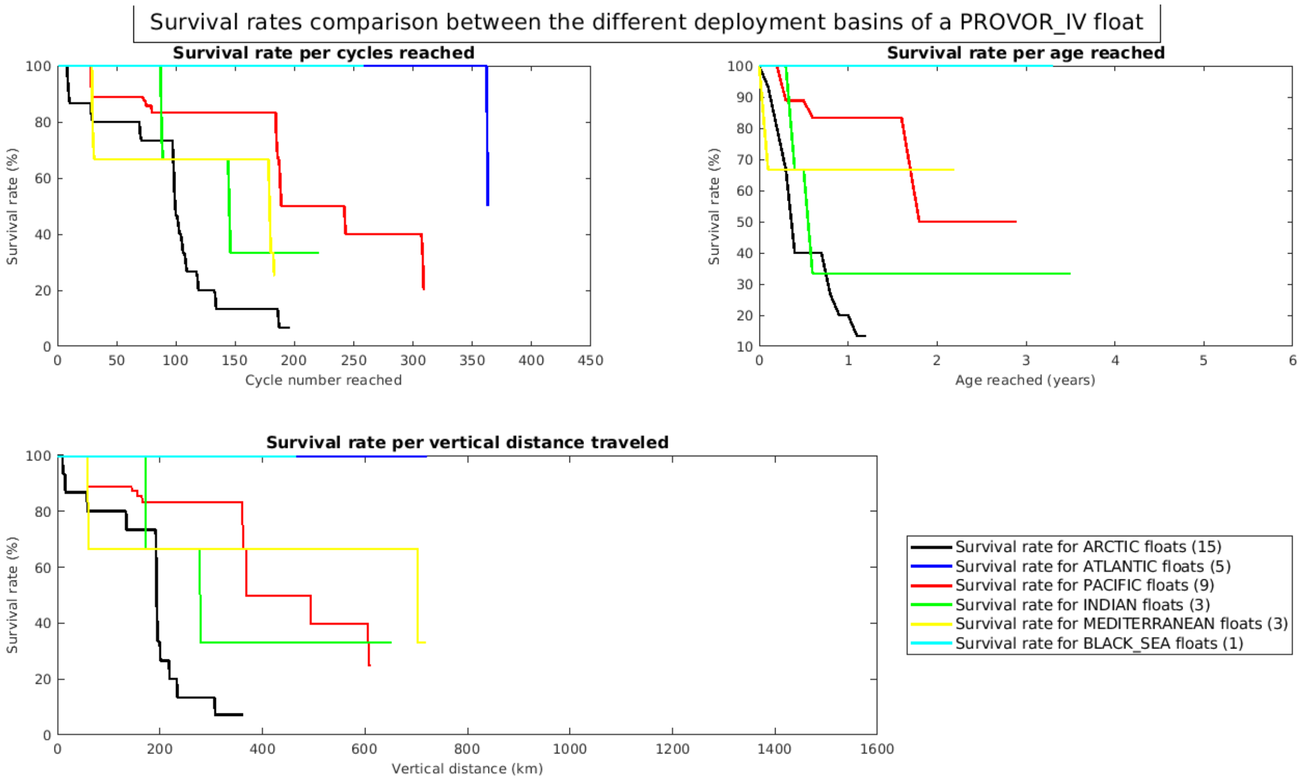

Figure 8 - Survival rates differences for Provor_IV floats, depending on their deployment basins.

Conclusion:

The most reliable model in the BGC array is the PROVOR_III (NKE CTS4), with a very few premature losses and an important number of cycles, vertical distance and age reached despite a significant number of floats cycling faster than the standard 10-day period.

APEX-BGC floats, followed by the NAVIS-BGC account for a good survival rate too.

PROVOR_IV floats survival rate curves were mainly impacted by the proportion (over 40%) of floats deployed in the Arctic Basin. The sample is still young and these Arctic floats does not reflect the overall performances of the model.

The PROVOR-V float model could not be included in this study since the model has only been deployed very recently, hence not enough floats to analyse.

NOTE: The figures obtained above are general statistics computed from the BGC fleet without considering the different sensors configurations and acquisition rates (that represent a significant part of the energy budget of a BGC float).

B. Comparison between basins/areas of deployment

Depending on the areas of deployment, the missions of the floats and their configurations, their survival rates will be different. A float deployed on the Open Ocean will supposedly have a better survival rate than one deployed in Marginal Seas, which are often more complex areas, shallower, with proximity to the coast, complex under water currents, etc. These harsher areas tend to increase the early death failures of floats.

The interest in comparing survival rates between areas of deployment grew alongside the comparison presented to the Argo community between the international array and the European one. The European array often tend to show lower survival rates than the international (Figure 9) for the reasons explained hereafter.

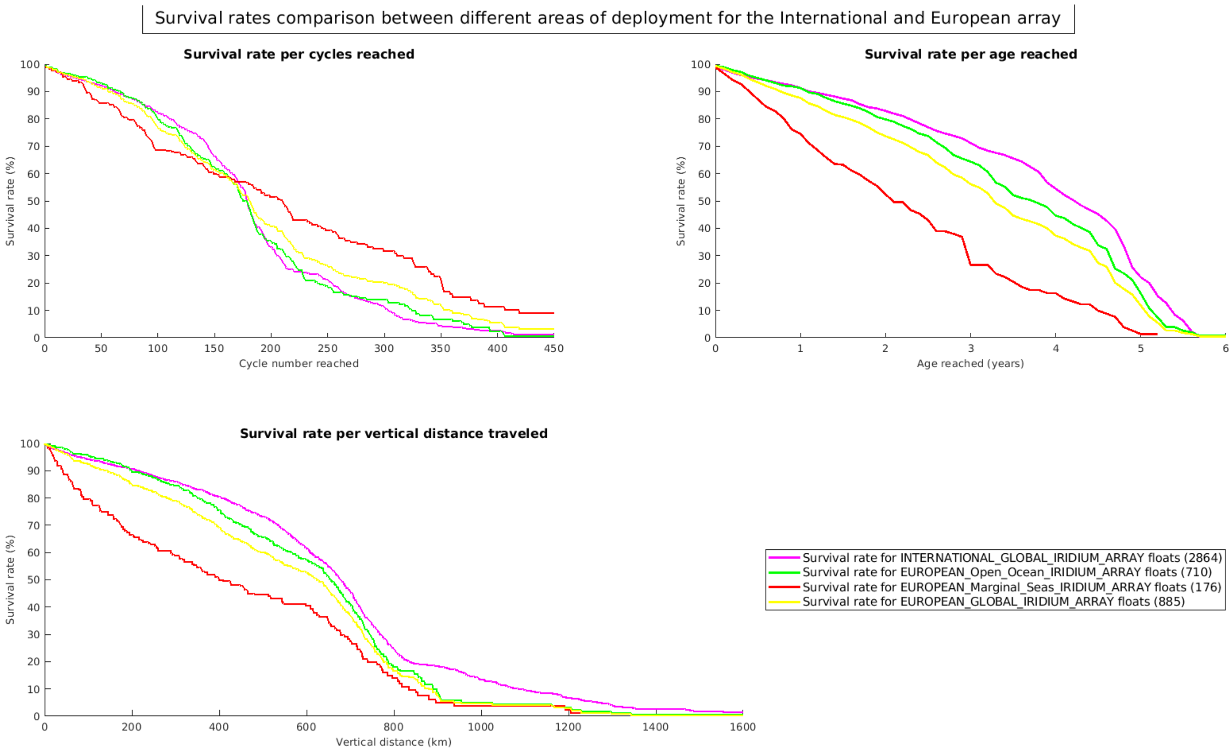

Figure 9 – European and International survival rates comparison for the Iridium floats array, deployed since 2016. The global international sample (magenta curve) contains all the deployment areas possible. The yellow curve is the equivalent of the magenta one for European floats. The other two curves are for European floats deployed in Marginal Seas (red curve) and Open Ocean (green). Note that the International sample does not contain European floats.

International deployments in Marginal Seas (excluding European floats) only represent 46 floats, since 89% of deployments in these areas are European. Therefore, the survival rate curve of the International deployments is almost completely influenced by deployments in Open Ocean, explaining why International deployments are only represented by one curve (magenta one) in the Figure 9 above.

Only considering the survival rates in terms of vkms and age reached, the global European Iridium array presents a lower survival rate than the International one. In fact, the influence of Marginal Seas deployments (red curve) can directly be observed and is partially responsible for decreasing the overall European sample survival rate (20% of the European Iridium array was deployed in Marginal Seas).

It is important to note a few observations analysing the Figure 9:

- The standard configurations for such areas of deployment are:

° **Open Ocean:** 10-day cycling period, 1000 dbar drift and 2000 dbar profile depth

° **Marginal Seas** (Mediterranean especially): 5-day cycling period, 350dbar drift and alternated profiles at 750/2000 dbar (Euro-Argo ERIC et al., 2017)

- By considering the overall Iridium sample, we compare here different models, using the same telecommunication type.

- The International sample (magenta curve), does not include European floats.

A float deployed in European Marginal Seas (especially Mediterranean and Baltic Sea), is cycling twice as fast as one deployed in Open Ocean, thus explaining the inversion of curves' trend in the top-left plot in the Figure 9 (number of cycles completed).

In order to highlight the impact on survival rates between different areas of deployment we will consider the same float model, deployed in Open Ocean and in Marginal Seas.

Adding to the analysis the metrics summarised in the Table 2, like the theoretical lifetime, the proportion of floats dead on battery level and their average survival rate, it should permit to draw some more detailed and reliable conclusions about this topic.

Because the European Iridium array is mainly consisted of Arvor-I floats (58% of the global European deployments since 2016 are Arvor-I floats), the following analysis will consider Arvor-I floats, not equipped with DOXY sensors, deployed since 2016 (**589 floats total**).

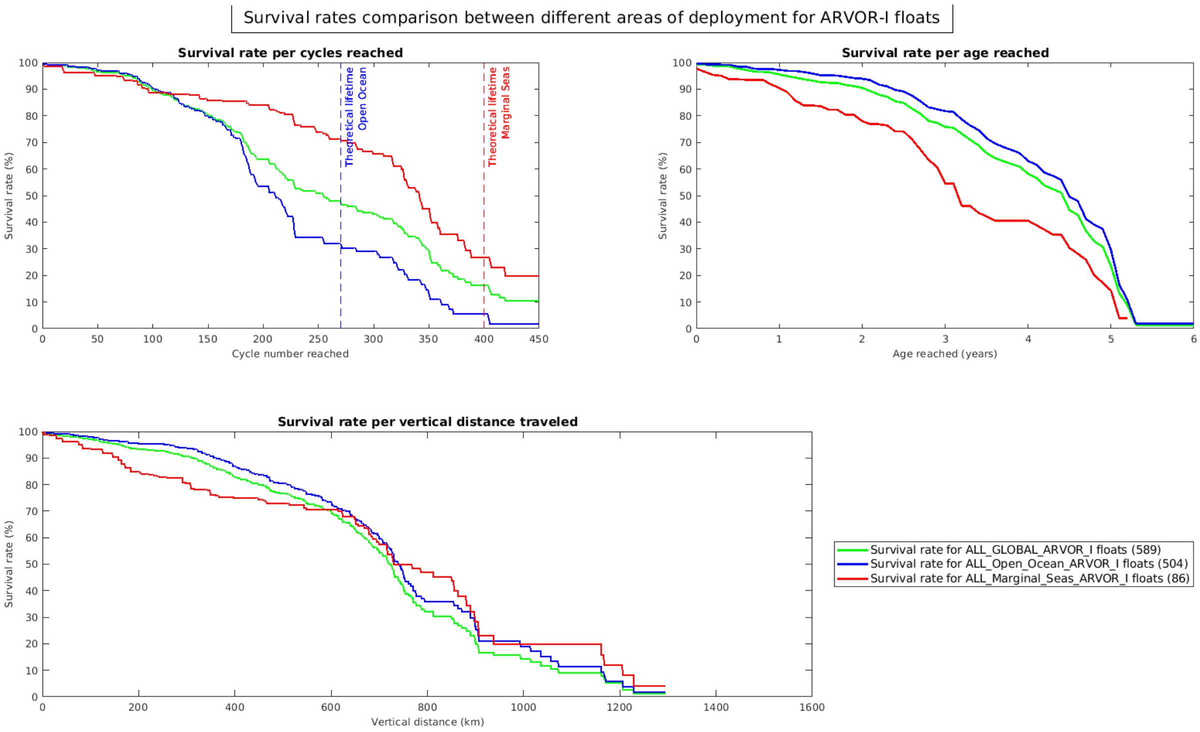

Figure 10 - Survival rates comparison between different areas of deployment for Arvor-I floats. Note that one float is present in both basin polygons (Open Ocean and Marginal Seas), therefore creating this one float differential.

The Marginal Seas curve (red) presents a better survival rate than the other two in terms of number of cycles, because of the cycle period configuration in these basins, like explained before. However, it is not because the float is cycling twice faster in Marginal Seas compared to Open Ocean that it will, in the end, reach a twice younger age. In fact, when taking a look at the 50% survival rate mark in the Figure 10, it gives us:

- Marginal Seas sample:	341 cycles	3.1 years	760 vertical Kms
- Open Ocean sample:	210 cycles	4.5 years	741 vertical Kms

Again, a float deployed in the Open Ocean cycling every 10 days **will not last twice the time at sea** of a Marginal Seas one (see Chapter IV.A.2). **The balance is reached in terms of vkms traveled** (a proxy for data points collected), between the increase of 38% cycles in Marginal Seas but with an alternate profiling depth at 750 and 2000m.

24 floats of the Arvor-I floats deployed in Marginal Seas sample (86 floats total) are not operational anymore. On these 24 floats, 33% (8 floats) died on battery exhaustion, the rest died because of:

End of life causes	**Number of floats**
Fisherman unintentional recover	2
Beached	1
Very high cycling rate (3h cycling rate)	1
Ballasting problem, maybe loss of lest due to multiple groundings	1
Internal vacuum failure, maybe because of a shock during transport/deployment	1
Unknown causes	1
Non-investigated end of life causes	9

Table 1 - Ending causes repartition for Arvor-I floats deployed in European marginal Seas since 2016.

The main reasons why marginal Seas floats are dying faster could be explained by:

- The difficult terrain and proximity to shore, increasing the possibilities of groundings and beachings
- The numerous trawl fishery vessels, unintentionally picking up floats
- The complex underwater masses circulation that might affect a float in its descending phase
- Other configuration/technical parameters related to Marginal Seas deployments (next chapter)

Conclusion:

This study highlighted that the marginal Seas floats, compared to open Ocean floats:

- achieve more cycles (after 150 cycles)
- last less time active
- have a more important early death failure rate (beaching, fishing, harsher environment, etc.)
- have similar performances in terms of vkms, a proxy for data points collected, once the early death failures phase is passed

The direct consequence from these conclusions is that marginal Seas networks have a shorter refresh time than the open Ocean ones and deployment teams should increase deployment numbers in order to maintain an operational network in these areas.

C. Summary table of floats model performances across Argo missions

	Model	Theoretical lifetime (@10 days / 2000m profile depth) (@5 days / alternating 700/2000m)	Average number of cycles for the sample / median	Dead floats	Averaged at sea lifetime for dead floats	% of floats dead on battery (compared to all the dead floats)	Averaged lifetime for floats dead on battery level / median	% of alive floats in the sample	Performances on target score[7]
CORE	Arvor-I (504/86 floats)	270 cycles 480 cycles	104 cycles / 90 213 cycles	51 24	151 cycles 226 cycles	31% 33%	245 / 221 408 / 340	90% 75%	32% 3.6%
	Arvor-I DO (24/15 floats)	230 cycles 400 cycles	33 cycles / 22 131 cycles / 133	2 3	32 cycles 131 cycles	0% 0%		87% 80%	37.5% 0%
	Arvor – Argos (425 floats)[8]	231 cycles	141 cycles / 161	326	152 cycles	45%	176 / 176	24%	2%
	Arvor – L (598 floats) [8]	190 cycles	136 / 142	498	137 cycles	20%	141 / 139	17%	8%
	APEX (710 floats)	250 cycles	113 cycles / 108	182	134 cycles	x		74%	?

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[7] The performances on target score is the survival rate % at the theoretical life expectancy given by the manufacturer

[8] The Arvor-Argos and Arvor-L models were included in this table because they will be presented in the Chapter IV. Since they are older models, a majority are dead and their observed lifetime at sea are pretty reliable (especially Arvor-L floats). Were considered, for these models, floats deployed after 2010 and onwards.

	NAVIS-A (88 floats)	300 cycles	123 cycles	28	164 cycles	x		67%	21%
	NAVIS-EBR (518 floats)	300 cycles	104 cycles	62	126 cycles	x		87%	8%
	SOLO-II (498 floats)	?	112 cycles	27	51 cycles	x		95%	?
	S2A (277 floats)	250 cycles	133 cycles	37	126 cycles	x		87%	41%
		10 days @4000m profiling depth							
DEEP	ARVOR-D (86 floats)	120 cycles (with additional DO measurements performed)	49 cycles	26	53 cycles	35%	100 cycles / 109	70%	28%
	APEX-D (46 floats)	?	88 cycles	18	103 cycles	x		61%	?
	NINJA-D (13 floats)	?	22 cycles	12	21 cycles	x		8%	?
	SOLO-D (70 floats)	250 cycles (@6000m profile depth)	120 cycles	14	174 cycles	x		80%	29%
		10 @ 2000m profiling depth – 6 variables							
BGC	PROVOR_III (60 floats)	250 cycles (minimum)	178 cycles	22	232 cycles	32%	360 / 370	63%	57%
	PROVOR_IV (38 floats)	250 cycles (minimum)	122 cycles	25	123 cycles	12%	130 / 179	34%	15%

Table 2 - Recapitulating floats model performances

The Table 2 above summarises the different survival rates observed at sea compared to the theoretical lifetime provided by the manufacturers. However, bear in mind the following points before deriving any conclusions from this table:

- 2 configurations are stated for the Arvor-I model (Arvor-I DO too), because the survival rate (in terms of the number of cycles) for this model in particular, highly depends on his area of deployment, i.e. Open Ocean configuration (cycling every 10 days at 1000/2000 m depth) or Marginal Seas configuration (cycling every 5 days @ 350 and alternating at a profile depth of 700/2000m depth). The manufacturer provided two lifetime expectations for these two configurations.

- Deep float models such as the Arvor-D and NINJA-D profile at a 4000m depth when the SOLO-D and Apex-D ones, profile at a 6000m depth. Please also consider that the Arvor-D floats are all equipped with an additional DO sensor, therefore decreasing the overall life expectancy of the float by 15% (according to float's manufacturer documentation) and is working with a continuous pumping method, also decreasing its overall lifetime expectancy by 50 cycles. Despite these two energy-consuming features specific of the Arvor-D model, they are not the cause of its shorter lifetime due to early failures.

- Regarding the PROVOR_III and PROVOR_IV BGC float models, please note that the theoretical lifetime provided by the manufacturer is based on at least 4 variables floats, cycling every 10 days at 1000/2000m depth, with roughly 150 CTD and all other sensors points acquired per profile.

Also, please consider that the theoretical lifetime of BGC floats is highly variable and depends mostly from the sampling strategy chosen for all the sensors.

- Battery related statistics are based on an alert set up on the fleet monitoring tool[9]. This alert trigger when the battery voltage goes under a certain threshold. The method of detection is explained at the beginning of the Chapter IV. Since this method was implemented at a European level, statistics on floats dead on battery level are only considered for Arvor/Provor float types.

One can note that no "performances on target score"[7] is above the 50% mark. Two comments could be made from this observation:

- The proportion of alive floats in the sample is very important (more than 70% for most of the models)
- There is a significant difference between the theoretical lifetime and the "at sea" one (see Arvor-L or Arvor-A).

Both of these comments are true:

The first one relates the necessity to take these analyses and conclusions carefully because performance trends could still evolve in the future once these samples contain more dead floats.

The second one is really the key of these low percentages. In fact, manufacturers often phrase the potential theoretical lifetime of the float like this: "[…] this float model carries enough battery to undertake x cycles at 10-day cycling period at a 2000m profile depth".

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[9] The Fleet Monitoring Tool is a web interface tool developed by Euro-Argo, accessible via the following address: https://fleetmonitoring.euro-argo.eu/dashboard

The theoretical lifetime of a float is based on an energetic budget depending on the energetic cost of each action undertaken by the float during a cycle and the overall capacity of the battery. These computations do not consider the impact of the life at sea on the floats. By taking a look at the column "Averaged lifetime for floats dead on battery level / median", this lifetime is generally closer from the theoretical lifetime given by manufacturers. In the case of a float performing well during its lifetime, with no anticipated death, exploiting the full capacity of its battery and dying of natural death (battery exhaustion), the average survival rate is generally closer from the theoretical one.

Comparing the survival rates of a float dead of battery exhaustion and its theoretical lifetime should always be coupled with the proportion of floats dead of battery exhaustion in the sample.

- The first comparison provides the information on a float **efficiency** (c.f. GLOSSARY)
- The second provides the information on a float **reliability** (c.f. GLOSSARY)
- The outcome, gives the overall **performance** (c.f. GLOSSARY) of the float

Conclusion:

Key theoretical lifetime for most of the float models (to our best knowledge, obtained from manufacturers documentation, workshops presentations and reports) are summarised in the Table 2.

The averaged at sea lifetime computed per models provide insights on the observed floats reliability.

The lifetime computations for the floats that died of battery exhaustion, when compared to the theoretical lifetime, provide a really strong metric about the float model overall performances and reliability. However, they should always be coupled with the proportion of floats dead on battery analyses.

Eventually, a major part of the samples considered are either very young or containing few dead floats, even less due to battery exhaustion. These figures will therefore require an update in a few years' time, in order to highlight new performances trends or strengthen observations made in this analysis.

III. Study to examine the potential impact of key configuration parameters and technical behaviour on float's survival rates

The main objective of this chapter is to investigate the possible impact of a configuration/technical parameter or a specific behaviour of the float at sea (number of repositioning, groundings, hydraulic actions, etc.) on its survival rate. These aspects might have an impact on the life expectancies on a **long-term scale**, hence the need of a refined sample selection.

A list of floats dead on battery exhaustion was put together in order to create this new sample. This list was created by Euro-Argo, analysing the battery voltage curve of multiple floats and defining some "critical" threshold, defined by the start of the drastic decrease of the voltage curve (Figure 11). Since Arvor/Provor platforms are the most deployed and known from the European operational teams, the following thresholds were used: **Arvor = 8V | Arvor-DEEP = 12V.**

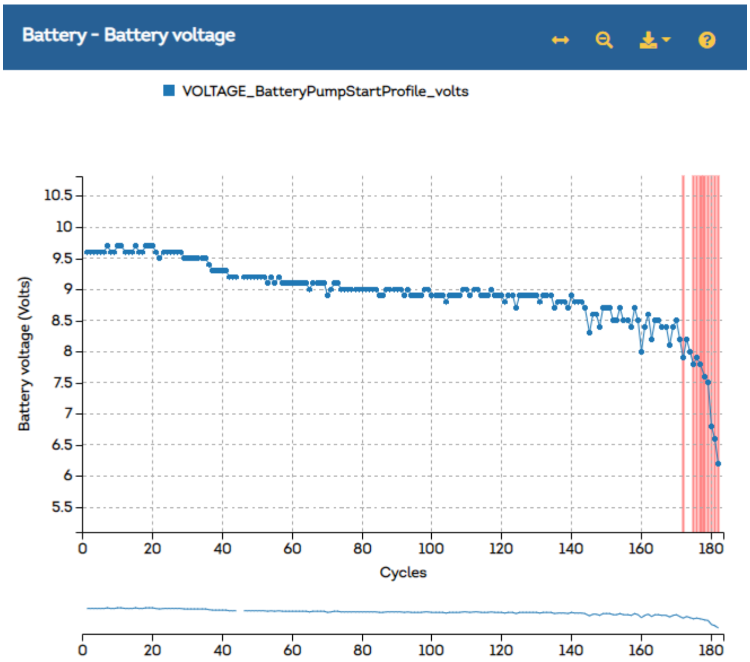

*Figure 11 - Battery voltage curve of the float **3901892**. Red lines represent the cycles were the 8V threshold mark is exceeded, symbolizing the death of the float in a short future.*

At a European level, the most common platform type deployed is the Arvor one. Since this list was based on European partners knowledge and experience, the thresholds for other floats technologies (Apex, SOLO, etc.) and battery types are not reliable enough.

However, discussions with foreign partners/manufacturers would be a critical point in the future in order to determine these battery voltage thresholds and complete our study ("?" in the Table 2).

SAMPLE DESCRIPTION:

351 Arvor type floats, deployed after 2010 and dead on battery level:

- 190 Arvor-Argos (Arvor-A in the figures)

- 43 Arvor-Iridium (Arvor-I in the figures)

- 118 Arvor-L (acronym for Arvor-light, with a lighter battery pack)

The Iridium telecommunication type being a younger technology, Arvor-I floats started to be deployed since 2016, hence the low number of floats that reached their battery exhaustion. For this sample, we took an older deployment date limit (2010 instead of 2016 in the first part of this document) in order to widen the number of floats in this study. After multiple discussions, we agreed on the fact that a configuration parameter would have the same long-term impact on the lifetime of an older float than on a recent generation one.

Please note that none of the Arvor floats equipped with a DOXY sensor died on battery exhaustion. Therefore, specific DOXY parameters such as the “in air sample frequency”, that were identified on the list of parameters that could impact floats lifetime, were put aside in this study but would be interesting to investigate in the future, once the sample contains some of these floats.

After discussions with NKE floats experts, a list of parameters of interest was put together, listing the configuration and technical parameters that might have an impact on the lifetime of the floats.

- ORANGE cells = Not enough different parameters values for the sample considered in this study
- GREEN cells = Comparison between different parameter values possible

Configuration parameters	**Description**
CONFIG_ParkPressure_dbar	Park pressure in dbars
CONFIG_ProfilePressure_dbar	Profile pressure in dbars
CONFIG_CycleTime_hours	For APEX and ARVOR floats this is the total duration of one cycle, usually 240 hours (10 days).
CONFIG_DescentToParkPresSamplingTime_seconds	Sampling period during the descent to parking pressure (in seconds).
CONFIG_ParkSamplingPeriod_hours (only Arvor-L)	specifies sampling period during the park phase (in hours).
CONFIG_AscentSamplingPeriod_seconds	Sampling period during the ascending profile (in seconds).
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_TransmissionRepetitionPeriod_seconds (only Argos)	transmission repetition rate, metadata for most floats - may be variable for two-way communication
CONFIG_TransmissionMinTime_hours (only Argos)	The time the float will remain on the surface transmitting its data at the end of each cycle. At lower latitudes you may wish to increase the value of this parameter to increase the probability of reception of all of your data.
CONFIG_TelemetryRepeatSessionDelay_minutes (only Iridium)	Delay before a second Iridium session performed by the float just before diving for a new cycle (in minutes).

CONFIG_PressureTargetToleranceDuringDrift_dbar	Defines the target pressure interval for float drift at parking or profile depth (in dbars).
CONFIG_PressureTargetToleranceForStabilisation_dbar	Defines the target pressure interval for float stabilisation at parking or profile depth (in dbars).
CONFIG_CTDPowerAcquisitionMode_NUMBER	Proper to the Arvor platform type. Either continuous pumping or spot sampling
CONFIG_number_CTDPoints[10]	See Footnote 10.

Technical behaviour	**Description**
Number of groundings (extracted from "traj" file entry "GROUNDED")	grounded flag, diagnostic bit - could also be logical? Yes/no? 0/1? Or can be number of profiles during which the float grounded
NUMBER_RepositionsDuringPark_COUNT	number of times the float readjusts its buoyancy during park phase - using either the pump or EV
NUMBER_PumpActionsDuringAscentToSurface_COUNT	number of pump actions between start and end of ascent

When looking at the configuration parameters listed above, an important proportion appears not to have enough different values for a comparison (orange cells). This homogeneity in configurations is strengthened by three aspects:

- The Argos telecommunication type, representing more than 87% (Arvor-A and Arvor-L) of the whole sample, is a one-way telecommunication type, hence, not permitting to change a float configuration once deployed at sea. Back then (majority of Arvor-Argos deployments were done between 2011 and 2015), configurations were more homogenous, respecting some standard configuration according to the area of deployment.

- In the original sample of **351 floats**, are considered for survival rates computations only floats that did not change the investigated parameter throughout their lifetime (Iridium floats that changed their configuration parameter through a telecommand at some point are not considered since their survival rates could not be computed with respect to one value of the parameter).

- For this next part, we reduced our sample size limit from 20 to 10 floats in order to still be able to make comparisons between different samples. Otherwise, with a float sample size limit to high, we would have rejected a lot of samples (i.e. floats with a certain parameter value) that led to interesting observations.

The following graph (Figure 12) is a good representation of the overall performances of these three models, according to a very common and completely homogenous configuration parameter for the sample: a descent sampling period of 0.

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[10] This configuration parameter is a hybrid one. It doesn't exist in the Argo reference table named as such but was computed thanks to other configuration parameters (depth slices, sampling time period, profile depth, etc.), in order to derive the number of CTD points gathered per profile.

One can note the very sharp decrease of the curve for the Arvor-Argos and Arvor-L floats, suggesting a quite precise estimation of the maximum cycles made for a float reaching battery exhaustion:

- 140 cycles +/- 10 cycles for an Arvor-L

- 180 cycles +/- 20 cycles for an Arvor-A

However, for the Arvor-I model, the curve shows a wide range of maximum cycles made for two main reasons:

- The two different standard configuration having different cycle time period

- The sample is small and the estimations will be more precise once more floats die on the battery level

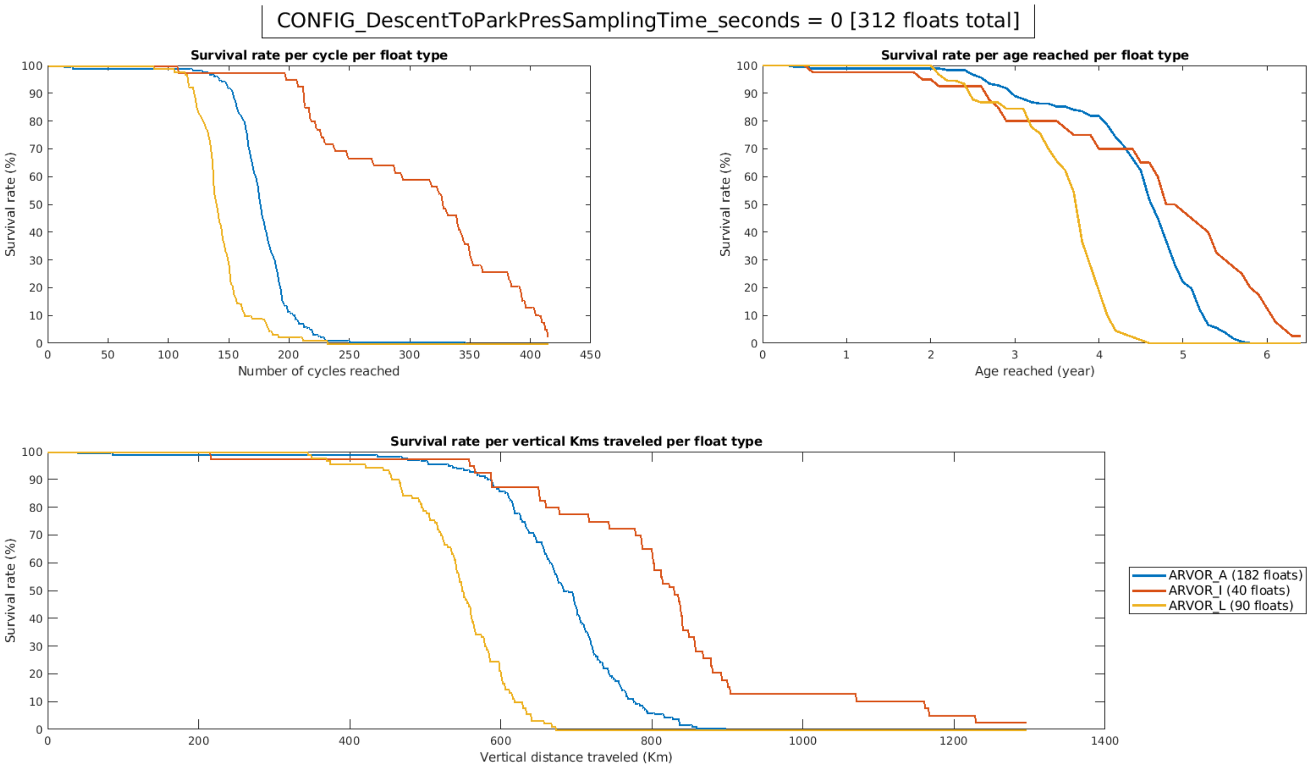


Figure 12 - Survival rates computations according to the configuration parameter value of a descent sampling period equal at 0; gathering most of the floats in the sample since none of them performed a descent profile (except during 1st cycle).

The Arvor-L has the smaller battery pack, hence the lower theoretical lifetime. The Arvor-Argos and Arvor-I have a larger battery pack than the Arvor-L. The transition from the Argos telecommunication type to the Iridium one is traduced by a quicker data transmission, hence reducing drastically the time on the surface between an Arvor-A and an Arvor-I. A lower transmission time results in a greater life expectancy since the transmission of data is directly tied up to the energy consumption of the float.

The energetic consumption of a transmission was estimated at 141 mAh per cycle for the Arvor-Argos model against 18 mAh per cycle for the Arvor-I model. This drastic energetic saving transitioning from an Argos telecommunication type to the Iridium is one explanation why the Arvor-I model present the best overall model of the three, together with all the major improvements the NAOS project (André et al., 2021) brought to the Arvor-I product.

A. Configuration parameters

1. Park Pressure

The park pressure is a pretty homogenous parameter for the different models. The standard pressure for a deployment in the Open Ocean is a 1000 dbar pressure when for a deployment in Marginal Seas (Mediterranean) it is 350 dbar. For other Marginal Seas like the Baltic it could be even shallower.

However, for some scientific objectives, it is sometimes useful to constrain a float in a specific area by making it ground every cycle, hence letting the default park pressure at a 1000 dbar when the bathymetry is shallower.

This parameter is part of the three main configuration parameters (cycle time, park and profile pressure), that are often changed throughout a float's lifetime to adapt its mission. Since we only consider floats that did not change configuration throughout their lifetime, it explains the difference between the number of Iridium floats considered in the survival rates computations and the original sample. As shown in the Figure 13, 30 floats are considered out of 43 Arvor-I floats in the sample.

The Arvor-A and Arvor-L models both only add one configuration value represented which is a parking pressure at a 1000dbar. Arvor-I floats were the only ones with different configuration values, at 350 and 1000 dbar. These two values are characteristic of the standard configuration for, respectively, the Marginal Seas and the Open Ocean. One can therefore observe the same trends in terms of the number of cycles made like in the Chapter III.B, comparing these two parameter values.

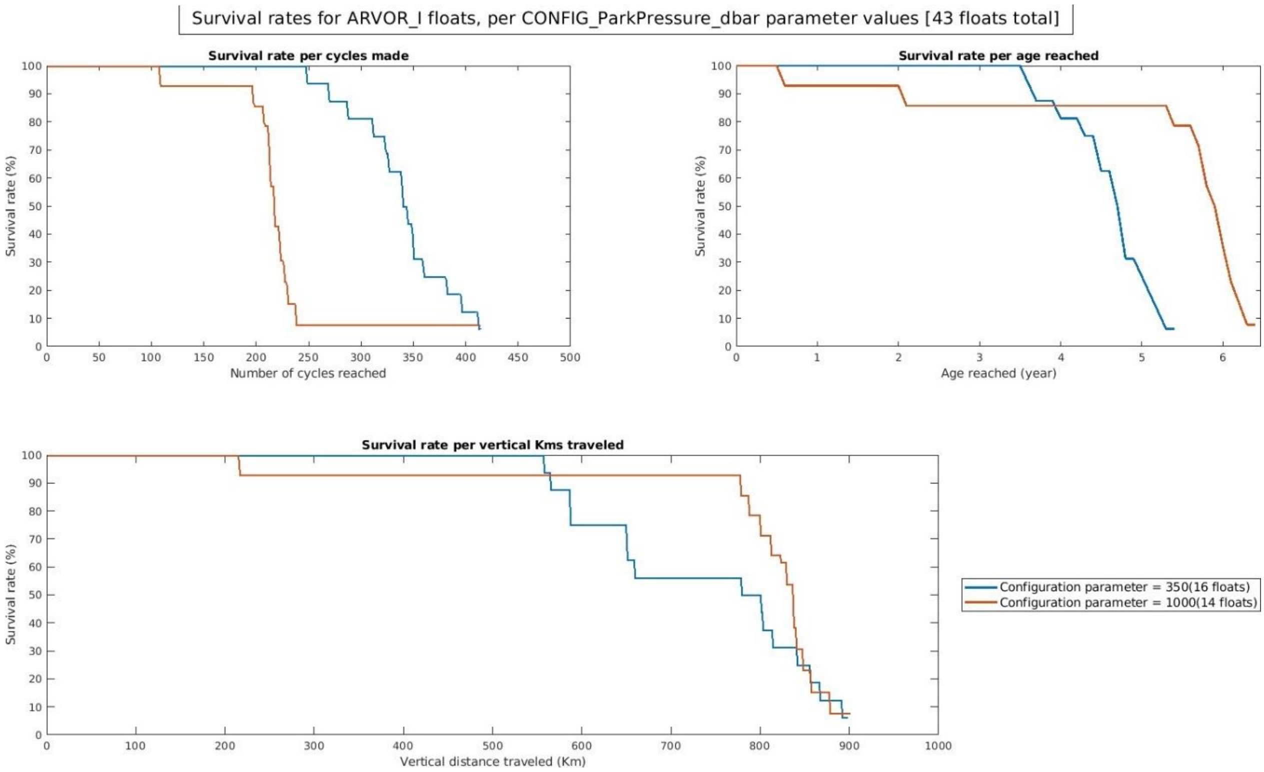


Figure 13 - Survival rates comparison for two values of parking depth pressure for the Arvor-I sample.

The survival rates comparison of this parameters values reflects the observations already written in the areas of deployment differences. Other than that, this parameter does not seem to affect the floats lifetime in a certain way.

2. Cycle time period

All float models had two parameter values: either 5 or 10-day cycling period (120 or 240h, respectively).

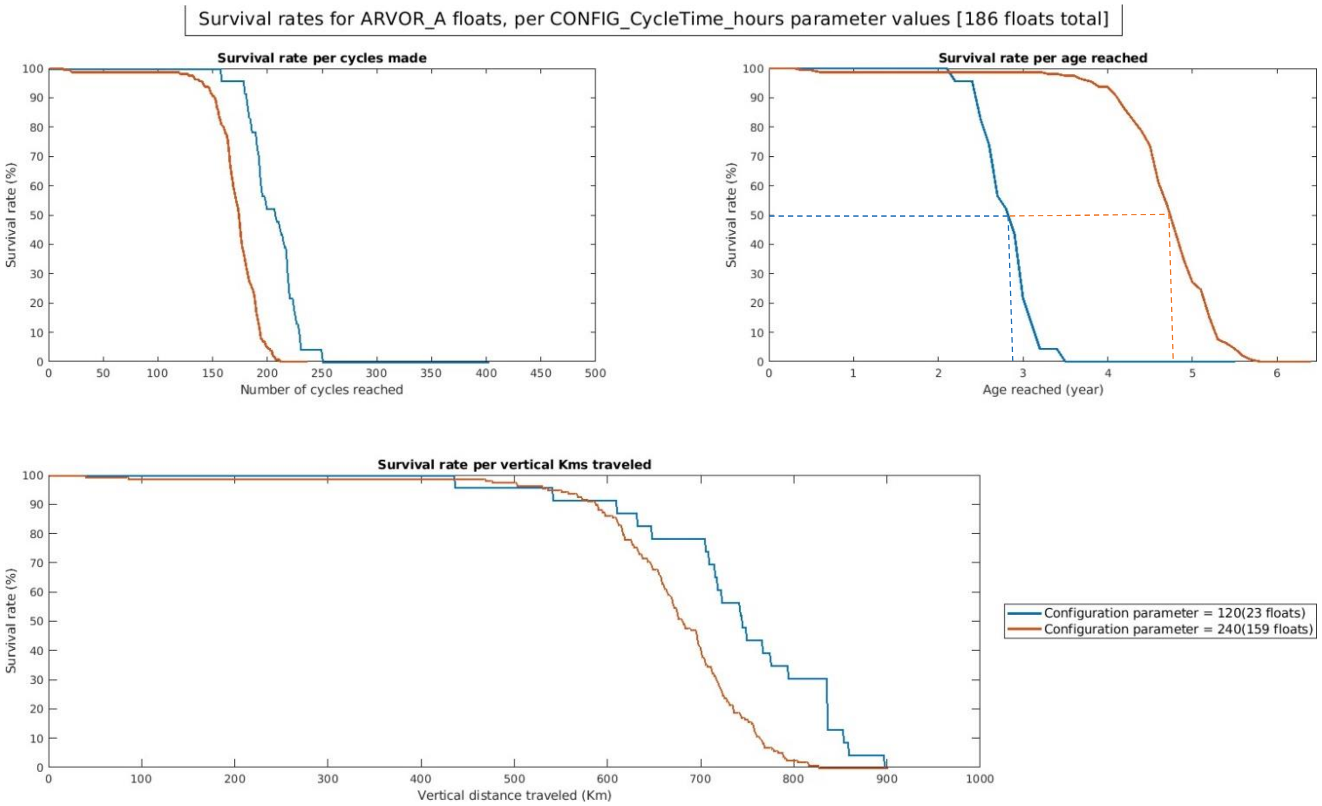


Figure 14 - Survival rates comparison for Arvor-A floats dead on battery level. The two curves correspond to 2 different values of the Cycle Time Period parameter (either 5-days:120H or 10 days period:240H).

Cycling at a 5-day period instead of a 10 days one results in:

- About 40 more cycles made

- A slightly more important vertical distance travelled (about 50 to 75 km differential), corresponding to the 40 additional cycles made by a 5-day cycling Arvor-A float

- A significantly lower age reached (2.8 years for a 5-day period cycling against 4.8 years at sea for a 10-day cycling period).

It is interesting to note that very few Arvor-A models were deployed in Marginal Seas (only one in this sample) and none of them had a profile pressure different than 2000 dbar. Arvor-A floats cycling at a 5-day period were profiling at a 2000 dbar, like the 10-days cycling ones. This explains the small difference in cycles made (only 40 cycles differential) and justify the gap in terms of vertical distance travelled:

75 kms / 2 km = 37.5 => roughly the 40 cycles differential

When comparing the survival rates according to different cycling time values for Arvor-I floats, some differences are observed. However, keep in mind that the overall lifetime of an Arvor-I is significantly better than an Arvor-A, regardless of any differences in configuration (Figure 14).

- The differential of cycles made significantly increases (about 130 cycles differential between a 5 and a 10-day cycling period)

- The age reached gap is smaller (4.8 years for 5-day cycling floats and 6 years for 10-day cycling floats).

- The vertical distance travelled is less important for a majority of 5-day cycling floats.

The main difference with the Arvor-A graphs is that Arvor-I floats cycling at a 5-day period (blue sample) are deployed in Marginal Seas, with a shallower park and profile pressure (usually alternating between a 700 and a 2000 dbar) than the 10-day cycling floats (orange sample) profiling every cycle at a 2000 dbar depth.

Since the blue sample is profiling at a shallower depth, its energetic consumption per profile is significantly lower than an orange sample float since the energetic consumption of a float is directly tied up to the number of hydraulic actions and the pressure at which they occur.

Therefore, a 5-day cycle at a shallower profiling depth is less consuming than a 10 days one at 2000 dbar, thus explaining why the age reached gap is reducing and the differential of cycles made is increasing compared to Arvor-A graphs (Figure 15). Even though the blue sample made a lot more cycle than the orange one, it does not compensate the shallowest profiling depth when analysing the vertical distance travelled (bottom graph).

However, the Arvor-I sample of floats dead on battery level is still very young since this is a recent float model and the analyses should be recomputed in the future in order to confirm or infirm the trends highlighted here and derive more reliable conclusions from it.

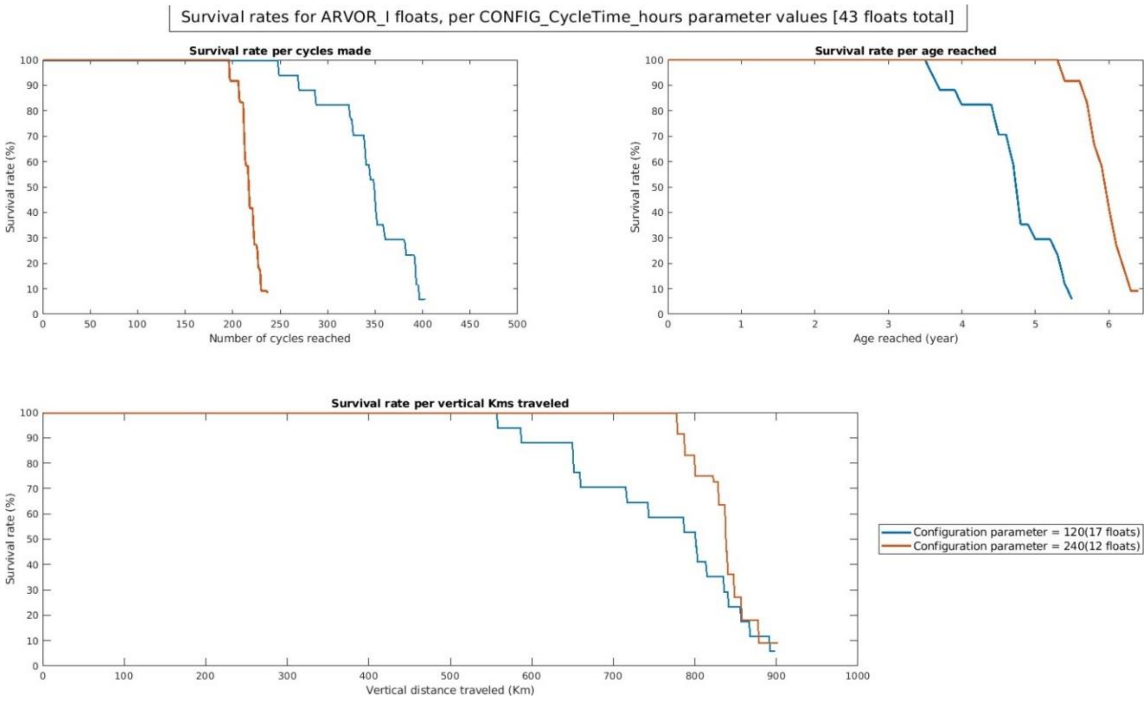


Figure 15 - Survival rates comparison for Arvor-I floats dead on battery level. The two curves correspond to 2 different value of the Cycle Time Period parameter (either 5-days:120H or 10-days period:240H).

Bear in mind that the Arvor-I observations made above are intrinsically related to the profile pressure associated to a 5-days or 10-day period. The two parameter values analysed for the Arvor-I match two different default configurations (the Marginal Seas and the Open Ocean one), which is not the case for the Arvor-A sample since only one was deployed in Marginal Seas and that they had all the same profile pressure. Therefore, conclusions about the impact of the cycle time period parameter are to be derived from the Arvor-A analysis, as follows:

- One should choose this cycling period accordingly to the scientific objectives the float should achieve. If the float's objective is to help monitor a long-term event, over several years, then a 10-day period should be privileged. At the opposite, if the objective of the float is to gather as many profiles as possible in a certain area, then a 5-day period should be slightly better.

- In most areas of the globe, surface currents are stronger than deep ones. With a reduced cycle time period, floats spend more time in the surface layers of the Ocean and might tend to drift more than with a standard 10-day cycle period. The biofouling is also more important for floats cycling at a higher rate, which might be a real problem, especially for optical sensors.

- It results from the survival rates curves that **cycling twice as fast does not result in twice the number of cycles made, nor half of the age reached.**

Once could see on Figure 15 that the survival rate curve for Arvor-I floats dead on battery level and with an Open Ocean configuration (orange curve, 240 hours) has a sharp decrease trend that could lead to a more robust estimation of the reached number of cycles for floats dead after battery exhaustion.

3. Sampling periods

None of these floats sampled during the descent to the parking pressure. They all performed CTD sample measurements at a 10s frequency during ascent and at a 12 or 24-hour frequency during parking.

The Arvor-A and Arvor-I models both only had a 12h sampling period in parking. The Arvor-L floats model had two configuration values: 12h and 24h sampling period.

This parameter does not have an important impact on the float performances as shown in terms of the number of cycles made and vertical distance travelled. However, in terms of age reached, the floats sampling at a 12H frequency (blue curve) instead of a 24H one, present some lower survival rates.

Since no particular impact of this parameter was visible in the other two x-axes graphs (cycles made and vertical distance travelled), this behaviour indicates most probably an impact from another parameter on the blue sample, having a strong repercussion on the age reached.

When checking more in detail the 78 floats of the blue sample with the “config fleet status tool” (c.f. D2.1), we found that 17% of this sample (13 floats) were deployed in Marginal Seas with a 5-day cycle time period and a 2000 dbar profiling pressure when all the floats from the orange sample were configured at a 10-days cycling period.

Since these 13 floats kept profiling at 2000 dbar, their impact on the number of cycles made and the vertical distance travelled is minor: about 20 to 30 additional cycles made, resulting in a 50/60 vkms differential (highlighted by the two green ellipses). In terms of age reached, this shorter cycle period results of 17% of the sample impacts the survival rate curve of the sample, as shown by the red ellipse.

However, this is an artefact from another parameter. The investigated parameter “CONFIG_ParkSamplingPeriod_hours” values (either 12 or 24H period) **does not have an impact on the survival rates of the floats considered.**

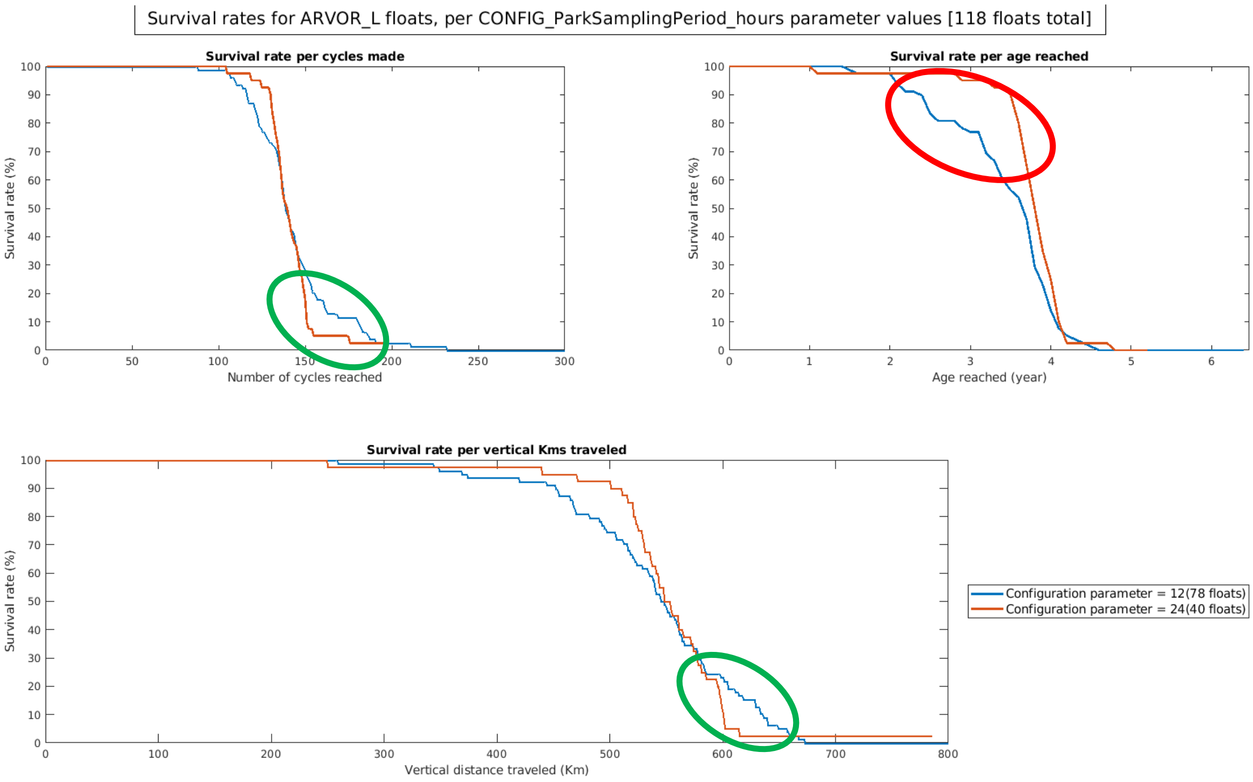
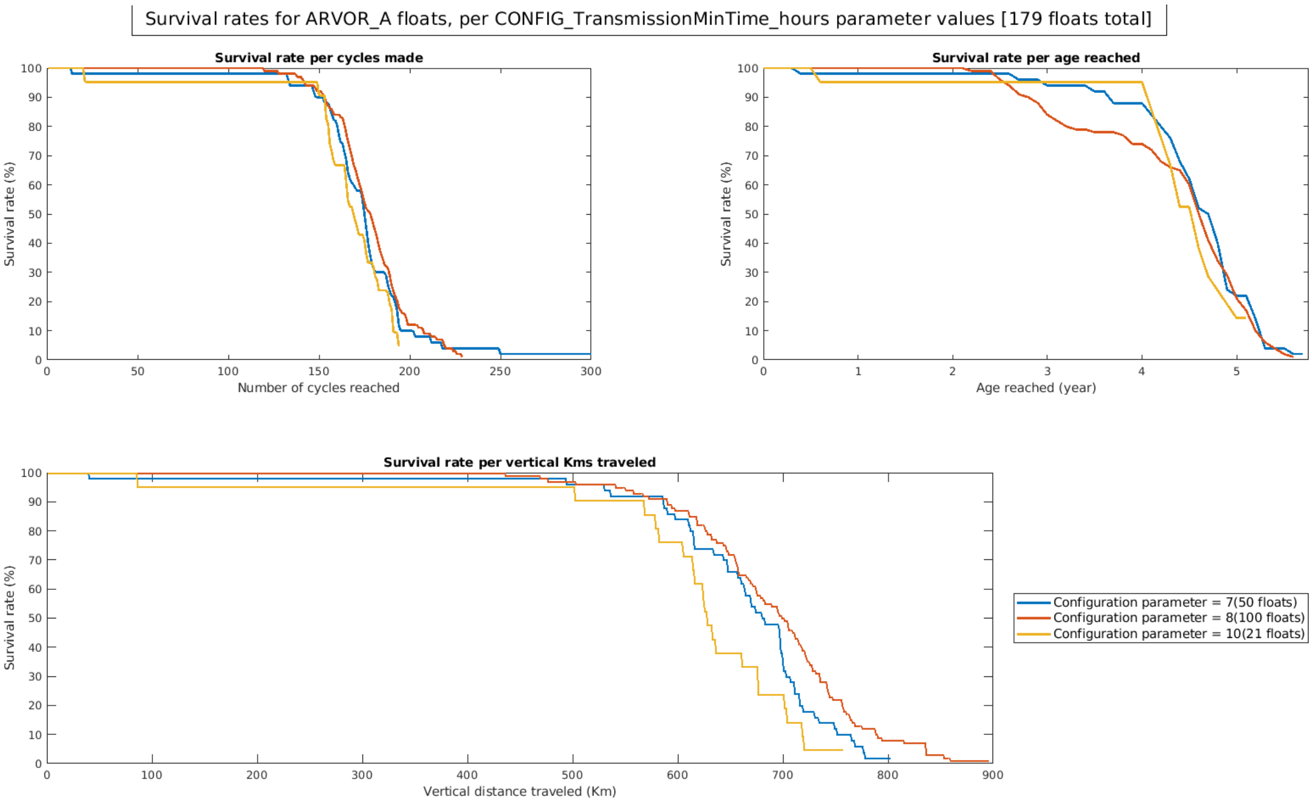


Figure 16 - Survival rates comparison for Arvor-L floats. These survival rates are grouped between a 12 and a 24 Hours park sampling period values.

4. Transmission times

Argos telecommunication type had a way longer transmission time than the Iridium one. The configuration parameter "*CONFIG_TransmissionMinTime_hours*" is specific to Argos floats and corresponds to the minimum transmission time for the float once at the surface. The constructor default minimum was 6H. If the float were to be deployed on a low latitude, it was recommended to pick a higher minimum transmission time in order to succeed transmitting all the messages.



There are no real differences in performances in terms of cycles made nor age reached. In terms of vertical kilometres travelled, there is a small difference in survival rates, but that could be directly correlated to the number of floats considered in each subsample.

Since differences are only observed according to one x-axis metric, this probably points out to a multi-parametric impact of the floats selected in this sample (like explained in the Chapter IV.A.3).

There is no equivalent configuration parameter for the Arvor-Iridium floats.

5. Pressure target tolerance threshold

There are two configuration parameters defining a tolerance for pressure target:

- "*CONFIG_PressureTargetToleranceForStabilisation_dbar*": for the ARVOR floats to reach the park and profile pressure depth

- "*CONFIG_PressureTargetToleranceDuringDrift_dbar*": for the ARVOR floats to maintain its parking pressure depth

These two parameters usually have a default value of, respectively, 30 and 50 dbar. However, different values were set by the manufacturer at delivery, presumably due to some mistakes in float configuration request (was modified after notification). Some specific tuning of configuration by the float experts for these two critical parameters have been decided to achieve a dedicated behaviour of the floats (e.g. Baltic Sea, Arctic basins, etc.).

Most of the floats where these parameters had different values throughout their lifetime changed it through a telecommand at some point. Unfortunately, as explained in the sample selection part and in the D2.1 method, only floats that did not change configuration after deployment are considered in survival rates analyses. Therefore, not enough floats (less than 10 with respect to the sample size limit) from this sample had different parameter values, hence no comparisons of survival rates could be made.

Following the manufacturer's recommendations and specific analyses of floats with a low tolerance threshold (parameter values smaller than default), **it is highly recommended not to change any of these parameters (at least for lower values than the default ones).**

If so, it will only result on the float struggling to stabilise itself at the defined pressure and will induce multiple repositioning, therefore generating more hydraulic actions and presumably decrease the overall energy budget of the float. These two critical configuration parameters are tightly related to the technical one registering the number of repositioning during parking: "*NUMBER_RepositionsDuringPark_COUNT*" (Chapter IV.B.8).

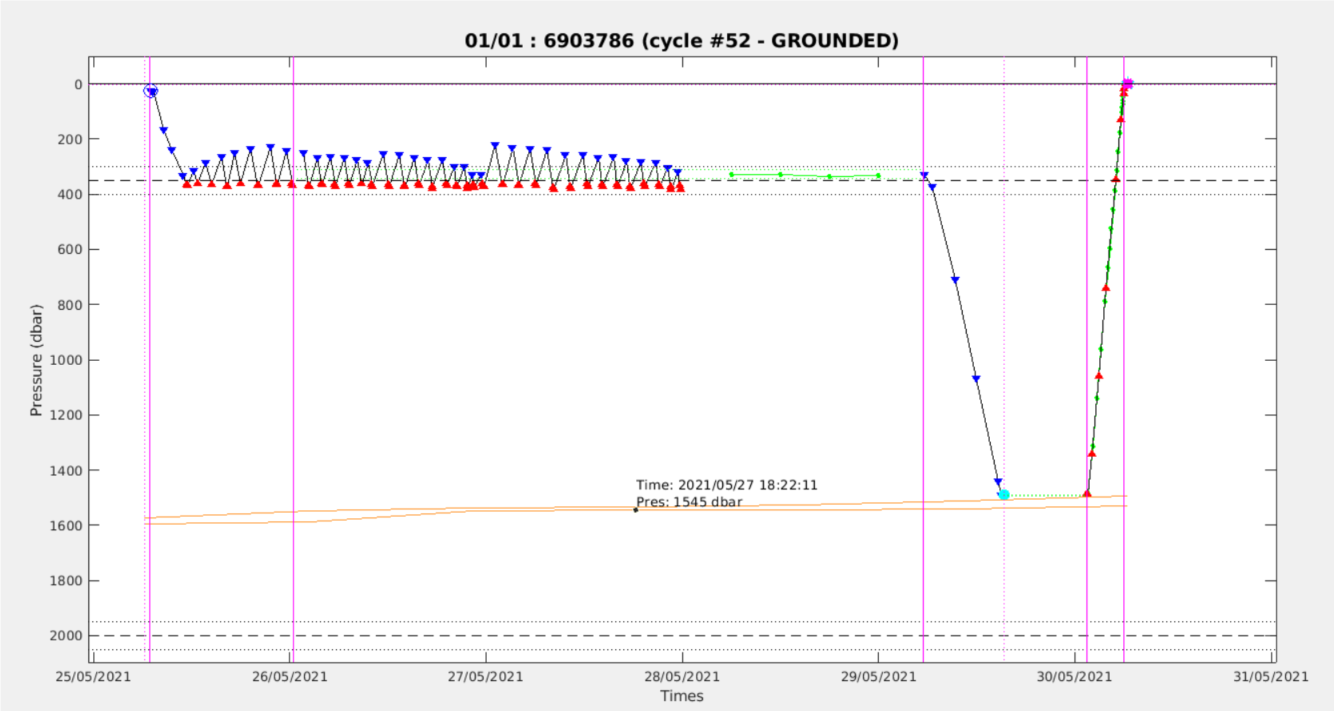
As an example of such an erratic behaviour caused by a small threshold tolerance pressure target, the float **6903786**, Italian Arvor-I + DO float deployed West of Israeli's coast. The tolerance threshold value for stabilisation was set at 10 dbar (instead of default 30 dbar). This float was flagged with a hydraulic alert on the "*Fleet Monitoring Tool*" for most of its life.

The "*Fleet Monitoring Tool*" is paired with a tuned system of alerts, permitting to automatically highlight an erratic behaviour of a float (battery voltage sudden drop, aberrant grounding respect to the bathymetry in the area, number of hydraulic actions per phase too important, etc.). For an ARVOR type float, some threshold limits were defined for the number of hydraulic actions a float should have per phase (descent, parking, ascent, final emergence, etc.).

When a float triggers a hydraulic alert on the "*Fleet Monitoring Tool*", it means that it performed too many hydraulic actions in a certain phase of its cycle. If this alert repeats itself for multiple cycles, it usually leads to an investigation and some actions (modification of configuration parameters through a telecommand, etc.).

This alert system provides a crucial help to all the monitoring activities of the fleet.

The following graph represents the hydraulic actions performed by the float **6903786** (blue triangle = solenoid valve action; red triangle = pump action) during cycle 52:



The multiple repositioning during the parking phase at 350 dbar are induced by this threshold being too small. Here, the energetic cost of additional pump actions is not that impressive because it takes place at a 350 dbar depth (see Chapter IV.B.7). If these additional hydraulic actions happened on a deeper parking pressure, during multiple cycles, this will significantly reduce the overall energetic budget of the float, hence its lifetime.

6. Number of CTD points

The number of CTD points configured for a float is derived, depending on float models, from the combination of multiple configuration parameters defining the vertical sampling scheme, such as: the pressure levels and bins, different pressure zones, the sampling frequency during the different ascent pressure intervals, the profiling depth, etc.

One of the main advantages of the Iridium technology in comparison to the Argos one is the possibility to transmit more data in a shorter amount of time. The number of CTD points that could be measured went from mainly 100 to 120 CTD points for the Arvor-Argos version to approximately 500 to 1000 points for the Iridium version of the float.

The number of CTD points measured during a cycle as an impact on the overall energetic budget of the float since:

- For ARVOR type floats, the CTD is in continuous pumping mode (turned on during the whole ascent), contrary to APEX or SOLO floats, using a spot sampling CTD method. Hence the activation of the sensor is not to be considered in our case.

- The float takes more time to transmit its data, hence an additional consumption during the transmission period.

The only float model in our global sample, to have different configurations for the number of CTD points is the Arvor-A model. However, the differences in these parameter values are too small to have an impact on the overall lifetime of the floats…

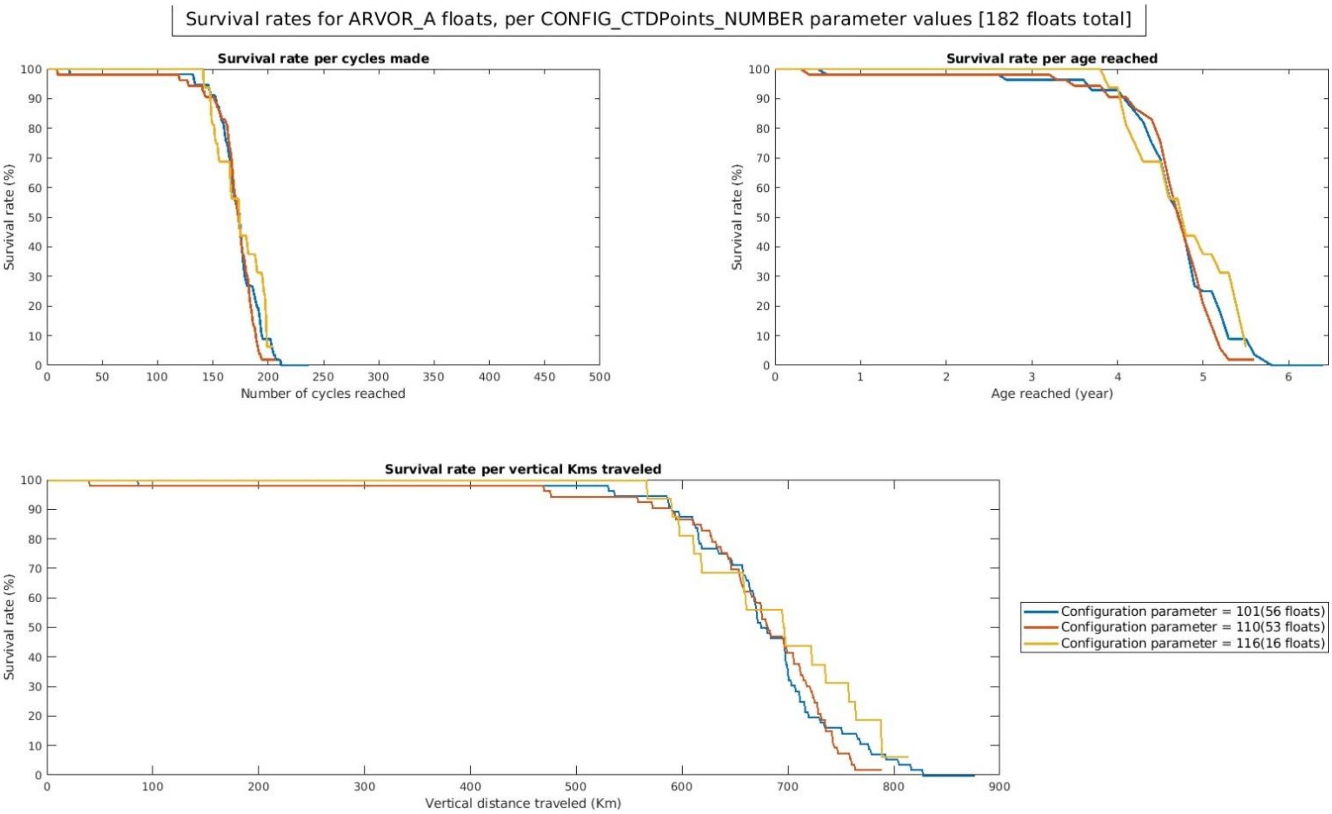


Figure 17 - Survival rates comparisons for ARVOR-A floats, depending on the number of CTD points collected per profile.

Unfortunately, on the 43 Arvor-I floats that are present in this sample, not enough of them had different number of CTD points, hence not permitting any comparisons with the usual number of CTD points performed by Arvor-I floats.

Most of the ARVOR-I floats had a sample rate of 100 CTD points per profile, which is similar to what ARVOR-A floats have. The fact that Arvor-I floats are not gathering as many points as they could, is most probably the transmission costs it will generate.

Conclusion:

On the configuration parameters identified in D2.1, that could have an impact on Arvor floats lifetime, only a few could have been thoroughly investigated due the sample selection limit: too few floats were dead after battery exhaustion (sample still young), or had enough different values for the considered parameter, or kept the same value for all the float mission. The study should be performed again in a couple of years.

The **cycling time period** could be chosen accordingly to the scientific purpose of the float (long term scale analyses: prefer a 10-day cycle period because the float will last more time at sea and collect more data; prefer a 5-day profile if the objective is to gather as many profiles as possible)

However, bear in mind that cycling twice as fast does not result in twice the number of cycles made nor half the age reached. A shorter cycle period will, as a side effect, tend to make the float drift more and could be confronted to more biofouling.

The **pressure target tolerance** for stabilisation and during the drift are two critical parameters that should not be changed to lower values than, respectively, 30 and 50dbar. Otherwise, it will induce additional repositioning.

Some of the configuration parameters are interrelated and reflect the different missions of the Euro-Argo fleet: Open Ocean and Marginal Seas.

The methodology developed for the report permitted to estimate the observed number of cycles performed for floats dead on battery level:

- 140 cycles +/- 10 cycles for an Arvor-L

- 180 cycles +/- 20 cycles for an Arvor-A

- 230 cycles +/- 10 cycles (*firsts results, young sample*) for an Arvor-I with a standard (Open Ocean) configuration

- 350 cycles +/- 50 cycles (*firsts results, young sample*) for an Arvor-I with a Marginal Seas configuration

B. Technical behaviour

1. Groundings

It is really key to understand that the estimation of the impact of groundings, in this chapter, is derived from analyses on a sample of floats dead on battery level. Therefore, this study only focuses on the impact of a grounding on an **energetic stand point** and not on the potential damages a grounding could cause to the platform.

An Arvor float considers itself grounded when it is stuck at a certain pressure and does not succeed going deeper despite executing multiple solenoid valve actions to sink more. The float will consider itself grounded if the pressure measured did not increase with this buoyancy loss (i.e. is not able to dive more).

However, by doing this, the float will need to compensate its buoyancy loss by executing multiple pump actions afterwards, that are energetically costly (proportionally to the depth).

When a grounding occurs, the float then relies on a configuration parameter named "*CONFIG_GroundingMode*" to define its course of actions:

- parameter value = 0: The float shifts upwards according to a defined pressure threshold (80% of the sample had a 100 dbar shift threshold pressure).

- parameter value = 1: The float stays grounded until it's time to start its ascent.

The Annexe 6 presents the repartition of these parameter values for the sample selected. In this graph, one can observe that almost all the floats considered in the sample (99%), had a grounding mode at 0, implying a pressure shift after a bottom contact. This "*CONFIG_GroundingMode*" parameter does not impact a difference in the energetic consumption of a grounding. Depending on its value (either 0 or 1), this parameter only defines at which time the float will perform its hydraulic actions to regain its buoyancy. The only thing to bear in mind is that a grounding mode of 0 might lead to other groundings in the same cycle, when a grounding mode of 1 should (in the majority of the cases), guaranty only one grounding per cycle.

Before analysing the following survival rate plots, one must keep in mind that a grounding:

- Decreases the **vertical distance** travelled by a float since it is stopped in its descent to park or profile pressure (for most of the cases. See: **footnote 11**).

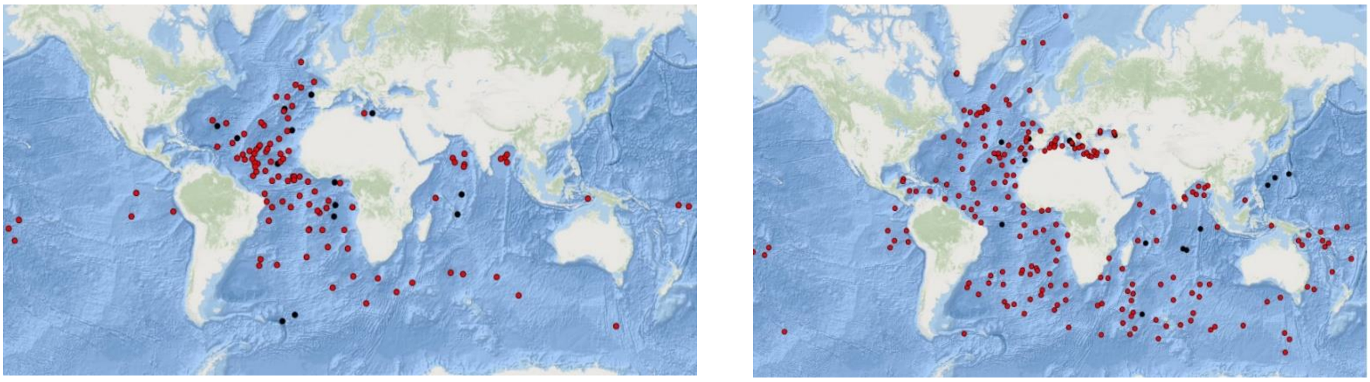
- Every float considered here do not stop their cycles when encountering a grounding. According to their grounding mode, they either shift pressure or stay grounded but they don't ascent back up. The **number of cycle** metrics is therefore not biased.

- The **age at sea** is not biased either by the groundings.

Here the parameter analysed is contained in the "traj" files of the floats. The "GROUNDED" parameter is a boolean one, only recording if a grounding occurred during the cycle considered. If multiple contacts with bottom occurred during one cycle, this parameter will not take a different value than 1.

The number of groundings was then sump up over the global float's lifetime. The intervals and graphs presented hereafter are derived from this metric.

The following map represents the deployment positions of the 351 floats considered in this chapter (Arvor-A, -L and -I), depending on the fact that they did or did not ground:



119 floats never grounded

232 floats did ground at least once

Figure 18 - Repartition of the deployment positions of the grounded and not grounded floats in the global sample (351 floats considered).

It is interesting to note here the fact that almost every float that did not ground were deployed outside Marginal Seas (except 2 floats). However, floats that did experience at least one grounding over their lifetime were deployed in Marginal Seas as well as in the Open Ocean.

Looking more closely into the Arvor-A model and the repartition of the deployment areas (Annexe 7), only one float was deployed in Marginal Seas. Before starting any interpretation on the Arvor-A sample, a quick run of the "*CONFIG fleet status*" tool is necessary to possibly highlight different configurations that might have an impact on the survival rate curves:

- On the 190 Arvor-A floats, 87% were deployed with a 10-day cycle time period and **13% with a 5-days** one (Annexe 8).

- 90% of these floats had a parking pressure of a 1000 dbar and the rest had shallower drift pressure.

- 98.5% had a 2000 dbar profile pressure.

The following graph (Figure 19) represents the survival rates comparison of the Arvor-A sample, by differentiating if the float experienced or not, at least one grounding throughout its lifetime.

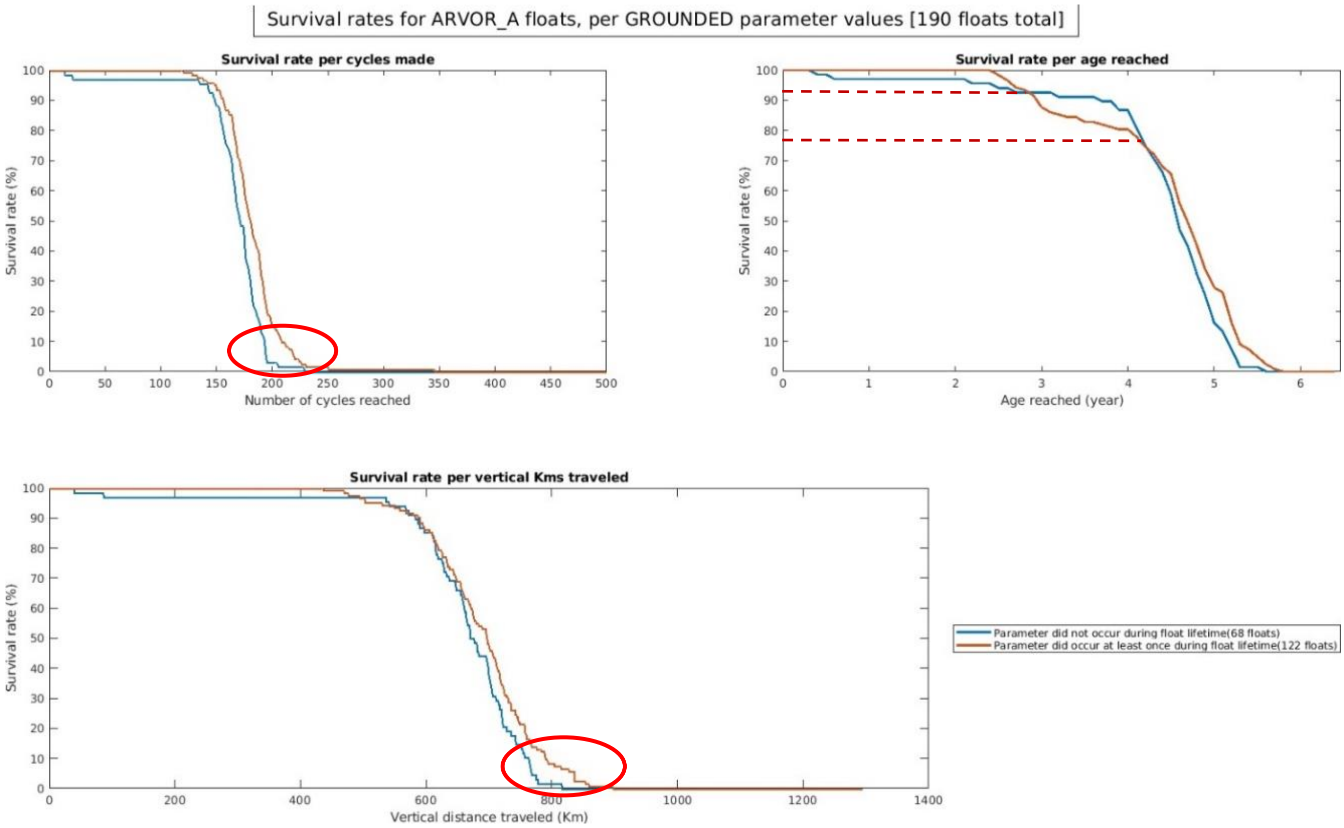


Figure 19 - Survival rate comparisons for Arvor-A floats, depending if at least one grounding occurred or not during the float's lifetime.

The curves have rather similar trends, on every x-axis considered. However, one can note the following observations:

- In terms of **number of cycles made**, no real differences are observed between the two sample. The orange sample (floats that did ground at least once) present a slightly better survival rate on this metric than the blue sample (no groundings at all).

- The blue sample floats, counterintuitively present a slightly lower survival rate according to the **vertical distance travelled**.

-From an **age reached** point of view, the curves coincide nicely below a 78% survival rate of the sample. Above this point, the orange sample presents a lower survival rate than the blue one. As seen in Chapter IV.A.3, when an investigated parameter shows an erratic trend on only one x-axis metric and not on the others, one should consider the potential bias from other parameters.

Here, approximately 14% of the sample (represented by the red dotted line above) presents a lower survival rate than the other sample when it was not the case on the other two metrics. This decrease of performance in terms of age reached could be explained by the proportion of Arvor-A floats that had a shorter cycle time period (as pointed out thanks to the *CONFIG fleet status* tool, 13% of the sample had a 5-day cycle time period). The impact of these floats is also slightly visible in the end of the survival rate curves in terms of cycle and vkms (two red ellipses).

The blue curve, representing the floats that did not ground a single time during their lifetime, presents a slightly lower survival rate overall than the orange sample.

At first sight, this observation could be counter-intuitive. However, since we are only considering here the energetic impact of a grounding, one could propose the following statement:

- When a float experiences a grounding, the maximum pressure reached is lower than during a normal cycle (most of the cases[11]). Since the energetic cost of a profile is mainly related to the pressure at which hydraulic actions are performed and the telecommunication of the data, a grounded float will perform hydraulic actions at a shallower depth than during a normal profile, meaning a lower energetic consumption. A grounded float will gather less data than during a complete cycle, hence spending less energy transmitting it.

This hypothesis could be a possible explanation on why blue sample floats present slightly lower performances than grounded floats. However, in the above figure, no differences are made between a float that only grounded once and one that grounded for an important number of cycles.

The following graph (Figure 20) gathers the survival rates computations for the Arvor-A floats, based on intervals on the number of groundings that occurred during a float's lifetime. The sample interval is set at 25 groundings.

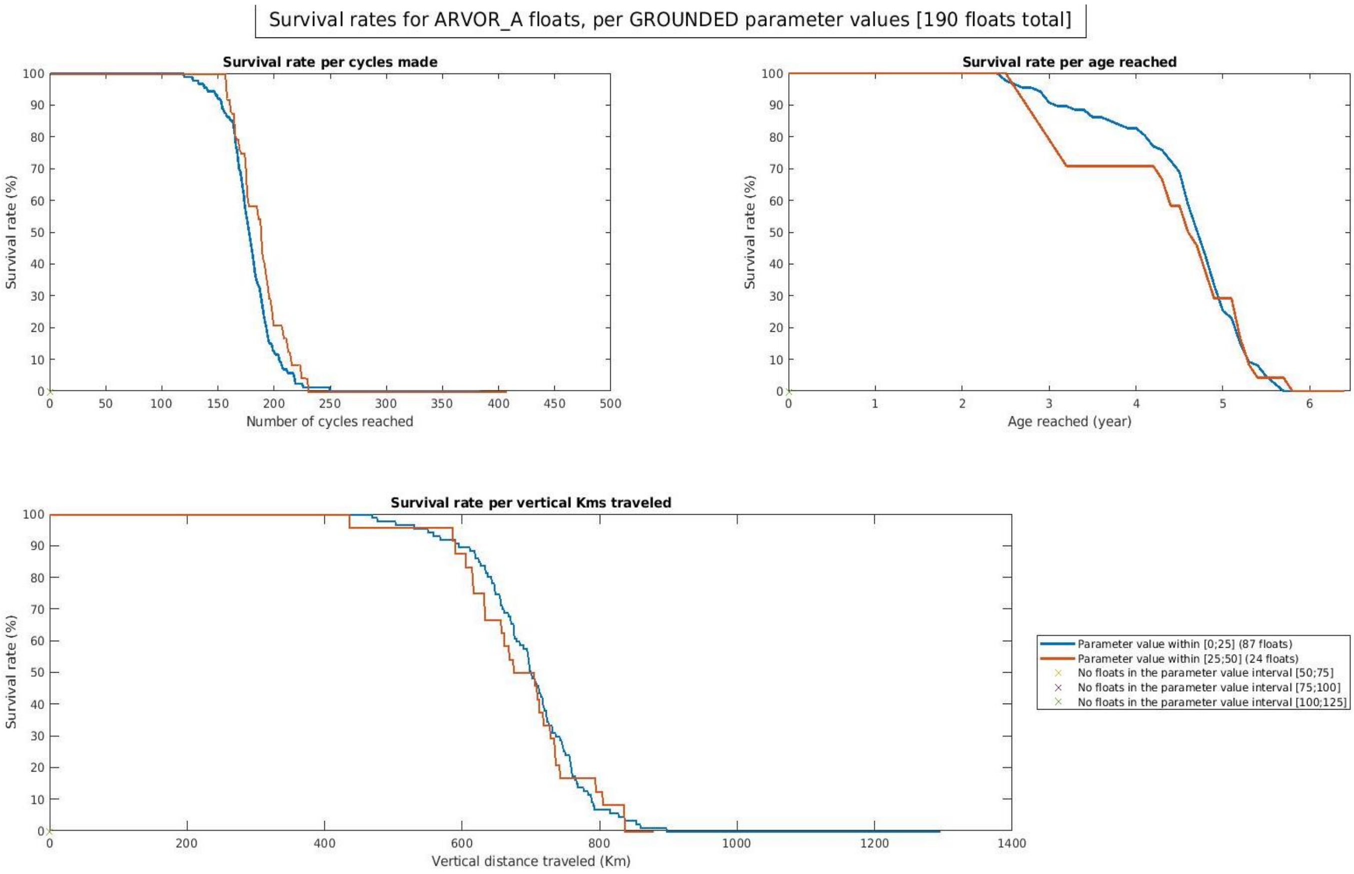


Figure 20 - Survival rates comparison for Arvor-A model depending on how many groundings occurred during their lifetime. The interval chosen to differentiate the samples is 25 groundings.

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[11] The only case where a grounded float will not automatically signify a lower maximum pressure is when a float grounds during a descent to park. With a "CONFIG_GroundingMode" = 0 it will shift upward and try diving again to reach its profile pressure. If it manages to do so without grounding again, it will reach a maximum pressure equivalent to the one reached during a normal cycle.

The same observations as in the Figure 19 can be made for the cycles made and the age reached. However, for the vertical distance travelled, the orange sample curve (floats that grounded between 25 and 50 times) does not present a better survival rate than before. The important number of groundings undertaken by these floats lead to an overall decrease of the vkms. The very few additional cycles that underwent the orange sample thanks to the energy saved with the groundings is not enough to balance out the vkms lost because of them.

Unfortunately, there are not enough floats in the different intervals for the other floats model than the Arvor-A.

- Most of the Arvor-L sample only grounded between 0 and 25 times.
- The Arvor-I sample is the model that experienced the most groundings. Unfortunately, since the sample of Arvor-I floats dead on battery exhaustion is small, higher number of grounding intervals were not composed by enough floats (i.e. more than 10) to derive robust and reliable conclusions from it.

To conclude on the groundings part, one can say based on the analyses provided before, that the repetition of groundings seems to have a **low, if not, inexistent impact on the overall energy budget** of an Arvor type float. The Arvor type float seems to manage nicely the grounding without inducing an overconsumption of energy. However, as shown in the Figure 20, a float grounding for an important number of cycles will, in the end, travel less vertical distance, hence gathering less data throughout its lifetime.

These conclusions are derived from survival rate curves computed for the Arvor-A model. Since the Arvor-I and Arvor-L model rely on the same operating principle and manage the groundings the same way, one could possibly extend these conclusions to these models.

The graphs shown above should be computed again in the following years, once the sample of the Arvor-I floats dead on battery level would be more important. These days, many Arvor-I deployed in Marginal Seas (Baltic, Adriatic, etc.) are grounding almost every cycle, hence providing in the future a more consistent sample for this float model and for high groundings intervals (>75 groundings/float). With a more consistent sample, some trends highlighted here might evolve and provide more contrasted conclusions.

Another aspect that could be considered is to **distinguish the cycle phases (descent to park, drift, descent to profile) in which the floats grounded**. A float that grounded one or several times in the descent to park or drift phases, and ultimately repositioned and reached the 2000dbar standard profile pressure, would have used more energy than a float that did not ground, or a float that grounded only during the descent to profile phase.

Although the Arvor float has been designed (hardware & software) to be able to survive groundings on the seafloor, a repetition of groundings might have a chance to damage the float and prevent it from performing normally. Some cases were reported by deployment teams where the floats lost their bottom hull and were unable to dive again after that (due to the loss of the weight ballast, located in the bottom hull). The chances that losing the hull because of multiple contacts with the ground are existing and NKE already analysed certain specific cases of unknown death where the float was probably damaged by groundings inducing its early death.

An idea to assess the impact of groundings on early death failure could be to gather all the floats dead of “unknown” and loss of ballast causes. Once this sample is containing enough floats, analyse the number of groundings they underwent during their lifetime. If all these floats have in common a large number of groundings, this could be linked to their early death failure and prove the fact that repeated groundings might damage a float.

This will only become possible in the future thanks to a more systematic and rigorous analysis and causes of death metadata “filling”.

This would be a **critical metric that permits to assess the overall health of the Argo array**. Work is ongoing between the Argo Vocabulary task team, Euro-Argo, OceanOPS, Argo experts and manufacturers to create a constrained fields index of causes of death to facilitate and widen this metadata gathering.

2. Number of repositioning

As it was presented before (Chapter IV.A.5) the repositioning during the parking (drift) phase is directly tied up to the configuration parameter defining the pressure tolerance stabilisation.

The survival rates graphs below were computed following different intervals, based on the sum of the repositioning undertook by the float throughout its life. The technical parameter recording the repositioning is named “NUMBER_RepositionsDuringPark_COUNT” and is a cycle-based parameter. If a float were to reposition itself multiple times during the same cycle, this parameter would record it.

Unfortunately for the Arvor-I sample, there were too few floats in the different intervals made, so no analyses will be conducted on this model.

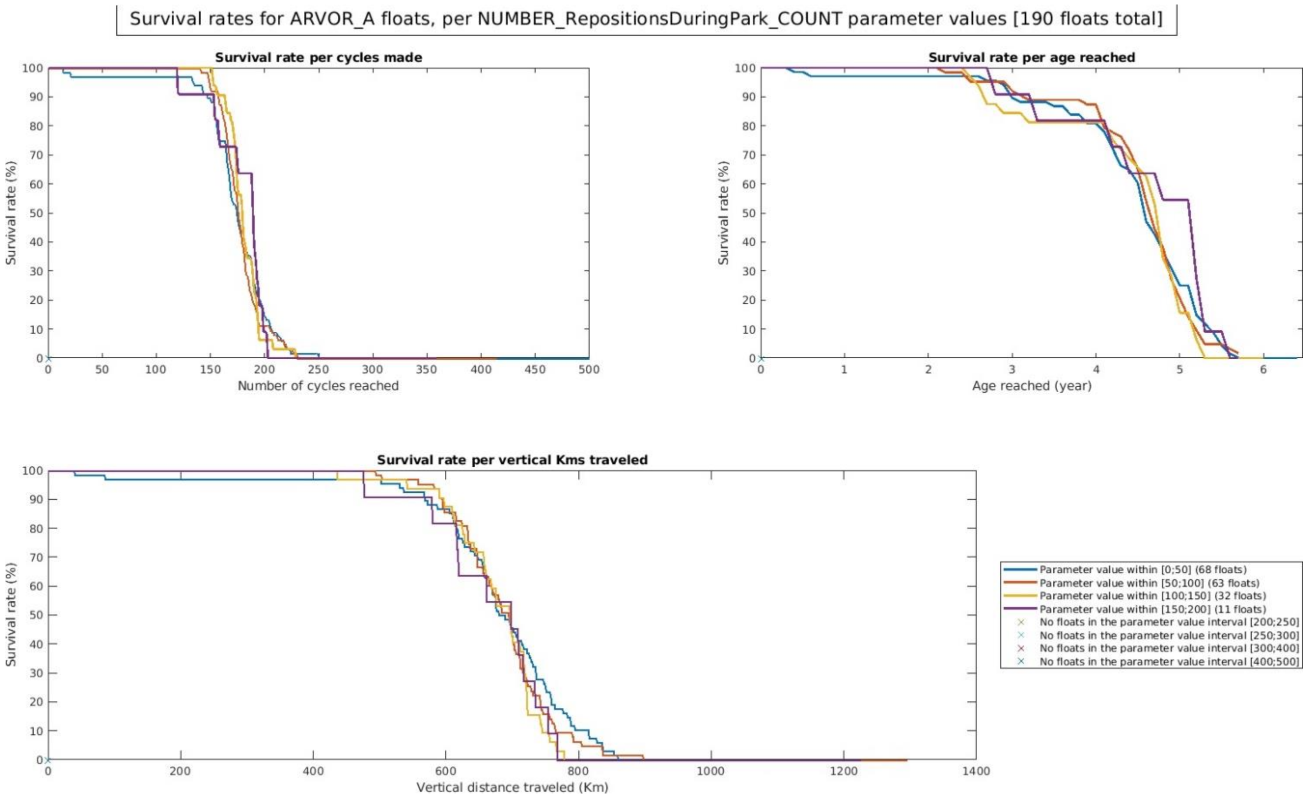

Figure 21 - Survival rate comparisons for Arvor-A floats, order per number of repositioning experienced throughout float's lifetime.

According to the graphs showed on the Figure 21 (Arvor-A) and the Annexe 9 (Arvor-L), the number of repositioning during parking does not have a clear impact on the float survival rates. When comparing the blue curve (floats that experienced the fewer groundings, between [0;50]) and the magenta one (floats that experienced the most, between [150;200]), no important impact can be highlighted. The only erratic behaviour observed (red ellipse) on the age reached magenta curve is associated to a single float event. Since the sample is pretty small, floats that survive longer have a strong weight on the curve trend and are associated with an important uncertainty.

Because the additional hydraulic actions induced by a repositioning during drift phase occur at the parking pressure, their energetic impacts are lower that if they occurred at the profile pressure.

The number of floats experiencing a high number of repositioning during park is not important enough to derive reliable conclusions from it. The following histogram presents the repartition of the number of repositioning the Arvor-A floats experienced throughout their lifetime:

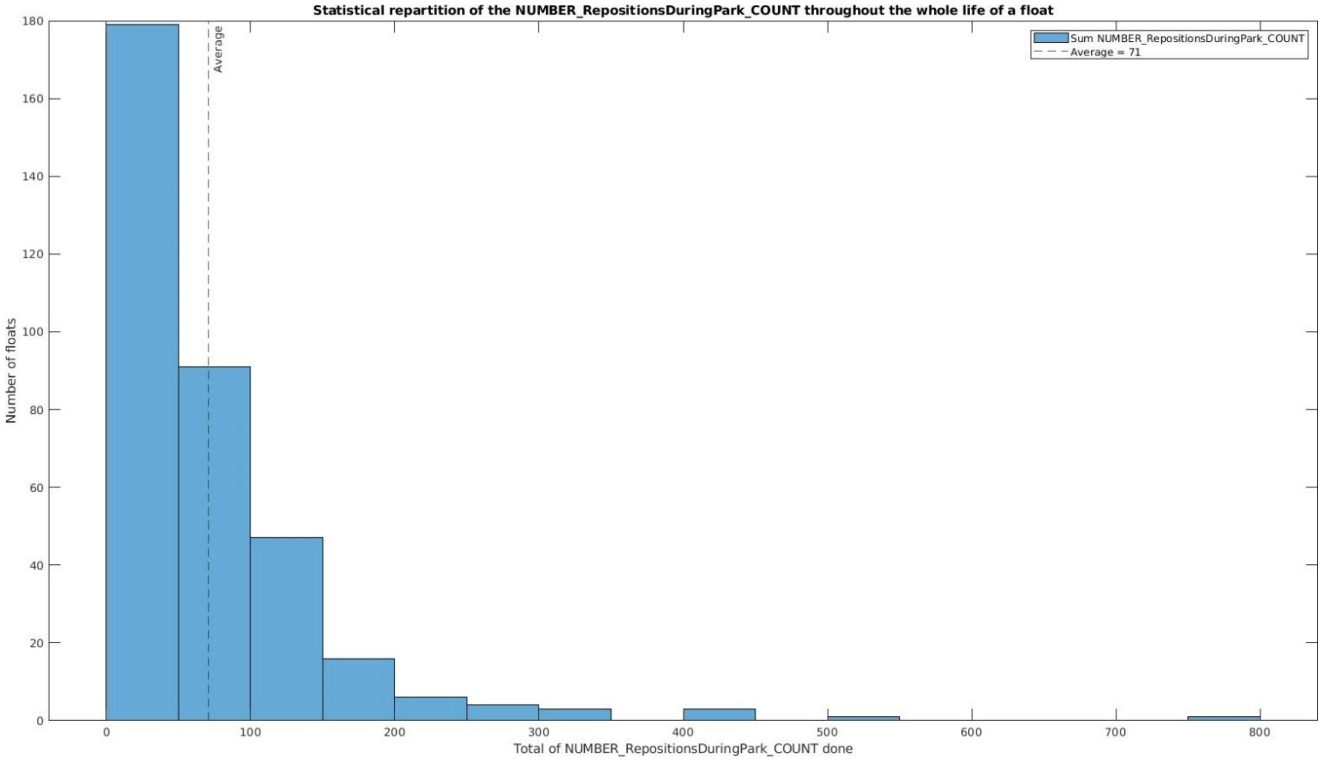

Figure 22 - Histogram repartition of the number of repositioning for the Arvor-A sample.

The majority of the sample experienced less than 100 repositioning during their life. However, some floats experienced an important number of repositioning (max = between [750;800]). The Figure 21 only compares floats that had, at a maximum, 200 repositioning.

Unfortunately, not enough floats (more than 10) in the sample experienced a high number of repositioning (>400) to be able to assess the impact of such a technical behaviour.

3. Hydraulic actions

For an Arvor/Provor platform type, the movement of the float is operated by a transfer of oil between two bladders, an internal one and an external one, thank to two pieces of equipment:

- **Pump action**: the oil transfers from the internal bladder to the external one, causing the float to ascend.

- **Solenoid valve action**: the oil transfers from the external to the internal bladder, causing the float to descend.

The most energetically costly action between these two actions is the pump one. The deeper a pump action is executed, the costliest it gets in terms of energy consumption. With these two pieces of information, it was decided to focus our analyses in the technical parameter recording the pump actions during a float's ascent ("NUMBER_PumpActionsDuringAscentToSurface_COUNT").

Most of the Arvor type floats have a number of pump actions during this ascent phase between 5 and 15 pump actions like shown in the histogram below (Figure 23). An increased number of pump actions could indicate: a problem with the pump efficiency; a float that became heavier (water intake for example, algae, etc.); a grounding; a float that has been stuck in soft material, suffering a suction effect after a grounding on a muddy bottom, etc.

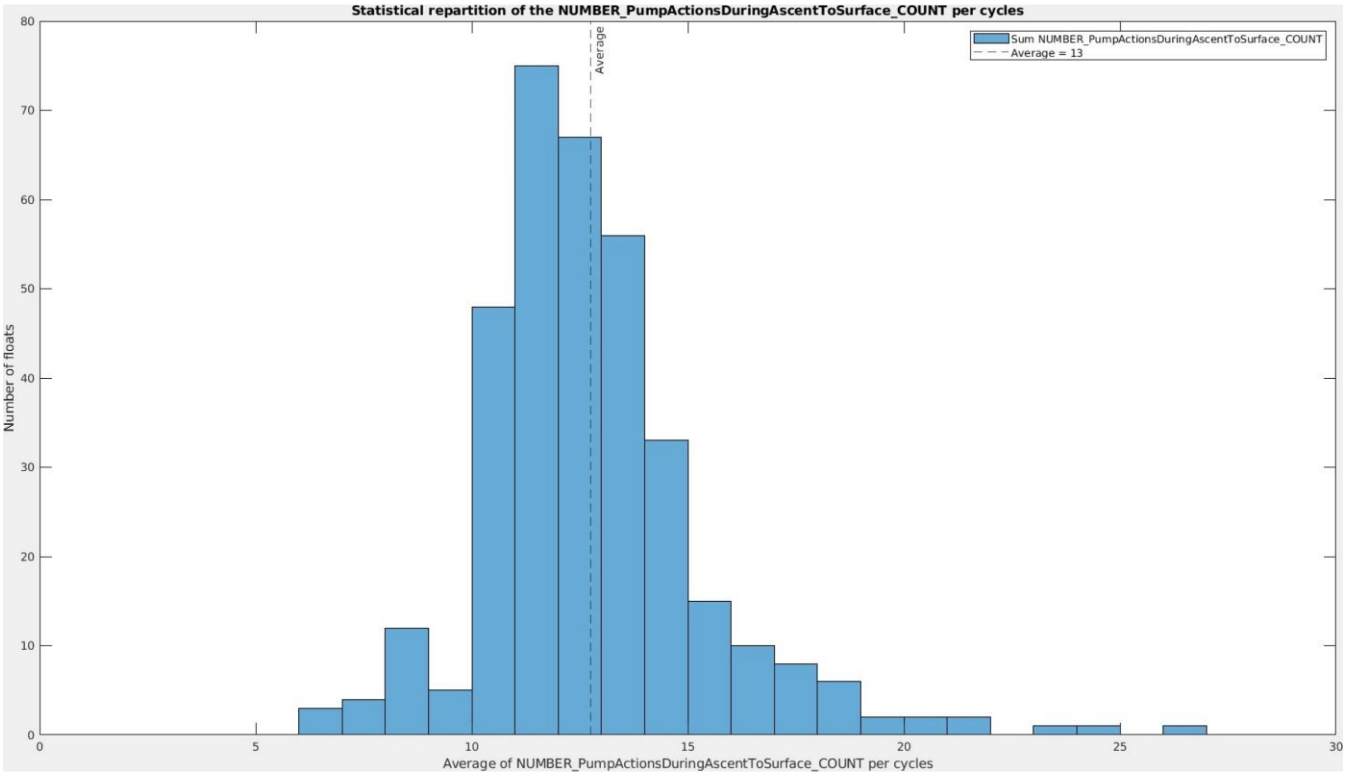

Figure 23 - Statistical repartition of the number of pump actions undertaken during the ascent phase.

By summing up the number of actions per cycle, we obtain the same histogram as presented above but with an x-axis corresponding to the sum of pump actions during a float lifetime (Annexe 10).

The following graphs present the survival rate comparison depending on the sum of the pump actions undertaken during the ascent to surface, grouped in different intervals (step is 500 pump actions).

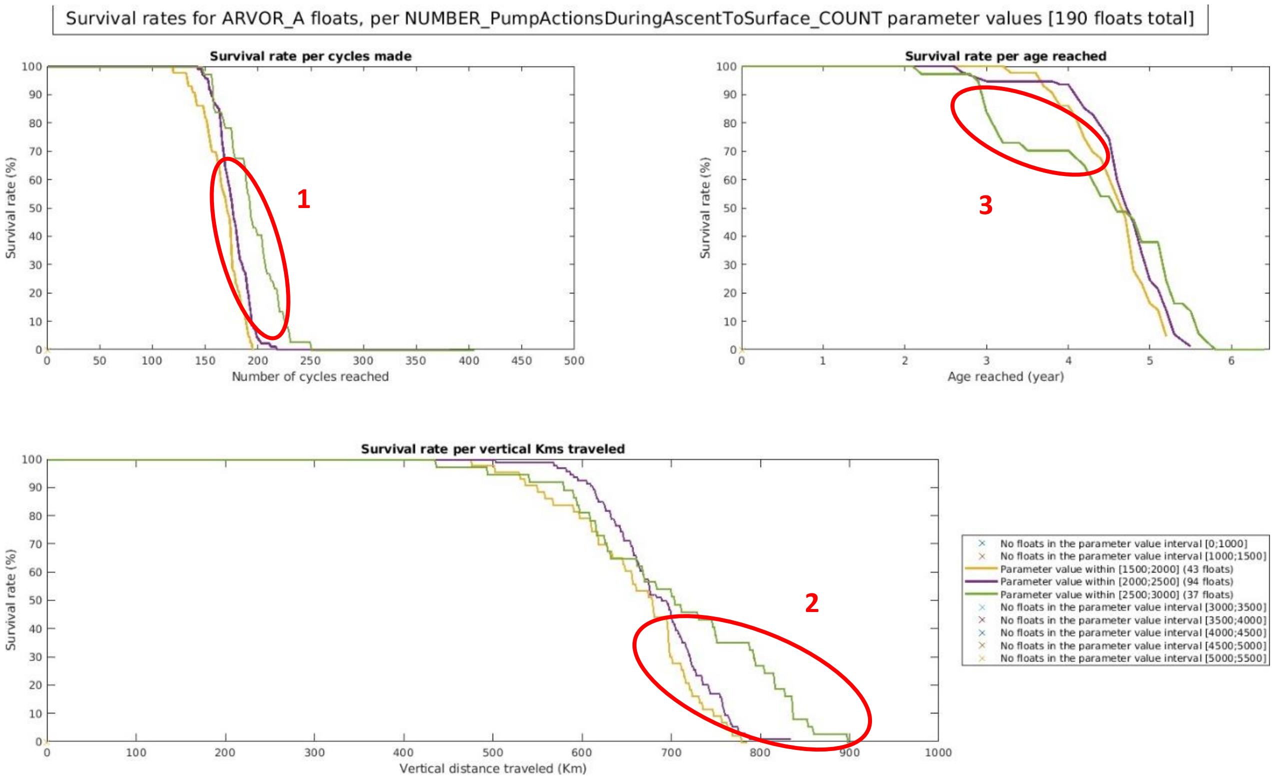

Figure 24 - Survival rates comparison for Arvor-A floats, depending on the sum of number of pump actions executed during the ascent.

Unfortunately, as we've already seen in the previous chapter, the other float models do not contain enough floats in the different intervals to make a comparison on survival rates. Even for the Arvor-A sample, the intervals with the higher number of pump actions (> 3000) are not represented because they contain fewer than 10 floats.

In the Figure 24 shown above, one can observe the same kind of trend as in the grounding chapter (Chapter B). It appears counter-intuitive that floats with a higher number of cumulated pump actions shows a better performance in terms of cycles made and vertical distance travelled (for 40% of them).

However, a better survival rate in terms of cycles made and vkms, paired with decreased performances in terms of age reached, is a situation that was already observed before and that is related to a slight part of the sample with a **shorter cycle time period** (c.f. Figure 19). In fact, when looking in detail, in the 37 Arvor-A floats composing the [2500;3000] pump actions interval, 28% of them had a 5-day cycle period.

These floats with a shorter cycle period are responsible for the additional 25/30 cycles made (red ellipse 1), the additional vkms travelled (red ellipse 2) and the decrease in performances in terms of age reached (red ellipse 3).

Without this proportion of faster cycling floats, this green curve ([2500;3000] cumulated pump actions interval) would have similar survival rate curves than the other two intervals. Since these intervals are close to the average of cumulated pump actions and the significantly higher intervals are not represented because of a lack of floats, the differences are not striking.

However, comparing a float with pump actions around 2000 and one around 5000 would be interesting.

Conclusion:

The main technical parameters identified in D2.1 that could have an impact on Arvor floats lifetime have been investigated. Some limitations of the analysis were due to the sample selection limit: too few floats were dead after battery exhaustion (sample still young), or had enough different values for the considered parameter. The study should be performed again in a couple of years.

From an energetic stand point, the **first analyses reflect that groundings of an Arvor float seem not to affect negatively its energetic consumption**. In fact, a float experiencing a grounding will, in most of the cases[11], reach a maximum pressure lower than during a normal profile. Its hydraulic actions will therefore be less costly and the amount of data collected will be smaller, also helping to reduce the energetic consumption during transmission.

However, the repetition of groundings could damage the float in the long term. A significant part of European floats experienced **early death failures**, that might be induced by repeated groundings (loss of ballast and bottom hull, etc.).

A more complete study and investigation about the impact of repeated groundings on a float performance should be provided in the future (looking up the phase of the grounding, the pressure at which it occurred, etc.).

Unfortunately, the sample did not contain enough float experiencing a high **number of repositioning** (>400) during their lifetime to really highlight the impact of such a technical behaviour.

Same as for the repositioning, unfortunately, the number of floats in the sample experiencing a lot more **pump actions** than the normal are not sufficient to draw conclusions.

These analyses should be done again in a couple of years, when more Arvor-I floats will be dead of battery exhaustion. Some of them deployed on the Mediterranean basins will help to derive interesting observations for some of the technical behaviour listed here.

IV. Case study in the Baltic Sea: main characteristics and best practices for floats deployments and recoveries

Most of the floats deployed in the Baltic Sea are recovered before the end of their batteries exhaustion. For this reason, the lifetime analysis for the floats on this area requires a different approach. It is equally, if not more so, important to estimate the possible lifetime of the float to be sure when it is prudent to recover the float; the options for recovery are typically tied to research cruises, which happen only few times per year on a given area, and in northern Baltic Sea the ice conditions may limit the possible recovery time even more. In addition the mission parameters can often vary, as the diving depth and frequency can be modified during the mission based on where the float moves, in order to constrain it to wanted location, or because a need to monitor a given event with higher frequency.

Recovery of a float needs to be planned well in advance also, because they often are in an EEZ of another country, so the permissions for the operation needs to be applied well in advance. This, and the rarity of the available missions often mean that the need to know whether the float is likely to survive at least half a year more is needed when making the decision of whether to pick it up, or wait for the next opportunity.

With the typical profiling cycle of 5-7 days the floats can rather safely operate for two years, and be recovered with some margin of safety.

Most of the floats deployed earlier on the Baltic Sea have been of Apex type, and had alkaline batteries. From these the depletion of power can be monitored moderately well based on the voltage drop.

Older floats, which do not detect the collision to bottom, consume easily extra energy trying to “drill” through the bottom. With newer software this is no longer an issue. When evaluating the energy consumption, both profiling frequency and depth are main variables that can be controlled to lengthen the floats lifetime when planning for recovery. Setting up the diving depth so that it ensures the bottom contact is also a method to ensure floats stay on the planned area for recovery, if there is a risk of it drifting away.
In the Baltic Sea, the salinity gradients can be steep. This can make the float decent be more energy consuming than the depth itself might suggest. Also, in some cases too sensitive bottom detection can stop the descent on a halocline.
The analysis on the Baltic Apex floats shows that while total control steps and profiling frequency are the most dominant factors on the battery consumption, more frequent profiling produces more profiles with the same energy, although with shorter total mission time. With floats that do not register bottom contacts well, the collisions with bottom consume a considerable amount of energy, as the float keeps adjusting its density on the bottom, thus adding to the needed control steps. (Figure 25).

With the typical profiling cycle of 5-7 days the floats used on Baltic Sea can operate for two years before being replaced. This gives enough space for planning the recovery. When the float recovery gets delayed for one reason or another, based on these analyses and earlier experiences, **the best way to extend the floats operation time for the next opportunity of recovery is to increase the profiling cycle period**. If the float is in an area where it is known to stay on set diving depth without collisions, that is ideal. If not it can be set deliberately to stay on bottom, to ensure it doesn’t drift to shore. This does cause some extra piston movements and thus consumes extra energy.

Experiences with the Baltic Sea floats studied, the **bottom contacts on Gotland Deep area and Bothnian Sea have only minor risk of the float getting stuck, Bothnian Bay has had some incidences where floats have got stuck on the bottom, which makes the contacts a higher risk strategy**.

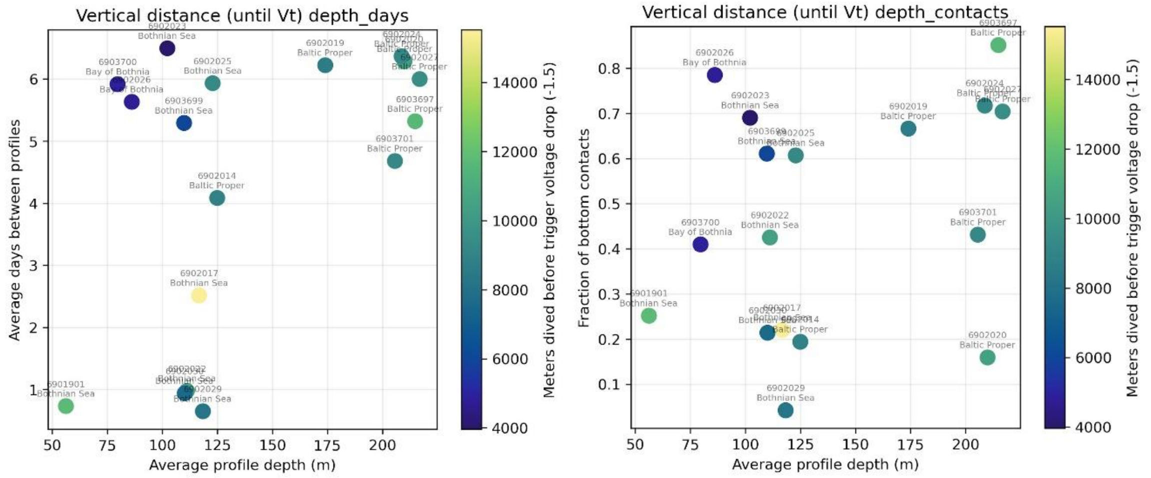

Figure 25 - Profiling cycle and profile depth. In shallower waters, less profiled meters are achieved with the same energy. More with increased frequency. On the right: Bottom contacts decrease the meters profiled, as they need more piston movements on the float.

V. Continuous at sea monitoring at OceanOPS

The methodology being developed and analyses carried out in the task 2.1 of the Euro-Argo RISE project showcase the importance of a continuous, in-depth fleet behaviour monitoring to estimate survival rates and performances of Argo floats model across missions, areas of deployments and configuration settings. This will continue on the OceanOPS website.

The computations of floats survival rates according to different x axis (age, number of cycles, vertical kilometres travelled, etc.) will be implemented in OceanOPS tools. Improved statistics and indicators on instrumentation on the dashboard will continue to be developed.

Being able to exclude recovered floats from the lifetime analyses is a key component when looking at float performances (and not only at the network refresh rates) and the audit carried out here will lead to a complete update of this metadata field in OceanOPS, together with the option to include/exclude recovered floats in the survival rates plots and metrics in OceanOPS.

Establishing an “ending causes” vocabulary to describe the possible reason why Argo floats have died was performed and this metadata field will be now populated by the Argo groups that have this information available. The use of this ending cause in the reliability, efficiency and performance plots and metrics of OceanOPS will be added. In particular the percentage of floats that have become inactive after battery exhaustion will be monitored.

Metadata is of crucial importance for at sea monitoring and regular audit and check for inconsistencies or missing information between OceanOPS and the GDAC will take place. The use of Euro-Argo fleetmonitoring tool APIs will greatly facilitate this work and will also give OceanOPS access to configuration and technical parameters of Argo floats, for possible use in lifetime studies.

VI. Conclusions

With the tools and methodology developed in this task throughout the duration of the project, Argo floats lifetimes and performances have been extensively investigated. Comparisons between models, deployment basins, Euro-Argo and international arrays have been performed. Observed at sea lifetimes, including for floats having exhausted their batteries, were compared to theoretical lifetimes provided by manufacturers or obtained from workshop presentations or reports. All these key figures have been summarised in Table 2 page 25, but will need to be updated as the Argo fleet become older.

For the CORE Argo mission, some float models present an overall poor reliability but are no longer deployed by European groups. Euro-Argo CORE fleet is relying mainly on the Arvor-I model which ranges in the top survival rates and keeps improving.

For the DEEP Argo mission, SOLO_D and SOLO_D_MRV clearly account for the best reliability of float models but are not used so far by European groups. Euro-Argo DEEP fleet is composed in majority of Deep Arvor and Deep Apex which present both a significant proportion of early death failures and a relatively short time of operation for the floats that worked until battery exhaustion, reflecting that the technology might not be fully mature and robust.

For the BGC Argo mission, the most reliable model is the PROVOR_III (NKE CTS4), with a very few premature losses and an important number of cycles, vertical distance and age reached despite a significant number of floats cycling faster than the standard 10-day period. This model is largely used by Euro-Argo. Performances need to be kept monitored with new models arriving in the market and the wide range of sensors and floats configurations implemented in this network.

Survival rates comparison between the two major Euro-Argo missions, Open Ocean and Marginal Seas, were conducted and highlighted that Marginal Seas floats achieve more cycles, last less time active (inducing the need for more frequent deployments to keep the array operational), seem to present more important early death failure rates that could be due to the environment where they have been deployed (beaching, fishing, currents, grounding, etc.), but present quite similar performances in terms of vkms travelled compared to Open Ocean floats once the early death failures phase is passed. These aspects could be of interest for the implementation of the Euro-Argo strategy that will be revised in the project.

An in-depth study to examine the potential impact of key configuration parameters and technical behaviour on float’s survival rates has been carried out. Close attention was paid to the sample selection to try to derive meaningful conclusions, avoid artefacts from interrelated parameters, yet gather enough floats to make significant comparisons. Preliminary steps to reliably identify floats that were recovered and floats that had become inactive after battery exhaustion have been essential and require significant work. This was done on the European fleet only for the recovered floats, and for the NKE float models for the battery exhaustion since it requires good knowledge of the behaviour (which was not the case for other models).

However with the study we could not conclude that a specific configuration parameter had an impact on Arvor floats lifetime: few floats were dead after battery exhaustion (sample still young), or had enough different values for the considered parameter, or kept the same value for all the float mission. An interesting outcome of the study was it permitted to estimate the observed number of cycles performed for floats dead on battery level, that were summarised in Table 2.

The possible impact of technical parameters and floats behaviour on survival rates was also examined. Again we could not conclude, at present time, that the investigated parameters (grounding, repositioning, pump actions) had a significant impact. These studies should be performed again in a couple of years.

We aim to investigate further the case of groundings, as a possible impact on early deaths failures, and for the case of battery exhaustion looking more closely at the different cycle phases where the floats grounded.

Case studies such as in the Baltic or Mediterranean Seas will be further extended to infer best practices for float deployments and recoveries.

All the work carried out in task 2.1 strongly relied on good metadata filled both at OceanOPS website and in the Argo netCDF on the GDAC. Audits permitted to detect issued that are now corrected. Checks for inconsistencies or missing metadata will be performed.

Eventually float lifetimes and performances will be continuously monitored, and enhancement of OceanOPS tools and metrics will enable the tracking and use of key metadata (recovered floats, ending causes) and configuration or technical parameters.

GLOSSARY

- **AIC:** Argo Information Centre
- **Arvor-I:** Arvor float, equipped with an Iridium telecommunication type.
- **Arvor-A:** Arvor float, equipped with an Argos telecommunication type.
- **Arvor-L:** Arvor float, equipped with a lighter battery pack and an Argos telecommunication type.
- **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
- **EEZ:** Exclusive Economic Zone
- **Efficiency:** The relationship between the amount of energy that goes into a machine and the amount that it produces. [source: Oxford Academic English Dictionary]
- **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 (now OceanOPS):** Joint technical Commission for Oceanography and Marine Meteorology in situ Observations Programme Support Centre
- **KNMI:** Koninklijk Nederlands Meteorologisch Instituut

- **Life expectancy:** In the frame of this deliverable, it is a statistical computation referring to the number of years a float or group of floats can be expected to live.

- **Lifetime (of a float):** It is derived from the survival rate computations and defines how well a float is performing at sea, often compared to its theoretical lifetime provided by the manufacturer.

- **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)

- **Performance:** How well or badly something works. [source: Oxford Academic English Dictionary]

- **PI:** Principal Investigator

- **Recovered floats:** Are defined as such, floats with a metadata status on the AIC (see below) filled in as "recovered", plus additional ones that were determined in a preliminary work for this study (c.f. Chapter I about Recoveries).

- **Reliability:** The quality of being able to be trusted to do something well; the quality of being able to be relied on. [source: Oxford Academic English Dictionary]

- **Survival rate:** It is the proxy used to estimate a float performance, in terms of: cycles made, age reached (years) and the vertical distance travelled (kilometres). It expresses the % of floats that reached a certain number of cycles/years/kms. For more detailed information on the survival rate of a float sample, how it is computed, please refer to the Deliverable 2.1 of the EA RISE – WP2 task.

- **WMO:** World Meteorological Organization

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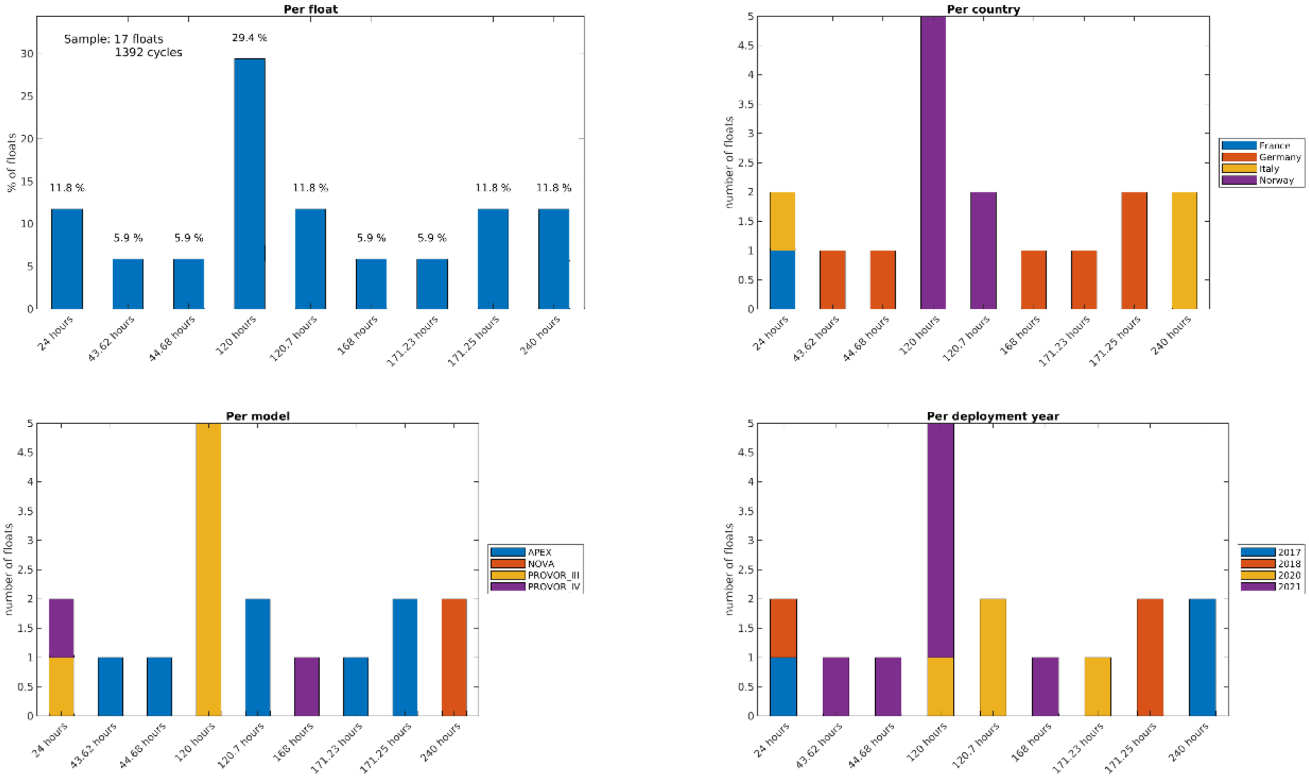
ANNEXES

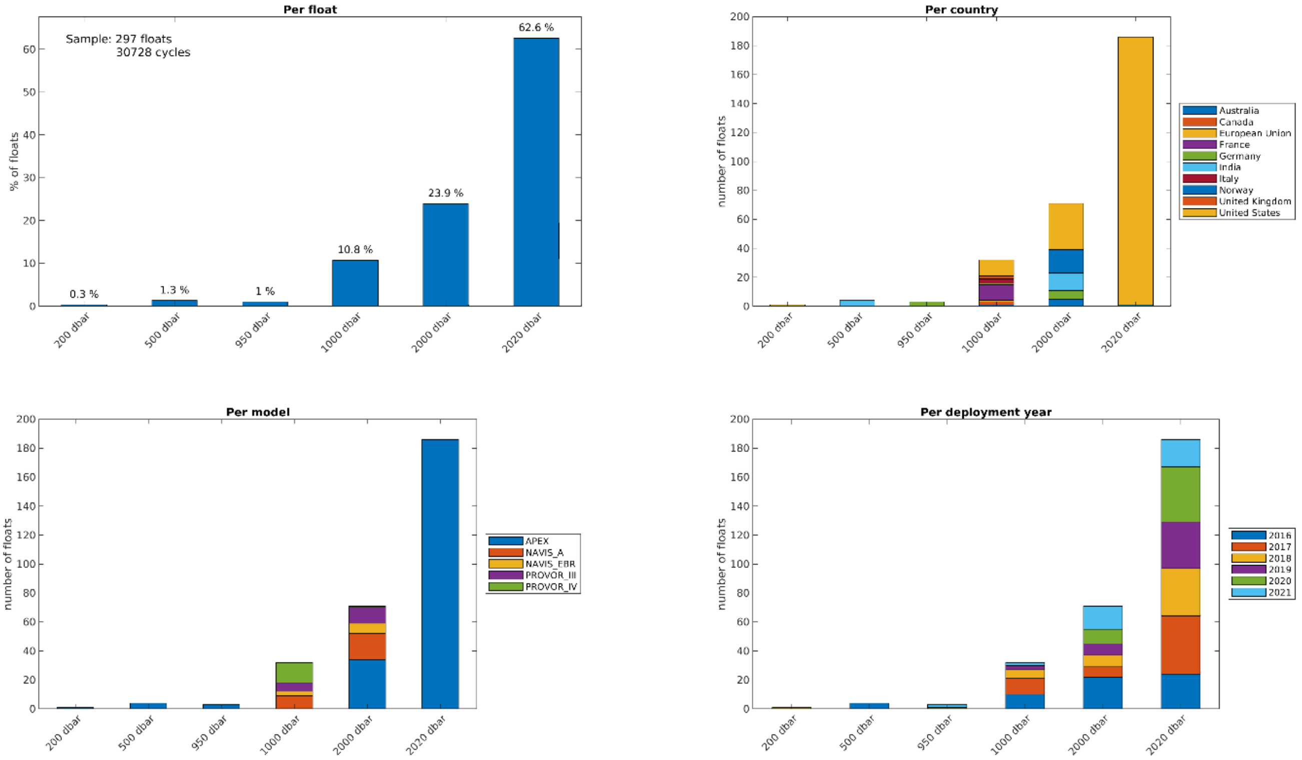
1. *BGC Cycle Time period*

CONFIG_CycleTime_hours for not changed floats



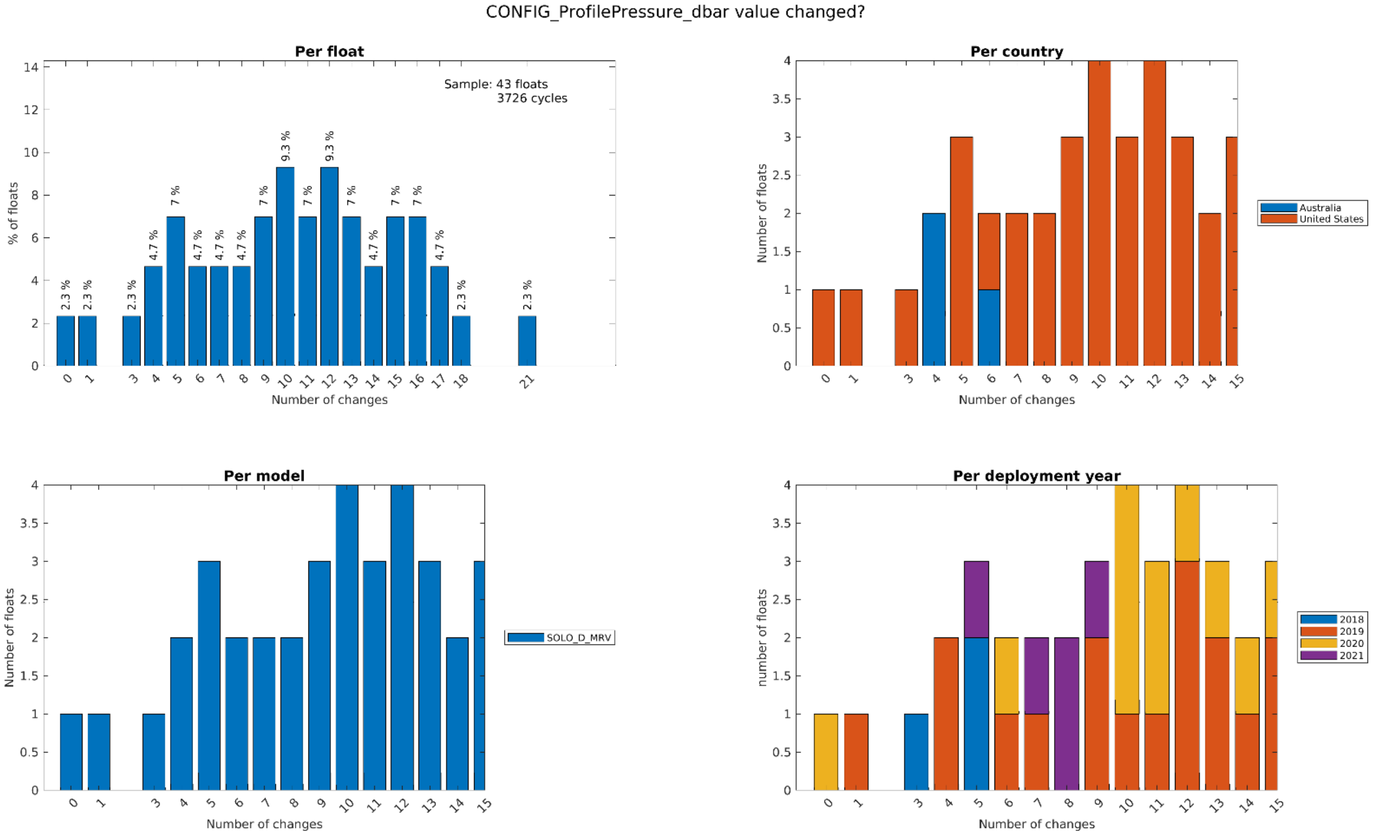
2. *BGC Profile Pressure*

CONFIG_ProfilePressure_dbar for not changed floats

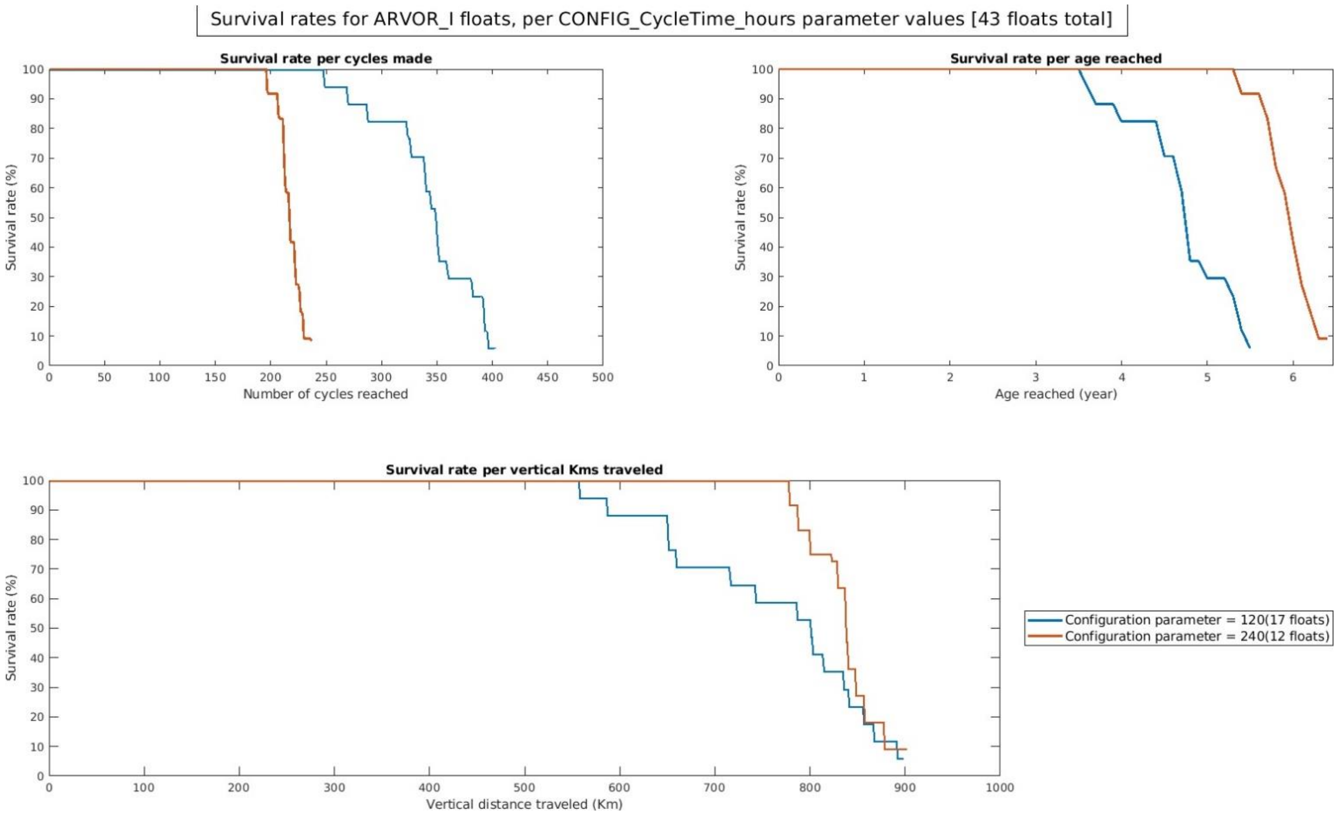


3. *ARVOR and APEX DEEP float models*

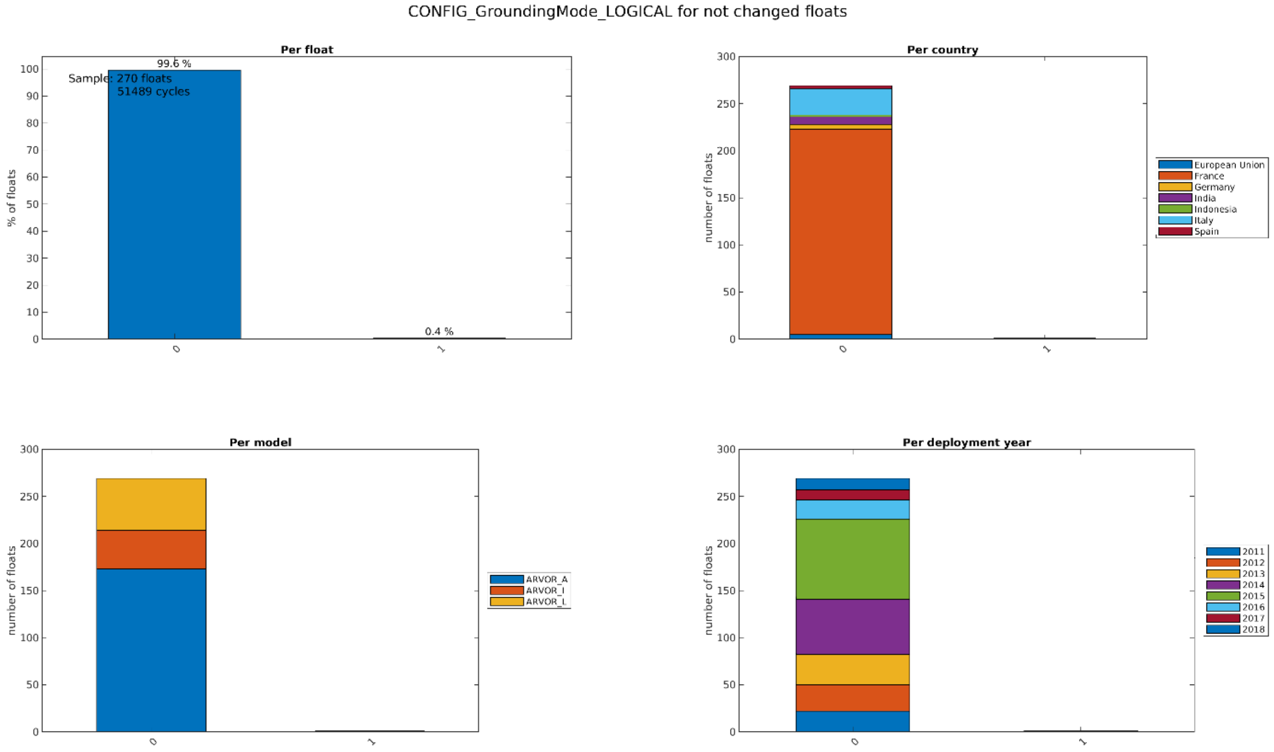
4. *SOLO-D MRV number of configuration changes*



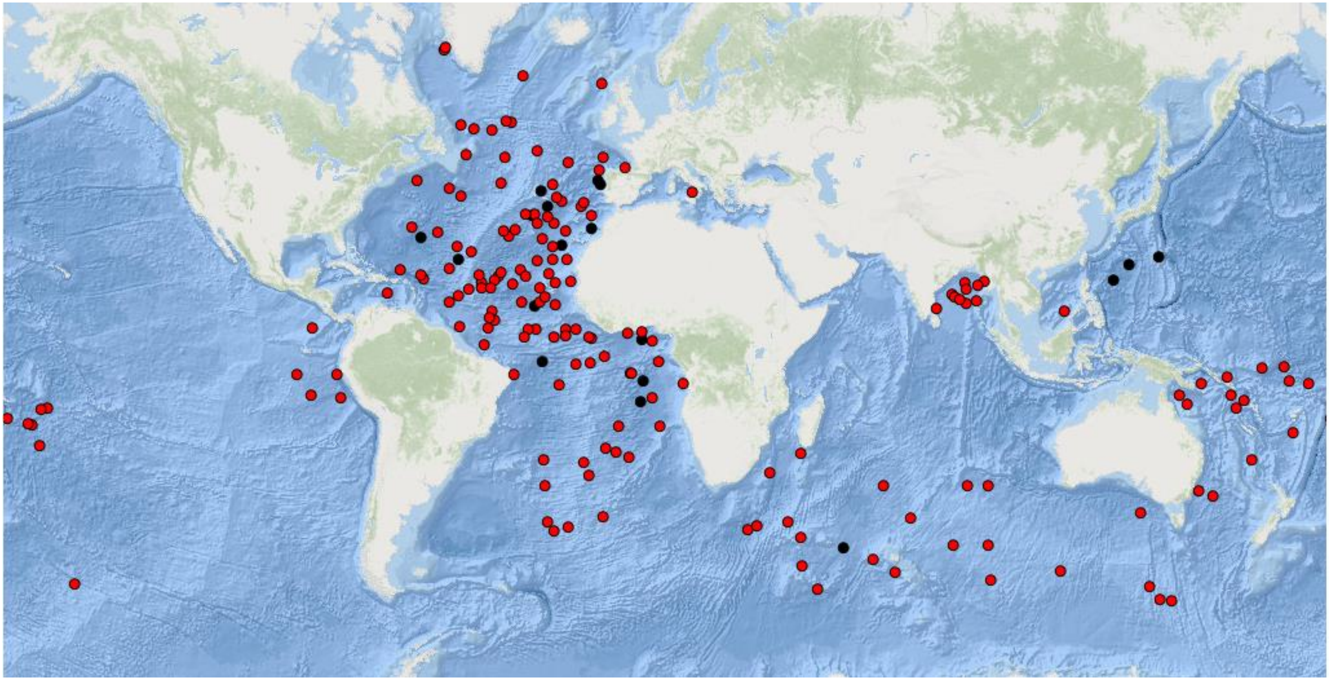
5. *Survival rates for the Cycle Time period on Arvor-I*


Survival rates for ARVOR_I floats, per CONFIG_CycleTime_hours parameter values [43 floats total]

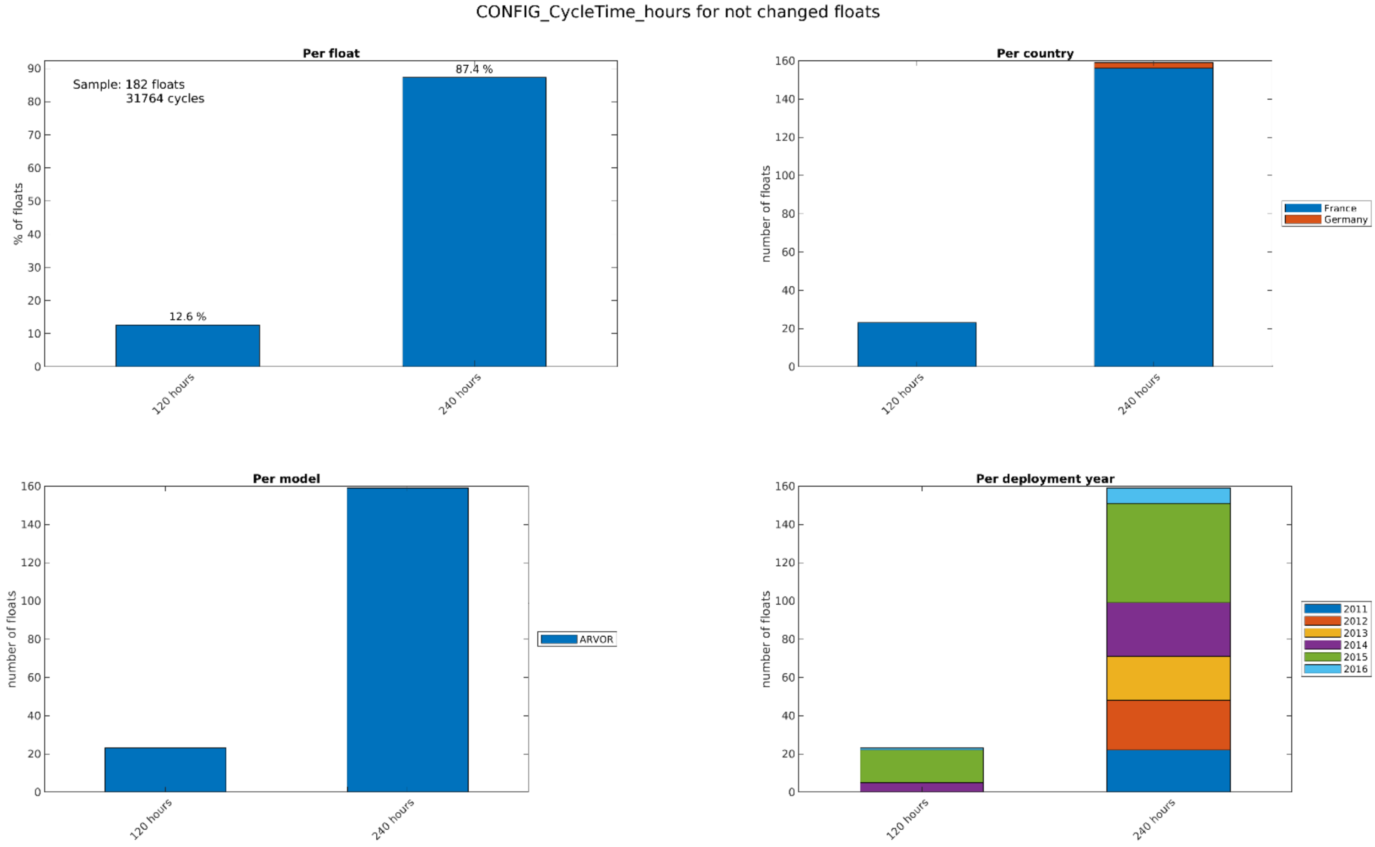
6. *Context on grounding mode parameter*


CONFIG_GroundingMode_LOGICAL for not changed floats

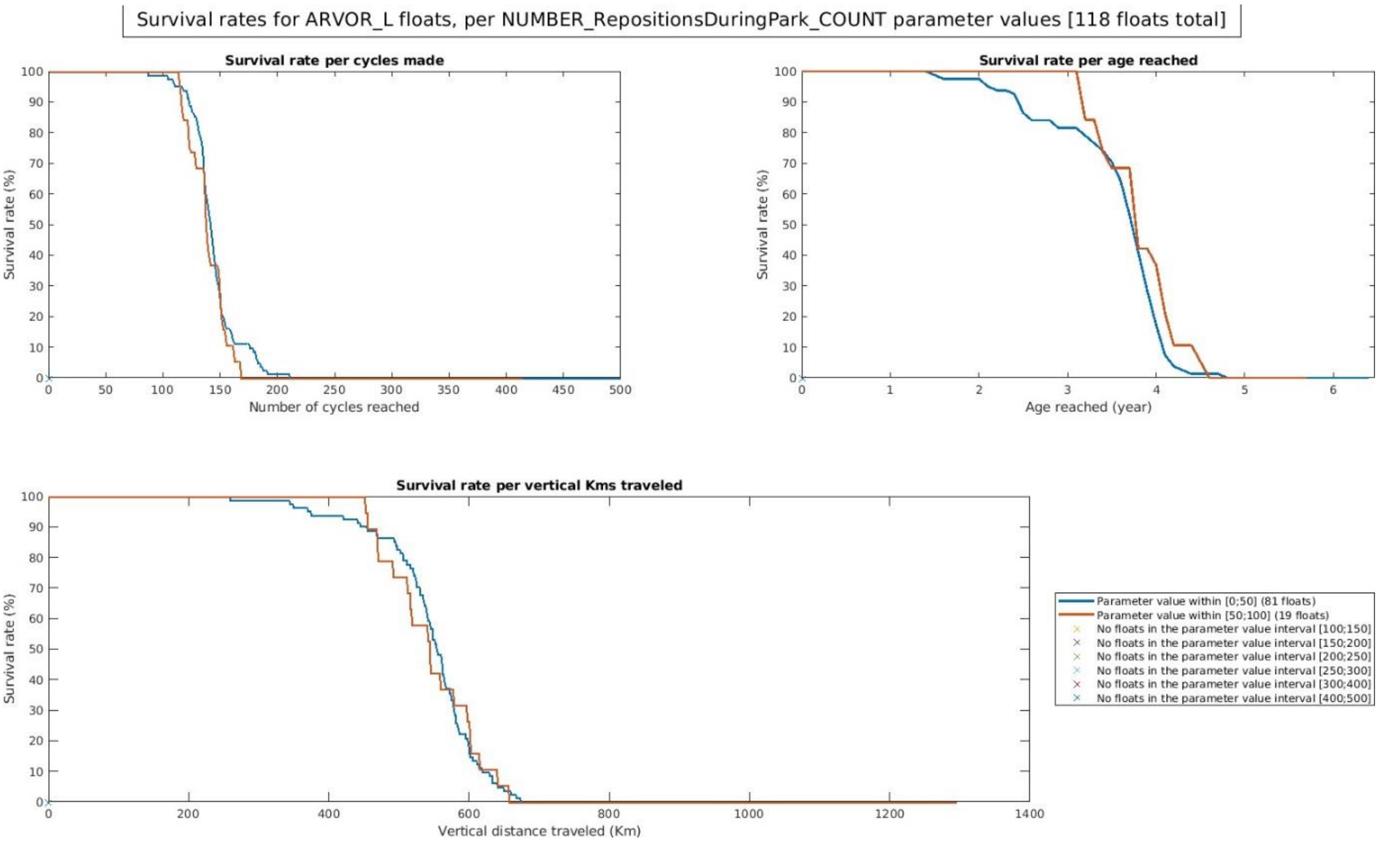
7. Deployment positions for the 190 Arvor-A floats dead from battery exhaustion



8. Config fleet status on the 190 Arvor-A floats, for the Cycle Time parameter



9. *ARVOR-L survival rate comparison depending on the number of repositioning experienced*



10. *Statistical repartition of the sum of pump actions during ascent during an overall float's lifetime*