Failure modes for the Australian floats.

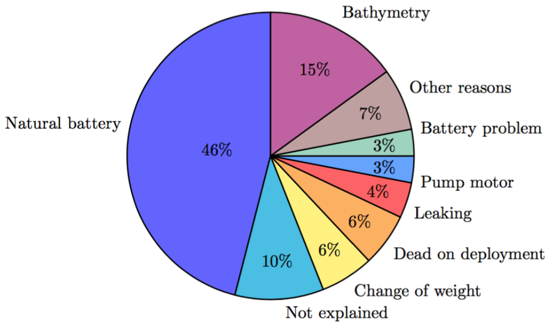
June 16th, 2017

Benjamin Briat

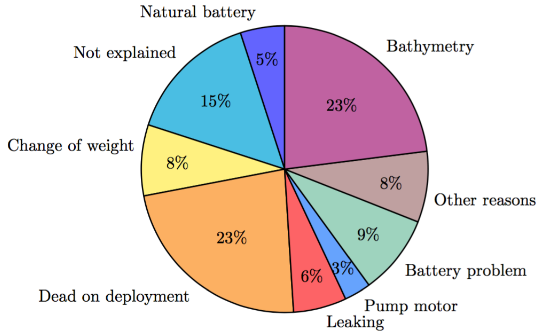
Contents

2 *Situation for the Australian floats*

Reason of failure	Nb of floats (all profiles)	Nb of floats (<100 profiles)
Natural battery	148	4
Bathymetry	49	19
Change of weight	20	7
Dead on deployment	19	19
Leaking	13	5
Pump motor	10	2
Battery problem	10	8
Under ice	9	7
Pressure sensor	8	1
Software error	3	1
Piston position	2	1
Air bladder	1	1
Not explained	28	13
Total	**320**	**88**



All floats considered.



Early deaths considered.

1 Abstract

The investment, human and financial, in a launching of a float is consequent. Then, in case of failure at an early age, a vast amount of time, money and motivation is wasted. That is the reason why it is crucial to get a clear idea on the life expectancy of a float.

This presentation aims at characterizing the main failures of the ARGOs floats. The death of a float can have different sources, and it is important to know what happens in order to have a particular solution for each problem. Because they evolve in the oceans, it is crucial to separate the reasons into two categories:

- **Manufacturing defect:** battery failure, piston position trouble, pressure sensor defect.
- **Environment:** presence of ice, increase of weight after grounding.

In this presentation, every source of problem will be developed by considering the data received at the lab.

2 Situation for the Australian floats

2.1 What kills a float in the long term?

Natural death

The natural end of life of a float should be due to a **low power of the battery**. Indeed, because it is the only source of energy of the float, if the power delivered is too low the float won't be able to work properly: the pump motor will need to work longer in order to reach the same piston position and during the last cycle, there won't be enough energy to move correctly the piston. Usually, the voltage starts being critical after hundred of cycles, which permits to the float to live long and give a lot of data to the lab.

Because the float follows the marine current, another natural death is the **bathymetry**. It is common that the end of life occurs on a shoal: after a grounding event, the characteristics of a float can change (especially the weight) or it can be stuck at the bottom of the sea.

Accidental death

However, a large number of floats die before having a low voltage, this is important to understand what happen to these ones. The main reasons are represented on table page 2 and will be explained through this report.

3 *Disappeared on deployment*

Name of the vessel	Type of vessel	Floats deployed	Failed floats	Failure rates
Lady Amber	Sailing	65	5	8%
Southern Surveyor	Scientist	57	3	5%
Investigator	Scientist	42	1	1.5%
HMAS	NAVY	56	1	1.5%
Aurora Australis	Scientist	182	2	1%
Kaharoa	Scientist	96	1	1%
Astrolabe	Scientist	45	0	0%

Table 1: Comparison of the failure rates between the different vessels used by the Australian floats.

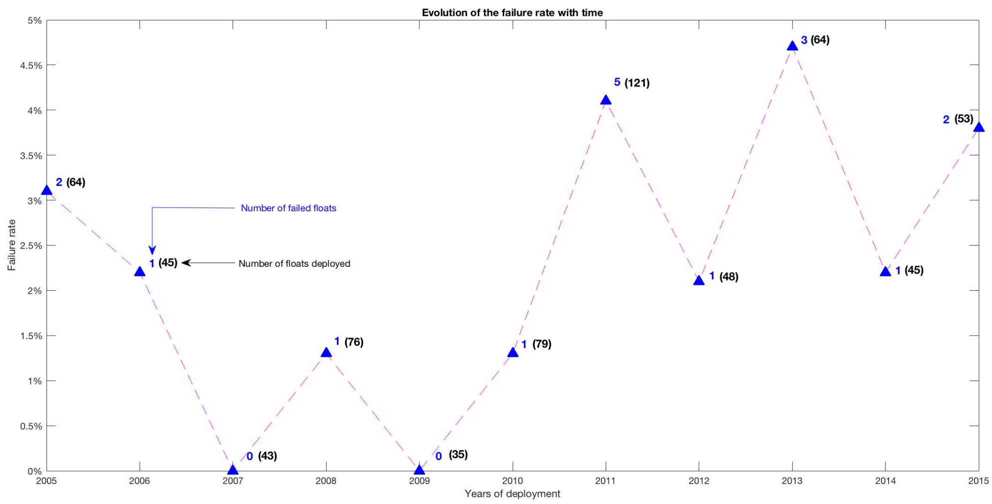
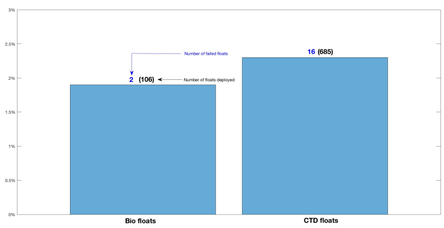
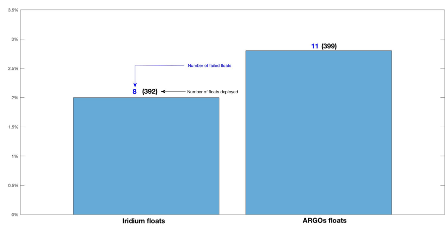


Figure 1: Evolution of the failure rate with time



Comparison between
BIO and CTD floats.



Comparison between
ARGOs and Iridium floats.

2.2 What destroys a float at an early age?

According to the ARGO website the expect life of a float is 150 cycles, then only the floats that died before 100 cycles were under study in this section. All in all, 91 Australian floats over around 800, have not reached the 100 cycles turn. That means about 10% of the floats die at an early age.

As pictured on page 2, the death at an early age are explained by a few different parameters, but their repartitions are different with the floats that live long.

3 Disappeared on deployment

There are several floats that don't transmit any data, that means they did not manage to take one cycle properly. For these ones, it is possible to guess the reason from the conditions of launching, and commonly this is a problem of :

- **Fail at launch:** if the float is not launched by a scientist vessel, failure rates are often more important because the design of the boat doesn't fit perfectly with the oceanography requirements. Indeed, as it is possible to get on table 1, the failure rate depends directly on the kind of vessel used: the float design is a key aspect for the success of a launch.
- **Passivation of the battery:** lithium batteries must be activate from time to time, if the period of storage is too long, it is common to have a failure on the float. Indeed, on the previous table, the higher failure rate is in the Lady Amber vessel which is propulsed by wind, that means it is slower and the risk of passivation is higher.

Especially, the evolution of the failure rate through time, tackles another crucial issue. Indeed, clearly on figure 1, the failure rate has increased during the last ten years. That means, the floats are less trustful, which is unnatural. It is important to feedback the builder of this trouble.

In order to fix this failures, it is better to launch the floats from a scientist ship and to activate the floats from time to time during the storage.

4 *Battery failures*

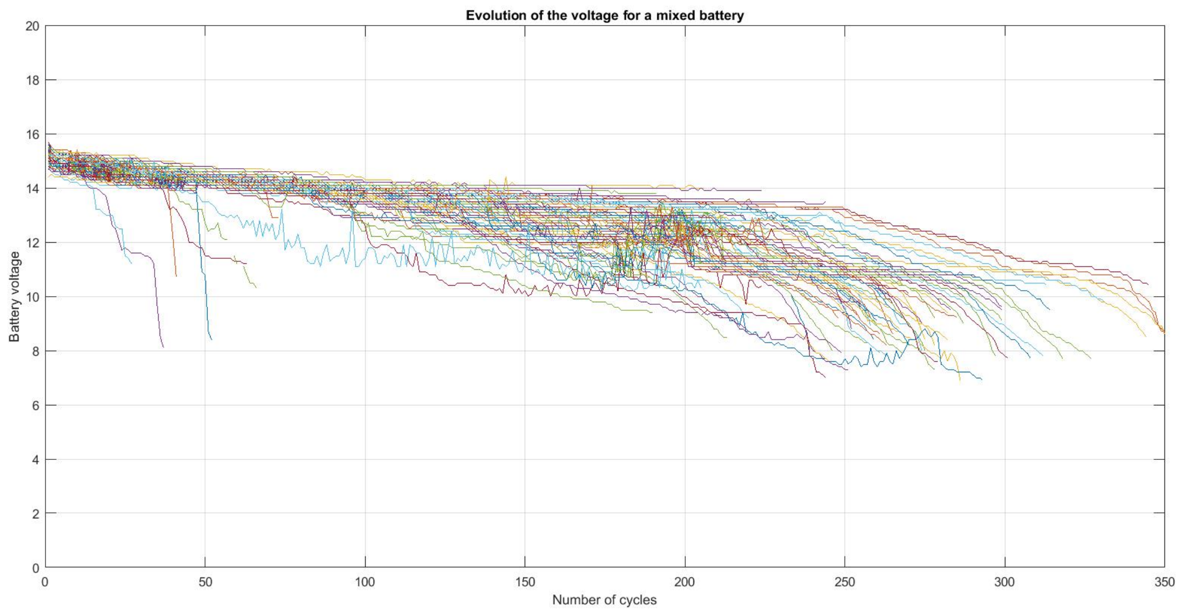


Figure 2: Detection of battery failures from an average approximation.

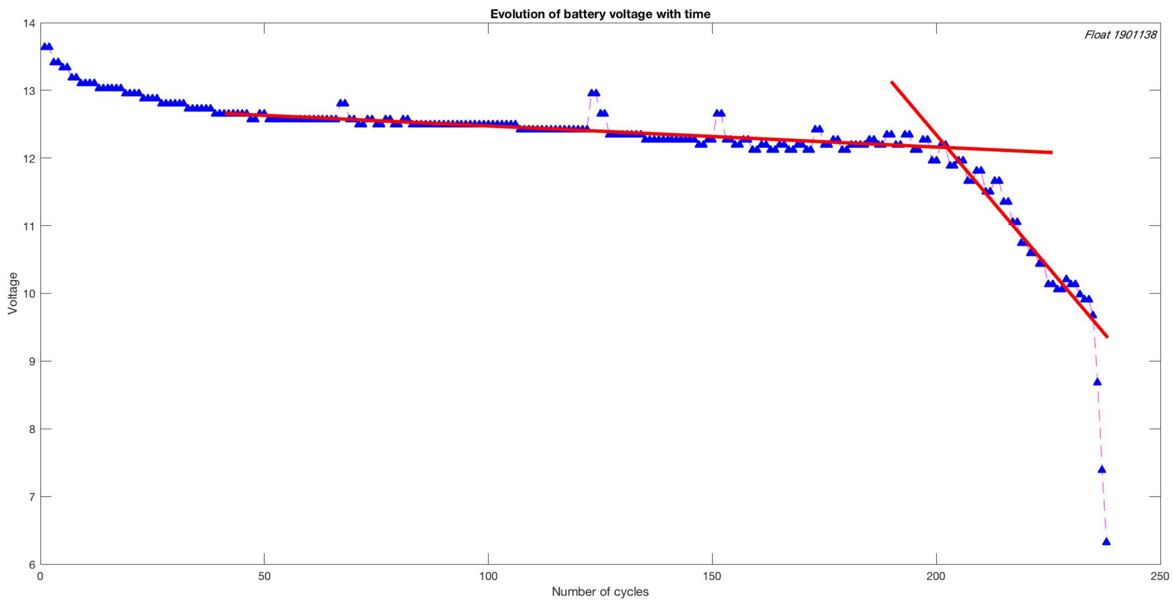


Figure 3: Detection of battery death from a characteristics evolution of a battery.

4 Battery failures

Because the battery is the only source of power, if the voltage starts being critical, the float will not be able to survive for a long time. Crucially, a battery failure needs to be recognized. In order to do it, two main reasons must be considered separately.

4.1 Different measurements of the battery power

First and foremost, several measurements can be under study, they all refer to the same battery (usually the battery support is a pack of five) but permit to know its status at different stages of the cycle.

- **Main battery**
- **Park battery:** battery status at parking.
- **SBE pump battery:** battery status after activation of the CTD profiler.
- **Buoyancy pump battery:** battery status after the use of the pump motor.
- **Air pump battery:** battery status after inflation of the air bladder.

If the evolution of this previous values are not the same, that means there is a problem of energy transmission elsewhere. Then it is important to plot all the different measurements.

4.2 Manufacturing defect

By plotting the battery voltage in function of the number of cycles for each type of battery, it is possible to emphasize a failure due to a manufacturing defect. Indeed, at an early age, the majority of the floats follows the same path, and so, if a float has an evolution at a low voltage, this is certainly due to a manufacturing defect.

Seemingly on figure 2, there are several floats that quit the main path at the beginning and they all failed early.

4.3 Analysis of failure rates for the Australian floats

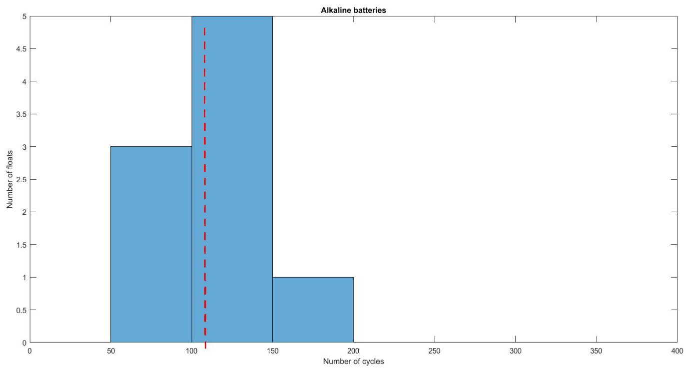


Figure 4: Histogram of life expectancy for alkaline floats.

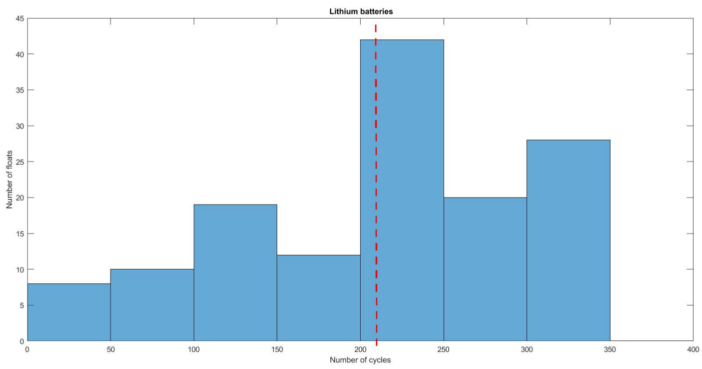


Figure 5: Histogram of life expectancy for lithium floats.

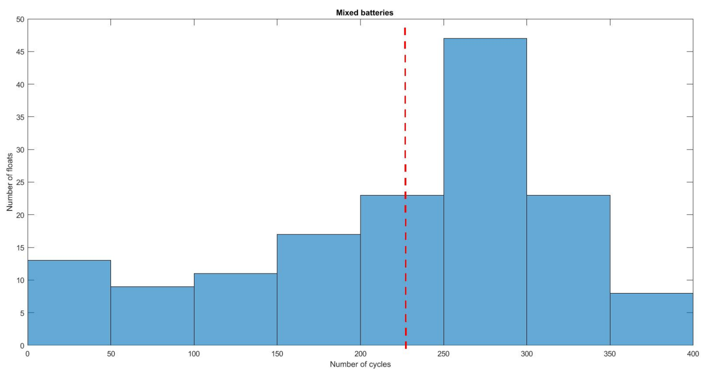


Figure 6: Histogram of life expectancy for mixed Alkaline-Lithium floats.

4.3 Natural death

The other main reason of battery death is directly linked with the natural decrease of power. As it is possible to see on figure 5, there are two different periods in the life of a battery:

- **Step 1:** slight decrease, when the battery is used, the stocked power decreases.
- **Step 2:** significant loss of voltage, at that time, more and more cells disappear and the clock is ticking. Indeed, when an element of a pack gets a voltage around 3 Volts, the chemical reaction doesn't deliver power. Usually, there are 4 elements in each battery so the death of only one doesn't kill the entire float, but can be detected on the power plotting. Indeed, when an element goes missing, there is a step in the power function of 600 mW, corresponding at 3 Volts (the minimum voltage before collapse) multiplied by 200 mA (current delivered at this voltage).

By plotting the battery power in function of the number of cycles for each float, it is possible to get the life status of the float: if the evolution starts being non-linear, commonly the life expectancy is limited.

4.4 Analysis of failure rates for the Australian floats

Considering all the Australian dead floats, it is possible to establish a failure rate for each type of battery. In order to understand with more precision what happens in reality, the floats have been grouped by number of cycles before death on figure 4, 5 and 6. Then, for the different types of battery, the result is altered:

- **Alkaline battery**: lots of failures at an early age, and few floats manage to live long. This is the reason why they have been dropped.
- **Lithium battery**: the average life expectancy is around 200 cycles.
- **Mixed battery** : the average life expectancy is around 230 cycles, and by fixing a certain number of failures at an early age, it could be slightly better.

Arguably, in order to increase the efficiency of the floats, the use of mixed batteries seems judicious because the failure rate is lower and the life expectancy is higher.

5.2 Diagnose a piston position problem

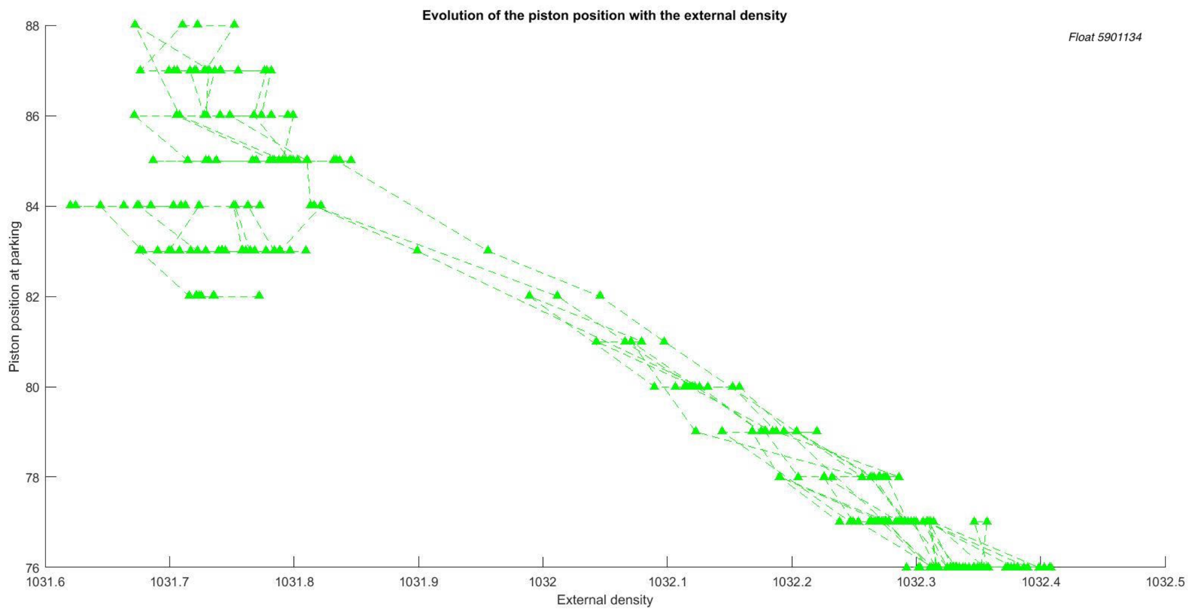


Figure 7: Evolution of the piston position with the external density for an healthy float.

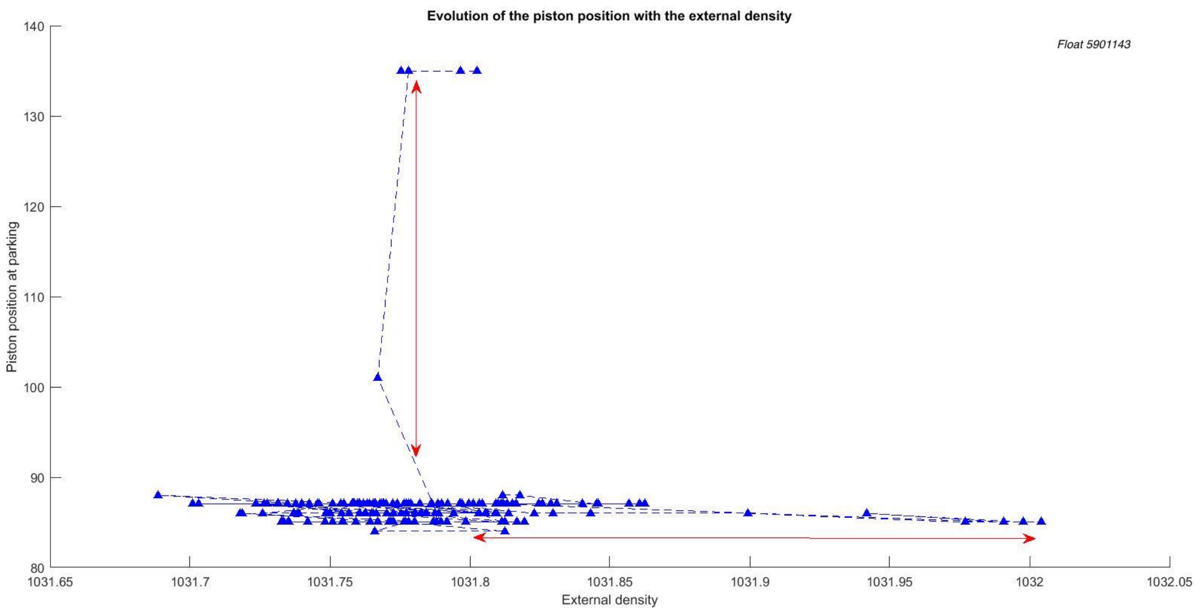


Figure 8: Evolution of the piston position with the external density for a failed float.

5 Piston position trouble

Another key element of a float is its piston because it permits to create the movement by controlling the buoyancy. If the piston position changes with no apparent reason, it would probably be a source of failure.

5.1 Understanding the piston position

In order to point out a trouble of buoyancy for the float, it is important to understand properly how the piston moves.

The higher the piston position is, the higher the buoyancy is.

Then, it is possible to read this sentence in two ways:

- For the same external density, if the piston position gets higher, that means the buoyancy needs to increase, the float weighs more: it could be due to a problem of leak or a gain of weight.
- For the same piston position, if the external density evolves, that means the characteristics of the float has changed.

5.2 Diagnose a piston position problem

Theoretically, because the buoyancy depends on the external density, the piston position should be directly linked to this parameter. Therefore, it is possible to plot the piston position at parking and to compare it with the external density. Thanks to figure 7 and 8, there are two important specific cases:

- **Figure 7:** the plot is very localized in the domain of study, there is a decrease trend of the piston position with the external density. Arguably, if the external density increases, the Archimedes force is higher, then the buoyancy of the float needs to decrease in order to stay at the same depth which explains why the piston position is lower.
- **Figure 8:** there are several scatter that are far away from the other points. But, the key aspect remains to understand if the piston position is correlated with the density: for that, the plot needs to be reading horizontally or vertically. Indeed, in case of change of density (by grounding as an example), it is natural that the piston position evolves.

5.4.1 *Detect a leaking problem through the piston position*

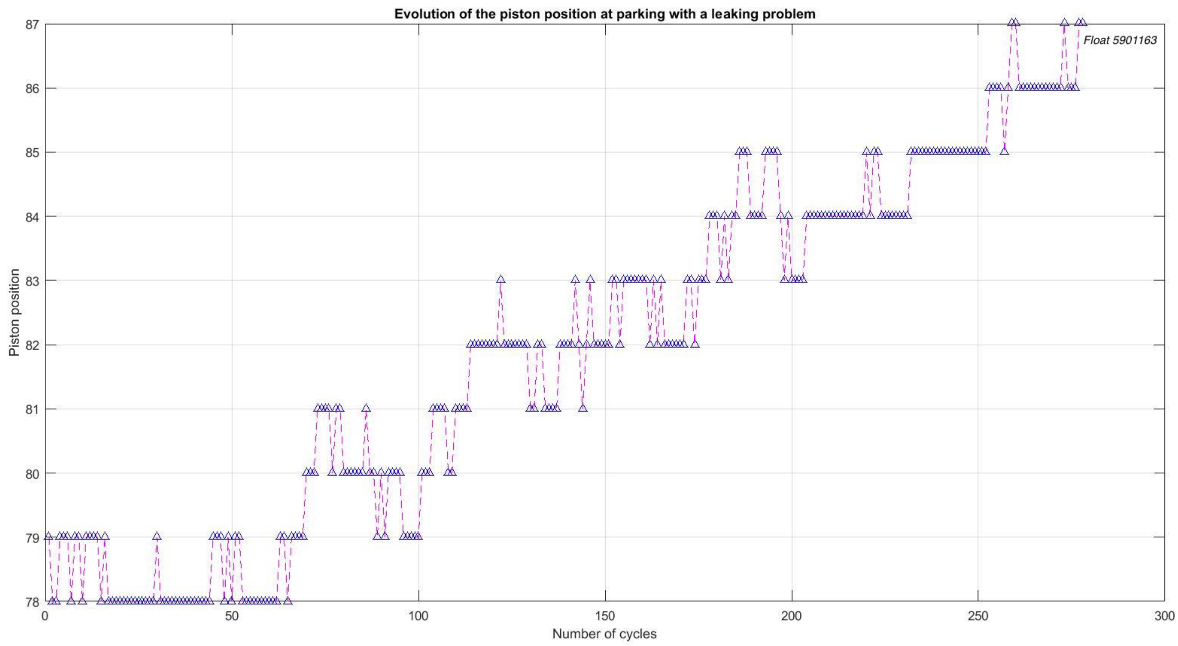


Figure 9: Evolution of piston position with a leaking problem.

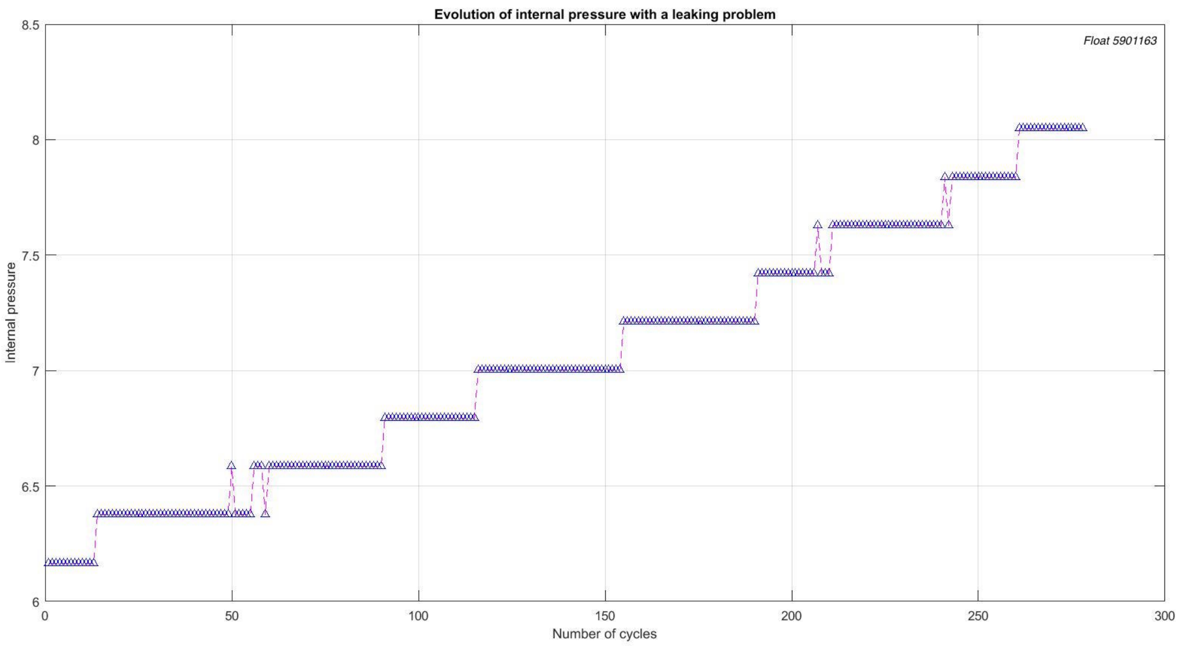


Figure 10: Evolution of internal pressure with a leaking problem.

5.3 Understanding a shift in piston position

Generally, for a dead float, there is an important shift of the piston position. For the main cases, it is explained by a few different elements:

1. **Battery problem:** if the battery voltage is too low, the pump motor won't work properly and, as a consequence, the movement of the piston won't fit with the buoyancy.
2. **Pump motor failure:** if the motor doesn't work properly, it will also entail an incoherent movement of the piston.
3. **Pressure sensor:** if there is a problem of pressure sensor, the controller of the buoyancy won't deliver the good set value (the float doesn't know its depth) and it can entail the death.
4. **Leaking:** in this case, the dynamic of the float is different, its buoyancy is altered and then the piston position must change.
5. **Change of weight:** if the weight of the float increases (generally after a grounding event), it won't be able to ascent to the surface, even if the piston is at its maximum position.

Therefor, it is important to make a difference between this different events. All have a different consequence on the float position.

5.4 Detect a leaking problem

Through the piston position

The evolution of the piston position, in case of a leaking problem, is very typical. Indeed, the shift of piston position happens at the end of the life, and can be brutal. It is important to compare the piston position with the internal pressure, as it is done on figure 9 and 10. In case of leak, there evolutions are characteristics:

- **Parking piston position:** if the depth is the same and the piston positions increases, that means the float needs to be more buoyant, then it probably weighs more (water inside of the float).
- **Internal pressure:** because the shape of the float is fixed, if there is water inside, the inside volume of the float decreases and then the internal pressure will be higher.

5.4.2 *Through inside volume*

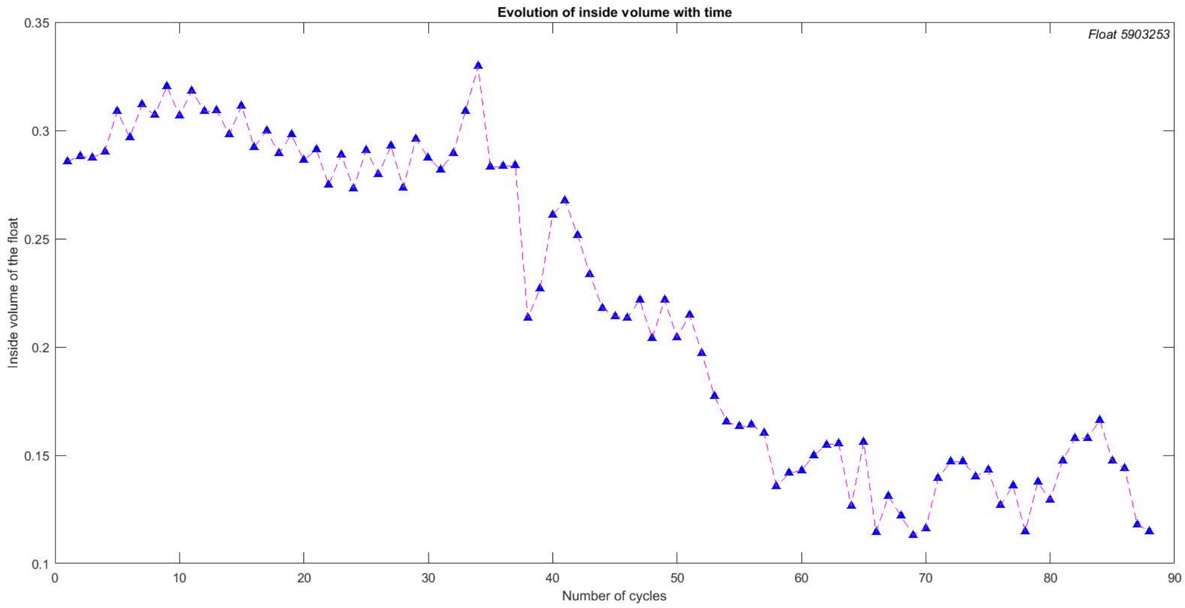


Figure 11: Evolution of the volume with time.

5.5 *Estimation of the float weight*

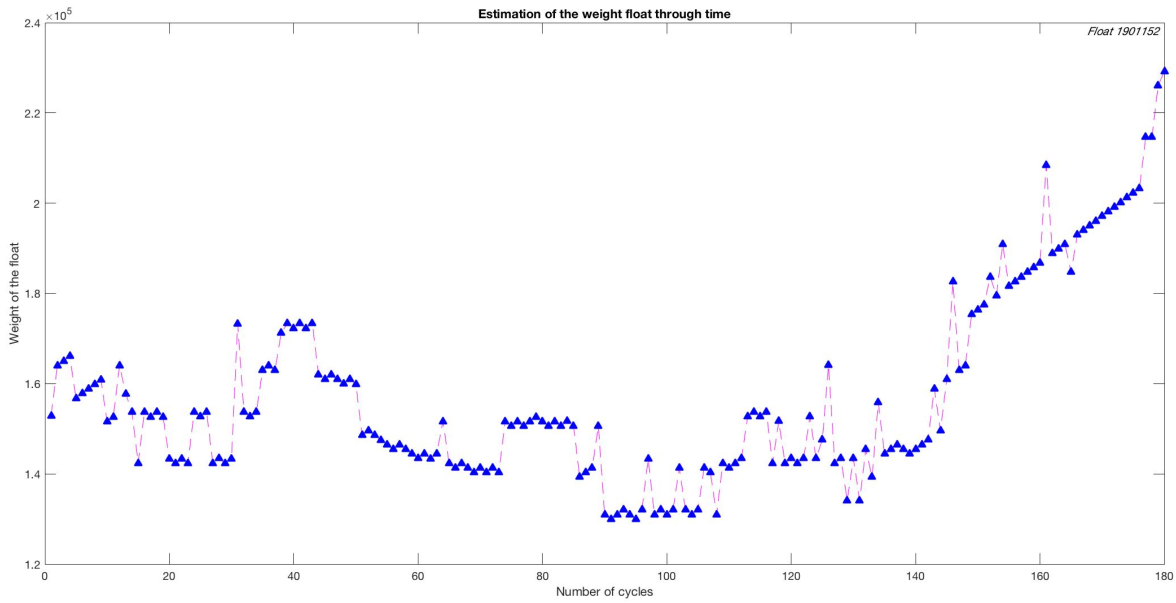


Figure 12: Evolution of the volume with time.

Through inside volume

A lack of tightness will entail an accumulation of water inside of the float, then its weight will increase and its propulsion system will be in trouble.

In order to figure out this problem from the set of data, it is possible to represent the inside volume of the float through the different cycles. In order to get the volume, the ideal gas law is used :

$$P_{inside} * V_{inside} = n * R * T_{inside} \tag{1}$$

In the ARGOs float, there is a sensor that permits to know the internal pressure through the vacuum, but only the external temperature is known. Then, it is important to check that after several days of parking, the outside temperature is equal to the inside temperature. The heat equation applied to the float hull gives :

$$\rho.C_p \frac{\partial T}{\partial t} = \lambda.\Delta T \quad where : \begin{cases} \rho = density. \\ C_p = heat\ capacity. \\ \lambda = thermal\ conductivity. \end{cases} \tag{2}$$

Then, from this equation it is possible to highlight the following time constant :

$$\tau = \frac{\rho.C_p}{\lambda} * d^2 \tag{3}$$

In the case of an aluminum float, the time constant is :

$$\tau = \frac{2700 * 897}{220} * 0,05^2 \approx 30\ seconds \tag{4}$$

Finally, the approximation $T_{inside} = T_{outside}$ is justified at parking.

It is now possible to plot the volume of a float with the number of cycles, which permits to understand if a float has leaked (figure 11). This plot is relevant, but depends on two different measurements and so cannot be realized for every float.

Furthermore, it is important to highlight a special evolution of this plot in a case of grounding. Indeed, if the float is not as deep as it used to be, the float compressibility evolves (the external density is sharply different) and then the volume of the float changes a lot. Then, it is common to have an increase of volume in case of grounding: this is due to the difference of volume of the hull.

5.5 Detect a change of weight

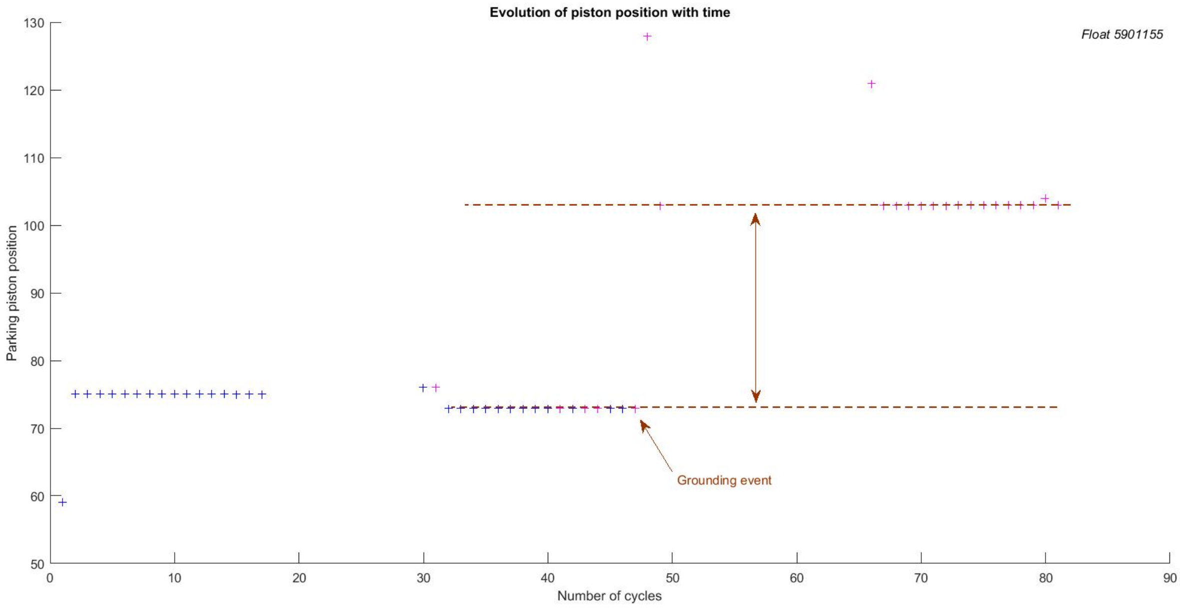


Figure 13: **Increase of weight:** typical evolution of piston position after a grounding event.

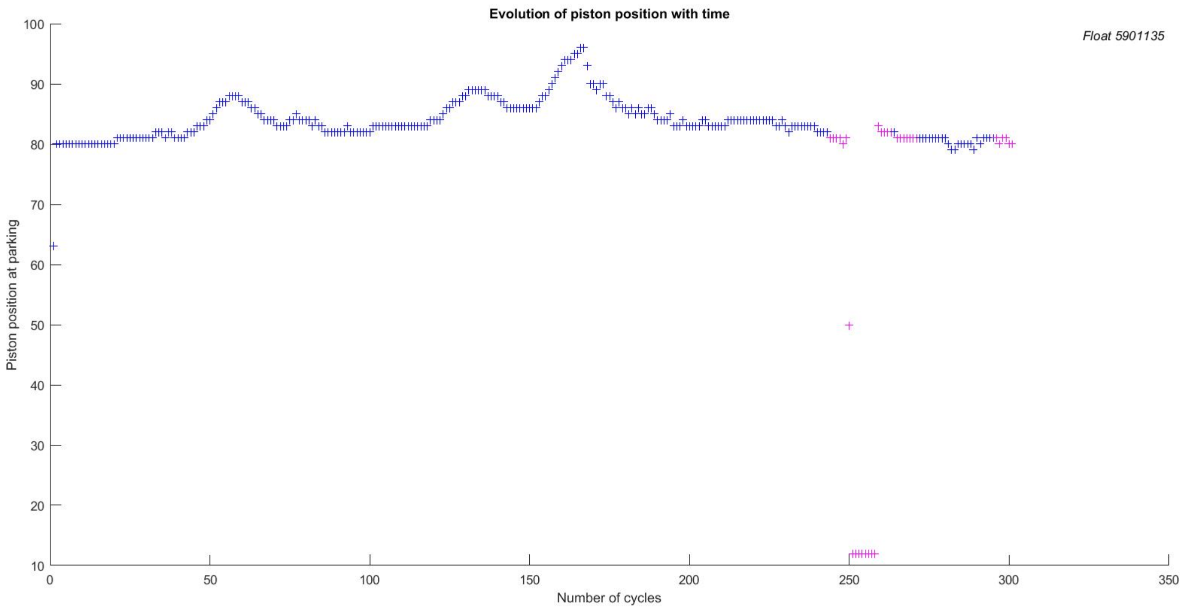


Figure 14: **Constant weight:** typical evolution of piston position after a grounding event.

5.5 Detect a change of weight

Through the piston position evolution

In order to understand if a shift of the piston position is due to an increase of weight, correlated with a grounding effect, the main idea is to plot the evolution of the piston position at parking for every cycles with taking into account a grounding event.

Easily, the plot needs to be carry on with two different colors in order to know if an uncommon evolution is due to a grounding trouble:

- **Blue:** it represents a common cycle of a float, without a grounded issue.
- **Magenta:** it represents a cycle in which the float has grounded.

During a grounding effect, the piston position is different, because the buoyancy has to adapt with the bathymetry. Then, it is important to consider the position in a common cycle, and compare with the older ones, two different cases can occur:

- **Change of weight:** as shown on figure 13, after a grounding event, there is a gap between two cycles: the weight has changed. Generally, the difference of weight is too important, and even as its maximum piston position the float doesn't manage to reach the surface.
- **Normalcy:** as shown on figure 14, after a grounding event (that happens after around 250 cycles), the piston restore to its original position. The weight has not changed, and the float still works properly.

Through an estimation of the float weight

At parking, the piston position is calibrated in order to equalize the buoyancy of the float to its weight. Then, through the external density and the inside volume is is possible to get an idea of the weight. Both parameters can be calculated:

- **External density:** a determination through the CTD profile is possible through the sea water equation.
- **Inside volume:** the position of the piston permits to have a clear idea of this one.

This estimation has a lot of variations, but in case of a sharp increase of weight, it is well detected (figure 12 on the previous page).

6 Pressure sensor

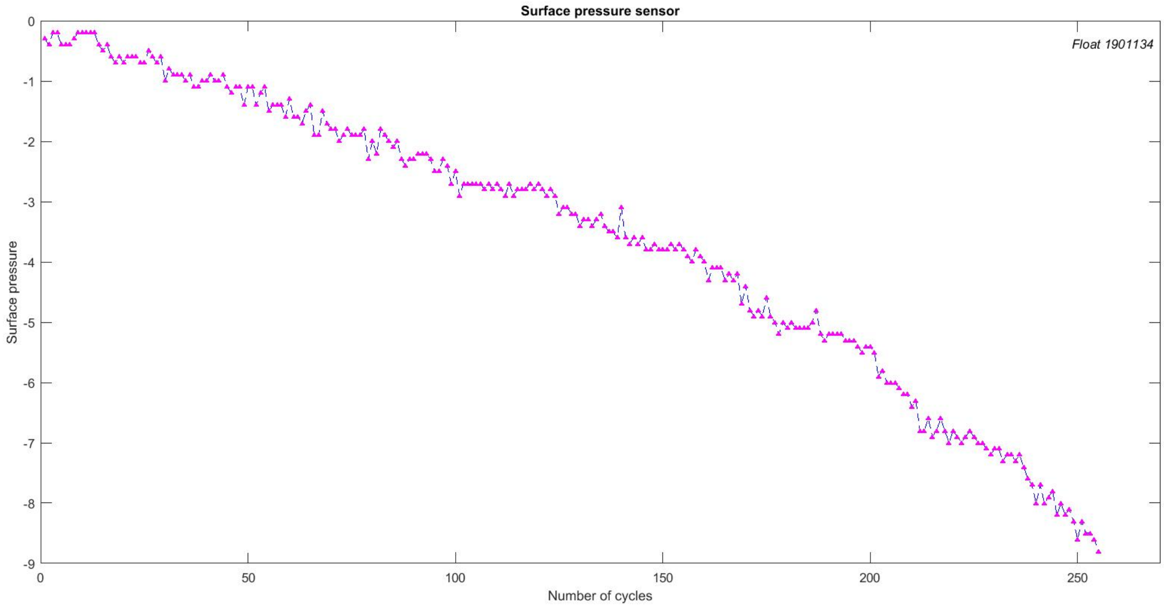


Figure 15: Determine the surface pressure from a sensor.

7 Pump motor

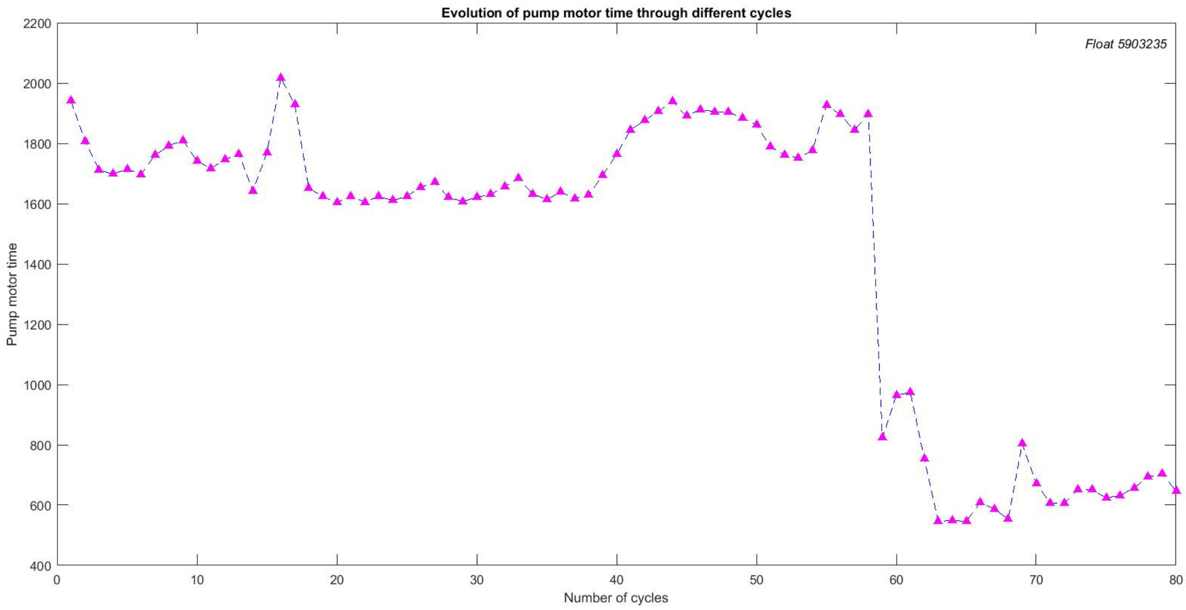


Figure 16: Typical evolution of pump motor trouble.

6 Pressure sensor

The accuracy of the pressure sensor is a key aspect of the float lifetime. Indeed, the controller of the buoyancy depends directly on the precision of the pressure determination. Then, if there is an error of measurements the float won't be able to survive long because it won't know the depth then the piston position won't fit with the external pressure.

Theoretically, the surface pressure should always be around zero, because it is calibrated after the first cycle. If there are a lot of variation (without a surface piston as its maximum position) that means the surface pressure is not trustful anymore, and it could entail the float death. This problem used to occur a lot with the Druck sensor but seems to have being fixed now.

7 Pump motor trouble

The role of the pump motor is crucial because it permits to link the source of power (the battery) to the control of the movement (piston position). If the pump motor dies, it will entail the death of the float. Graphically, a problem of motor is always linked with a change of working regime, as it is possible to see on figure 15. This is due to a change of power received by the pump motor.

The tricky part is to understand if the failure of the pump motor is the consequence of another problem (leaking, battery) or if it is the reason of the failure. In order to do this, it is important to compare the different plots previously quoted with this one.

The pump motor is scarcely responsible for the failure, but it occurs from time to time. In order to fix these, more attention should be paid on the quality of the product and especially for the power transmission from the main battery to the motor.

8 Air bladder

The air bladder permits at the float to reach the surface. If the pressure is not high enough, the bladder won't be full of air, the volume won't increase and then the buoyancy won't be high enough to permit the float to ascent the last few meters under surface. In that case, the float won't be able to transmit its data and will appear as not reporting.

8 Beaching

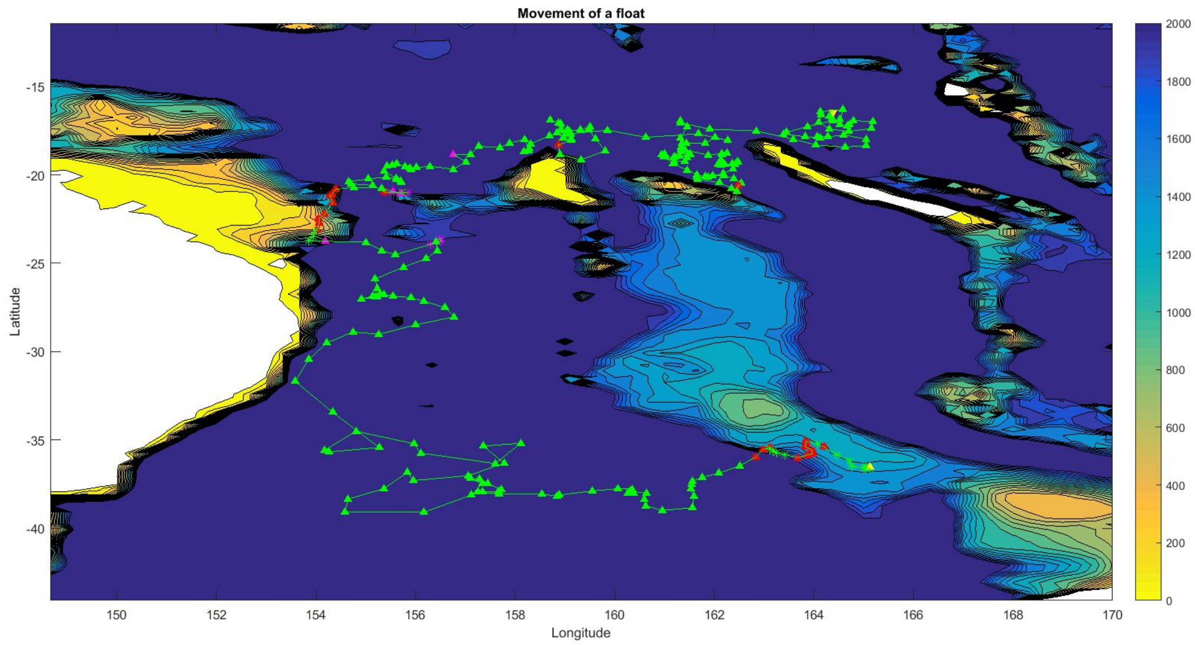


Figure 17: Trajectory of a float that dies from a grounding event.

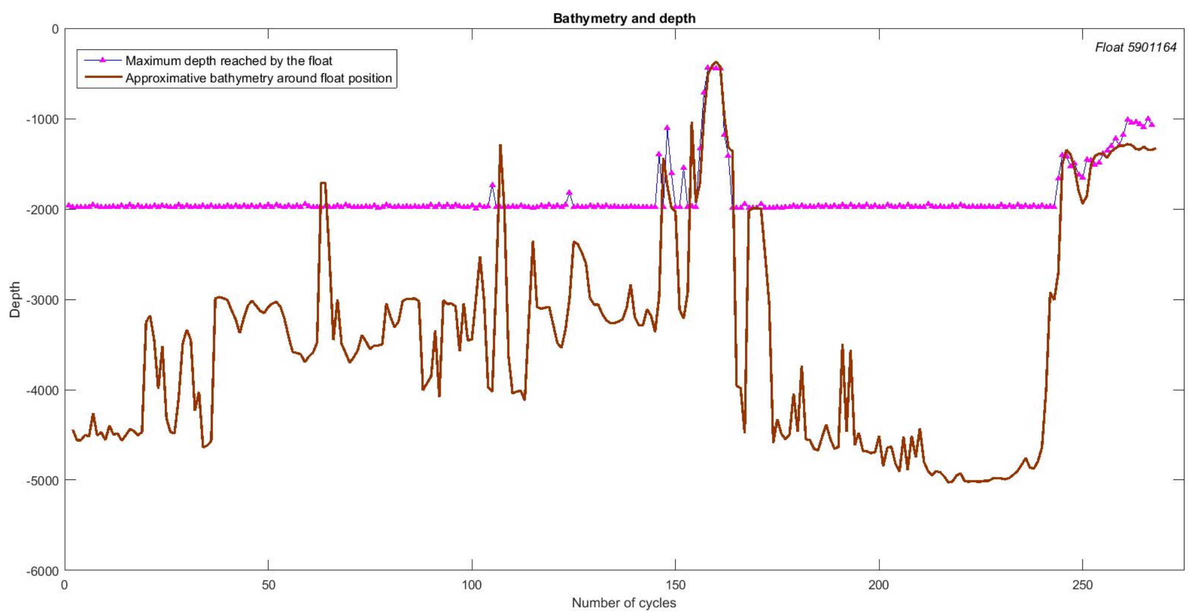


Figure 18: Comparison between the maximum depth reached by a float and the bathymetry.

9 Environment of the float

9.1 Beaching

Especially for the ARGOs float (that spend more time at the surface and then ground more because they drift more), it is common that the bathymetry entails the death of the float. To characterize this problem, there is no other way than mapping the position of the float, and having a quick look to its environment (as it is done on figure 19).

In order to determine a grounding event, a comparison between the maximum depth reached by a float during every cycle and the bathymetry is useful. It permits to get a clear idea on the environment of the float (figure 20).

9.2 Under ice

If the float is under ice, it is impossible to receive its data, but often the float reappears after several cycles (especially during the summer). It is almost impossible to know if the float would be able to make it during the winter, but even if it was possible, it would be impossible to get the float back.

In order to characterize this trouble, the surface piston position can be plotted with incorporating an ice detection flag, as it has been done with the grounding issue. Logically, if the float is under ice, it doesn't manage to reach the surface, then the surface piston position is altered and can be understood with the presence of ice detection.

9.3 Parking pressure

The final plot to understand the environment of a float is the one that permits to now at what depth the parking has occurred. If the float has not done its cycle properly, it is possible to know where it has spent most of cycles.

It is not rare to have a float that spend several cycles at the surface (stuck in fisherman's net), or at the bottom (stuck on a shoal).

9 Implementation

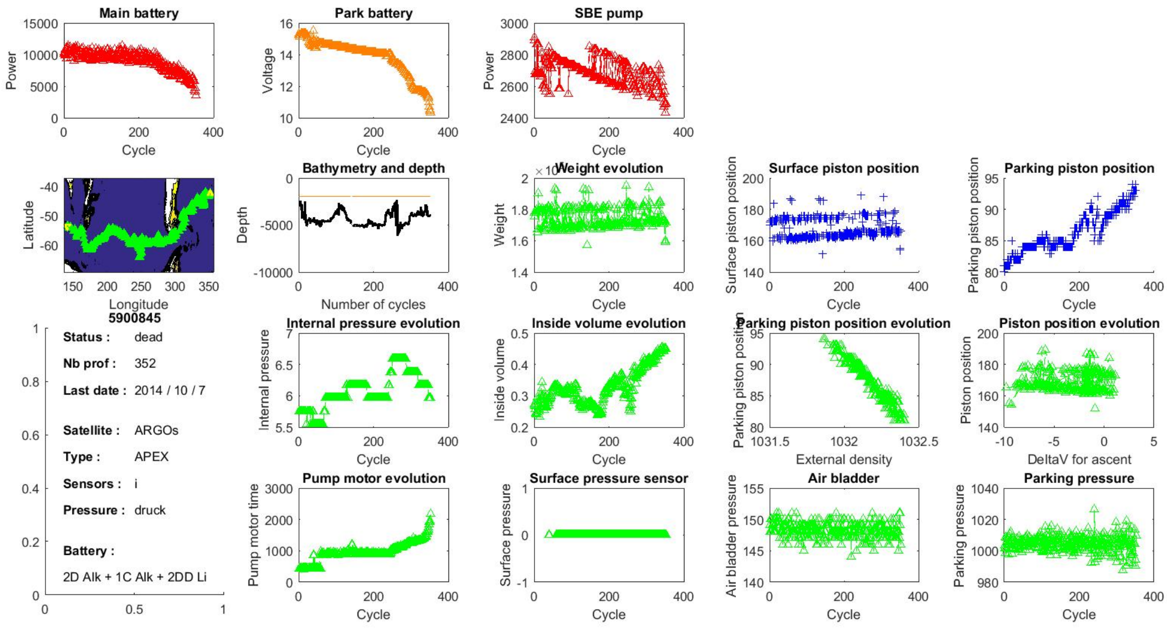


Figure 19: Matlab program that permits to determine every kind of failure.

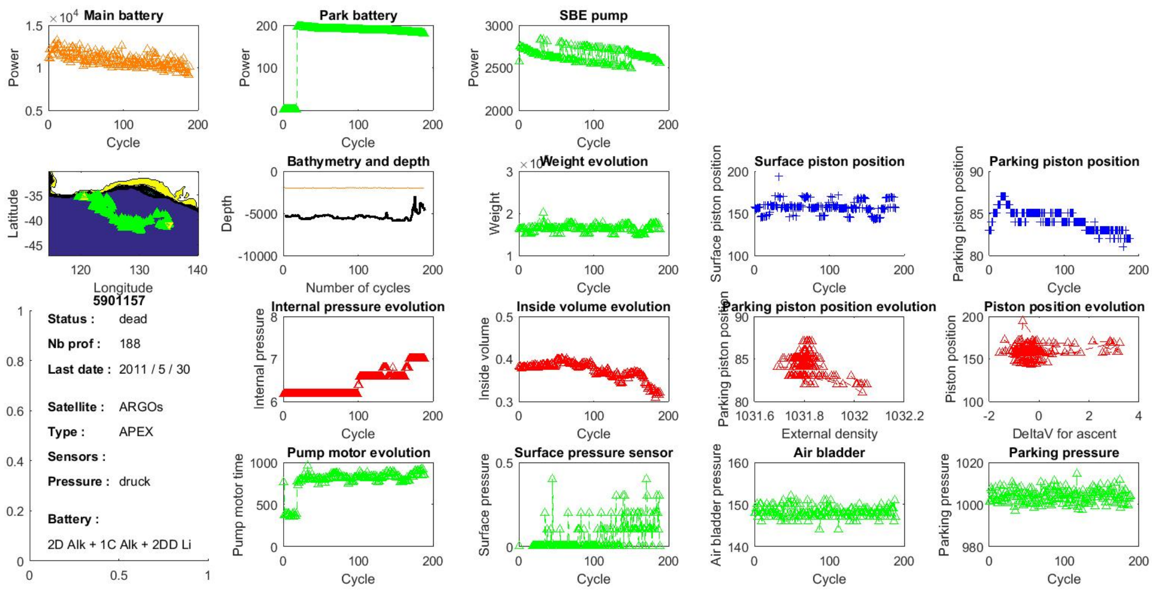


Figure 20: Matlab program that permits to determine every kind of failure.

10 Implementation

In this section, all previously results will be implemented into one figure that permits to easily get an idea on the cause of the failure. In figure 21 and 22, several parameters are represented:

1. **Battery:** the first row is dedicated entirely to the battery failure. There are five different subplots that permit to get the battery status at different stage of each cycle. For each of this figures, the meaning is the same:
   - **Axis X:** number of cycles.
   - **Axis Y:** power of the battery, it represents: $power = voltage * intensity$
   - **Color:** the code of color is very precise, and permits to have an quick understanding of the problem, it is determined like this:
     - **Red:** the voltage is very critical (lower than 10 Volts), it entails the death of the float.
     - **Orange:** the voltage is critical (lower than 12.5 Volts), it could entail the death of the float.
     - **Green:** the voltage is not the source of the problem, but a problem of power delivered (lack of current) can still be the source of the problem.
2. **Bathymetry:** the first two plots of the second row tackle the issue of a grounding event. On the one hand, there is a geographical representation of the float movement, ad on the other hand, there is a comparison between the maximum depth reached by the float with the bathymetry.
3. **Weight evolution:** the other plots on the second row permit to address the weight evolution trouble. The figures are respectively:
   - **Weight through time:** estimation of the weight of the float through different cycles.
   - **Surface piston position with ice detection:** permits to understand better the movement of the surface piston position.
   - **Parking piston position with ground detection:** aims at characterizing a change of weight after a grounding event (as studied in section 5.5).

4. **Leaking:** the third row is dedicated exclusively to a leaking trouble. Indeed, in this one, it is possible to get every set of data that permits to characterize a leaking problem, which are:

   - **Evolution of piston position at parking with density.**
   - **Evolution of surface piston position with variation of volume required for ascent determined by the compressibility of the float.**
   - **Evolution of inside volume with time.**
   - **Evolution of internal pressure with time.**

5. **General information:** in this plot, it is possible to get some data about the float, especially its number and its latitude during the last cycle (permits to characterize the presence of ice).

6. **Other parameters:** In the last row, in order to get a full picture of the situation, several other parameters are represented:

   - **Pump motor trouble:** as shown in section 7, this plot aims at characterizing a pump motor trouble.
   - **Surface pressure sensor:** as considered in section 6, this plot permits to highlight a problem of pressure sensor.
   - **Air bladder:** the air bladder pressure permits to have an idea on how the surface was reached for transmission.
   - **Parking pressure:** this plot permits to know where a float spent most of its cycle.

Arguably, this figure is the key to characterize a float failure.

Bibliography

Corpus d'articles :

- **Energy efficiency and consumption - the rebound effect - a survey** (2000) , Lorna A. Greening, David L. Greene , Carmen Difiglio.

- **Empirical estimates of the direct rebound effect: A review** (2009) , Steve Sorrell, John Dimitropoulos, Matt Sommerville.

- **The rebound effect is overplayed - NATURE** (2013) , Kenneth Gillingham, Matthew J. Kotchen.

  Based on equation supplied in a memo from Dana Swift, UW, Seattle as well as a program supplied by Russ Davis, SIO.