Preparing the new phase of Argo: technological developments on profiling floats in the NAOS project

Supplementary materials

*** Correspondance:**
Xavier ANDRÉ
xavier.andre@ifremer.fr

1 Supplementary materials

1.1 Deep-Arvor profiling float: parameters

The Deep-Arvor profiling float has 18 standard parameters and 36 expert parameters, as shown in Table 1, Table 2 and Table 3, allowing configuration of the mission (e.g. cycling period, depth, sampling characteristics), technical configuration of the float (hydraulic parameters, displacement parameters – restricted to experts) and ISA parameters (temperature threshold, etc.).

Table 1 – Deep-Arvor mission parameters

#	Description	Unit
PM0	Number of Cycles	-
PM1	Cycle Period	days
PM2	First Cycle Period	days
PM3	Estimated Surface Time	hours
PM4	Delay Before Mission	min
PM5	Descent Sampling Period	s
PM6	Drift Sampling Period	hours
PM7	Ascent Sampling Period	s

PM8	Drift Depth	dbar
PM9	Profile Depth	dbar
PM10	Surface/Intermediate Layers Threshold	dbar
PM11	Intermediate/Bottom Layers Threshold	dbar
PM12	Surface Slices Thickness	dbar
PM13	Intermediate Slices Thickness	dbar
PM14	Bottom Slices Thickness	dbar
PM15	End Of Life Transmission Period	minutes
PM16	Inter-Cyle Surface Waiting	minutes
PM17	Surface Waiting After Subsurface Grounding	minutes
PM18	Bottom Area Threshold After Grounding	dbar

Table 2 – Deep-Arvor technical parameters

#	Description	Unit
PT 0	Max valve activation at surface	csec
PT 1	Max valve volume during descent and repositioning	cm^3
PT 2	Max pump activation during repositioning	csec
PT 3	Pump duration during ascent	csec
PT 4	Pump duration for surfacing	csec
PT 5	Pressure tolerance for positioning (+/-)	dbar
PT 6	Max pressure before emergency ascent	dbar

PT 7	1st threshold for buoyancy reduction	dbar
PT 8	2nd threshold for buoyancy reduction	dbar
PT 9	Repositioning number threshold	-
PT 10	Grounding management mode	-
PT 11	Max valve volume before grounding detection	cm^3
PT 12	Grounding management threshold	dbar
PT 13	Pressure shift on grounding	dbar
PT 14	Pressure tolerance during drift (+/-)	dbar
PT 15	CTD acquisition mode (1: continuous ; 2: spot sampling)	-
PT 16	Alternate profile period (1: disabled)	days
PT 17	Alternate profile depth	dbar
PT 18	Average descent speed (mm/s)	mm/sec
PT 19	Pressure increment	dbar
PT 20	Cutoff pressure of CTD pump during ascent	dbar
PT 21	Auxiliary sensors measure (0: none; 1: dissolved oxygen)	-
PT 22	Ascent end pressure	dBar
PT 23	Average ascent speed	mm/sec
PT 24	Ascent speed control period	min
PT 25	Minimum pressure difference during ascent speed control	dbar
PT 26	Descent speed control period	min

PT 27	Minimum pressure difference during descent speed control	dbar
PT 28	GPS session timeout	min
PT 29	Hydraulic message transmission (0: no; 1: yes)	-
PT 30	In air acq.: Sampling period	s
PT 31	In air acq.: Acquisition duration	min
PT 32	In air acq.: Duration of pumping at surface	cs
PT 33	In air acq.: Periodicity measurement	
PT 34	Iridium session delay	min
PT 35	Ballast sensor (0: not used; 1: used)	-
PT 36	Vacuum coef A	-
PT 37	Vacuum coef B	-

Table 3 – Deep-Arvor ISA parameters

#		Description	Unit
PG0	General	Number of days without surface emergence if ice detected	days
PG1		Number of days before surface emergence even with ice detected	days
PG2	ISA	Number of detections to confirm ice at surface	-
PG3		Detection start pressure	dbar
PG4		Detection stop pressure	dbar
PG5		Temperature threshold	m°C

PG6		Slowdown pressure threshold	dbar
PG7		Pressure acquisition period during ascent (slow speed), once Pressure < PG6	min
PG8		Minimum pressure difference before pump action	dbar
PG9		Pump action duration	0.01 second
PG10	Satellite criteria	GPS timeout	min
PG11		1st Iridium lock timeout	min
PG12	Ascent blocking	Delay before ascent blocking detection	min
PG13	Buoyancy inversion	Pressure variation for buoyancy inversion	dbar
PG14		Volume of valve action for buoyancy inversion	cm^3
PG15		Volume before grounding detection (while in buoyancy inversion phase)	cm^3

1.2 Satellite communications: equipment description

Table 4 indicates the types/references of modems and the technology of antennas used for this experiment.

Table 4 – Modems and antennas used to compare satellite-communication performance on profiling floats at sea

	Argos-2	Argos-3 low-data-rate mode	Iridium SBD	Iridium RUDICS
Profiling float	Arvor	Arvor Argos-3	Deep-Arvor	Provor CTS4 or Provor CTS5
Modem	Custom-made	Kenwood PMT	9603	A3LA-RG
Antenna	1/4 wave antenna	Uplink: 1/4 wave antenna; downlink: 1/4 wave antenna	Helical antenna	Helical antenna

1.3 Under-ice BGC

1.3.1 CTD data used for ISA estimation in the Baffin Bay

The water masses in Baffin Bay are very different from those in the Antarctic with larger freshwater inlets (Curry et al., 2014). These characteristics led us to consider, from the outset, that the ISA setting should be adapted to Baffin Bay. To do so, a database of 392 CTD profiles, obtained from ships and associated with ice-presence information, was compiled. From these data, we advanced that the best parametrization was to compute the temperature median between 30 and 10 dbars and compare it to the threshold of -0.5°C. This threshold was used on two prototypes before we determined that the initial database was probably too coastal. The ISA parametrization, in particular the threshold, evolved during deployments of the NAOS fleet thanks to the use of more offshore profiles provided by the floats themselves: in this way, the threshold shifted from -0.5°C to -1.1 °C in 2016 and to -1.3°C in 2017. In this study, we present the ISA parametrization used during the last deployments and make an assessment on the basis of all the data produced during the Baffin Bay deployments (Le Traon et al., 2020). For this analysis, 1,396 CTD profiles from Pro-Ice floats deployed in Baffin Bay in the framework of the NAOS-WP4 were used. The CTD database initially used for estimations for the first parameterization was discarded to increase the homogeneity of the database. Only CTD profiles starting at a minimum of 200 dbar and associated with a Sea Ice Concentration (SIC) were retained. The WMO numbers of floats used in this study, as well as the number of retained profiles per float, are reported in Table 5.

Table 5 – Float references and number of retained profiles, used for ISA assessment

Login	WMO	Number of Profiles	First Profile	Last Profile
takapm005b	4901803	90	09/07/2016	18/10/2016
takapm006c	4901804	9	20/07/2017	29/07/2017
takapm007b	6902666	70	23/07/2017	27/09/2017
takapm008b	6902669	101	20/07/2017	03/11/2017
takapm009b	6902667	94	09/07/2016	18/10/2016
takapm011b	6902896	126	17/07/2018	27/05/2019
takapm012b	4901805	114	20/07/2017	09/08/2018
takapm013b	4901802	93	09/07/2016	18/10/2016
takapm014b	6902668	85	09/07/2016	18/10/2016
takapm015b	6902670	105	20/07/2017	05/11/2017
takapm016b	6902671 / 6902953	183	23/07/2017	29/07/2019
takapm017b	6902829	103	23/07/2017	09/04/2018
takapm018b	6902967	62	14/07/2019	15/09/2019
takapm020b	6902897	161	24/07/2018	15/09/2019

1.3.2 Altimeter data used

The data used to assess sonar usage was extracted from 14 profiling floats deployed in the Baffin Bay area as part of the NAOS project, on which sonar-distance data were recorded every 20 dbars from 200 dbars up to the surface. In order to assess the capabilities of this sensor to detect objects, we calculated the draught of the object, namely the depth of the float (converted to meters, oce R-package (Kelley, 2017)) minus the distance measured by the sonar.

It appeared from the first deployments that we had a very large number of objects with a draught of about 150 m even if the float could then continue its ascent normally through this artifact. This false detection was simply due to the interference between two consecutive pings. Indeed, these are separated by 0.2 s (5 Hz ping rate), which corresponds, at an average speed of 1,500 m/s, to about a 300 m round trip, i.e. 150 m in distance. Subsequently, we started acquiring the sonar at 145 m depth because it was impossible to modify the ping rate easily.

Measurements of a distance under one meter or draught above 120 meters have been removed from the analysis. A total of 3,236 sonar measurements (ping) were collected. The list of profiling floats is given in **Table 6.** Two types of corrections are used to correct the data for the sound speed. The first, noted as “corrected at ping”, takes into account the sound speed calculated at the depth of the ping. The second, noted as "corrected to surface", uses the average speed from the ping depth to the surface. This average is calculated by interpolating the velocities measured at regular intervals (every meter) and using the last velocity measured to the surface. In this way, if the last CTD point was measured at 15 dbars, the same sound velocity value is used from 15 dbars to the surface.

Table 6 – Float references and number of altimeter data

Login	WMO	Number of ping	First altimeter data	Last altimeter data
takapm004b	4901806	55	17/07/2019	30/08/2019
takapm005b	4901803	252	01/08/2016	18/10/2016
takapm006c	4901804	24	23/07/2017	29/07/2017
takapm007b	6902666	280	23/07/2017	27/09/2017
takapm008b	6902669	352	30/07/2017	25/10/2017
takapm009b	6902667	83	10/09/2016	18/10/2016
takapm011b	6902896	240	17/07/2018	20/09/2018
takapm012b	4901805	436	23/07/2017	09/08/2018
takapm013b	4901802	88	10/09/2016	18/10/2016
takapm014b	6902668	113	02/08/2016	08/09/2016
takapm015b	6902670	404	22/07/2017	03/11/2017
takapm016b	6902671 / 6902953	506	23/07/2017	08/09/2018
takapm017b	6902829	392	23/07/2017	12/03/2018
takapm020b	6902897	11	09/09/2018	15/09/2018

1.3.3 Assessment of float braking

On the basis of described mechanisms, a decision to stop the float can be taken by the *Payload* board, which sends a stop request to the APMT navigation board. If this request is accepted (see Mission and Ice-Avoidance Management section), the float will initiate a hydraulic braking action (Figure 1) at an intensity that can be selected from 1 (lowest) to 4 (highest) in the float parameterization. We report here the experience obtained from 90 braking operations, always at 3/4 intensity, carried out by 5 floats in Baffin Bay (Table 7). It appears that for 4 floats (63 brakings), the braking is carried out on average in less than 3 m, with only one profile (1.6%) accidentally reaching the surface without damage to the float. However, for one float (WMO6902896, 27 brakings), the brakings were efficient (minimum depth higher than 3 dbars) in only 44% of cases and the float remained stuck in ice once. After studying the technical data of this float, it appears that the flow rate of its solenoid valve was probably 30% lower than the average of the other floats. This difference may explain the difference in braking. For future deployments, we suggest increasing braking power, especially if the technical data show a solenoid valve with a low flow rate.

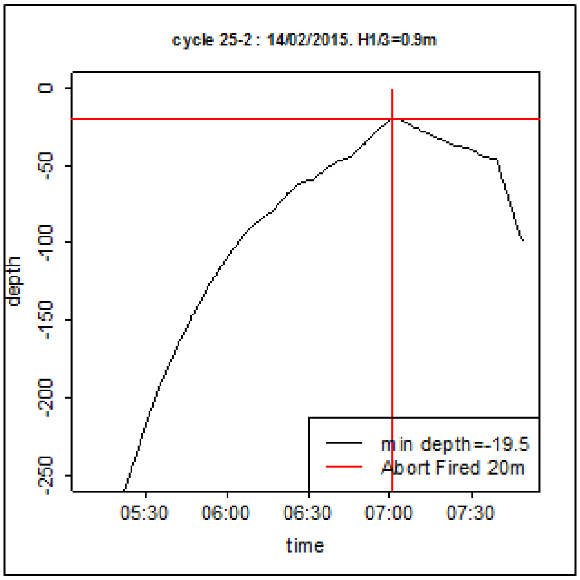

Figure 1 - Example of the trajectory of a Provor CTS5 (fitted with an Ice-Sensing Algorithm) after braking at 20 dbars.

Table 7 – Braking success rate and emergence reduction time for 5 floats deployed in Baffin Bay. The only float with a low success rate is associated with the highest emergence reduction time.

WMO	Nbr. Abort	Success	Surface reduction time (%)
4901805	16	100%	116%
6902671 / 6902953	22	100%	96%
6902829	5	100%	103%
6902896	27	44%	133%
6902897	20	95%	85%

1.3.4 Prototype validation at low temperatures

At the beginning of the project, the manufacturers of the float and the sensors were contacted to obtain information on the minimum temperatures tolerated by their products. Two main problems were then identified concerning the float and the CTD. First, the float should not be stored at low temperature due to the impact on its batteries. On the other hand, short-term exposure to low temperatures, typically during deployment, is not a problem. Secondly, the CTD can withstand negative temperatures, even when filled with seawater, but can be damaged if it is filled with freshwater.

In addition to this information, two series of field trials were conducted in Canada in order to verify the functioning of the equipment in polar conditions and especially at low temperatures. The first trials were conducted in a frozen lake in the vicinity of Québec City, the second experiment at the Green Edge ice camp (Figure 5 of the main paper, left) located in Qikiqtarjuaq (Nunavut). The Pro-Ice float, equipped with a complete payload, was deployed in a captive mode in a hole in the ice and profiled under the ice floe as thick as 1.1 m. No issues with hardware related to low temperatures were identified during these tests. However, the tests led to various software adjustments. In particular, it appeared that the self-test of the SUNA sensor, performed in air, failed at low temperatures. This was simply due to the fact that the temperature, sent by the float to the sensor for onboard nitrate processing, must be higher than -2°C to be compatible with seawater temperature, which was not the case during these tests. Trials helped to fix the indicated problems but the strong tidal current during the tests covered up another issue linked to the buoyancy of the float in very cold conditions. Indeed, a low environmental temperature modifies the viscosity of oil (mineral type) in the float's hydraulic system, triggering a substantial effect on the flow rate of the electro-valve (confirmed by further results of factory trials led by nke instrumentation: a flow rate at 0°C is divided by 2 compared to a flow rate at 25°C). As a result, when the first deployments at sea took place in early August 2015 in Baffin Bay, 2 floats went into rescue mode as they were unable to dive in the allocated time, and they were recovered. Changing the oil type to avoid the effect of cold would have induced too many factory and field tests for qualification, and therefore delays in the deployments. So far, a modification in several hydraulic parameters has been programmed to bypass the phenomenon.

Finally, a float (WMO4901801) was deployed in the Labrador Sea at the end of May 2016 during the Green Edge cruise. This float, equipped with CTD and a Dissolved Oxygen (DO) sensor, was used to test the ProIce float, operationally and in cold water, but in an area without sea ice and therefore without loss of contact with the float during winter. This test float was intended to overcome one of the difficulties of this project, namely the very discontinuous nature of feedback on deployments. As the deployments taking place in a year were necessarily carried out in July to take advantage of the Arctic summer, any software developments had to be finalized at the beginning of spring of the same year. On the other hand, feedback from the current wintering experience was obtained, at best, at the beginning of July, sometimes only a few days before the next deployment. The float (WMO4901801) could be tracked throughout its entire deployment and showed healthy performance, completing 363 profiles. Several surfacing avoidance tests (reproducing an ISA mechanism) were also carried out, showing the float's good reactivity, even in cold water.