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1. INTRODUCTION

Argo uses autonomous, vertically-profiling neutrally-buoyant floats to collect (primarily) temperature and salinity data from the uppermost 2000m of the oceans. The horizontal movement of the floats also allows subsurface and (to a letter extent) surface currents to be estimated. The continued improvement and evolution of float technology is crucial for the success of the international Argo project. This process of technology improvement and innovation is also a central aspect of the Euro-Argo infrastructure.

In this report, we review the status of present-day float technology and consider its likely evolution over the coming years in respect of float design, lifetime, cost, new sensors, improved telecommunications etc. Float manufacturers and their products are first analyzed and the competitiveness of European providers assessed. New and emerging requirements for improved capabilities and performances (communications, lifetime) in particular for marginal seas and additional or improved sensors (e.g. O_2, sea ice, density, sea surface temperature and sea surface salinity, bio-optical, plankton), are also detailed. Bio-geochemical and bio-optical sensors are currently under development. Combining such sensors with the mature profiling float technology should allow us, in particular, to address requirements coming from new research communities (e.g. biogeochemical, optical and ocean colour, carbon cycle, ecosystem, fishery). Trade-offs between additional costs, increased complexity and development of the user community need to be analyzed.

The floats being used in Argo and Euro-Argo have their origins in technologies developed during the 1990s in programmes such as the World Ocean Circulation Experiement (WOCE) which used Autonomous Lagrangian Circulation Explorers (ALACE) floats (Davis et al, 1992) and their later profiling derivatives (P-ALACE) floats (Davis and Zenk, 2001). These later became the APEX float manufactured by Webb Research Corp (a division of the Teledyne Corp) in the USA. In Europe the MARVOR float (Ollitrault et al 1994) used in projects such as SAMBA, ARCANE (Speer et al 1997) and Eurofloat (Bower et al, 2002) evolved into the present PROVOR and ARVOR profiling derivatives manufactured by NKE. A further float design, the SOLO was designed by the Scripps Institution of Oceanography in the USA but since it is not used in Euro-Argo it will not be described here. A derivative of SOLO, the Nemo float, is manufactured in Germany by Optimare.

The basic operating cycle as recommended by the international Argo Scientific Steeering Group is for floats to spend most of their submerged life at a “parking” depth of 1000m and, during the profiling phase, to first descent to 2000m and to then profile during the ascent to the surface. After transmitting the profile data and having the float position determined by satellite communication the floats return to the parking depth. The recommended time for repeating a complete cycle is 10 days. These parameters (cycle time, parking depth and profile depth) are sometimes modified to suit the area in which the measurements are being made (e.g. in the Mediterranean sea a shallow park depth and 5 day cycle time). In all float models the ascent and descent are initiated and controlled either by pumping fluid between a reservoir inside the float’s pressure case and an external bladder, or by displacing fluid to or from an external bladder by mean of a piston, thus changing the float’s volume while its mass remains constant. All floats are powered by batteries.

The breakdown of float types being used in the whole of the international Argo programme and the Euro-Argo component in February 2010 is as follows :-

	Apex	Provor/Arvor	SOLO	Nemo	Other	Total
Argo	2176 (68%)	149 (5%)	823 (25%)	37 (1%)	13	3198
Euro-Argo	320 (65%)	137 (28%)	0 (0%)	37 (7%)		494

2. TECHNICAL DESCRIPTION OF FLOAT TYPES

2.1. PROVOR and its derivatives

PROVOR has been designed by IFREMER from its earlier MARVOR float, and is manufactured by its industrial partnership NKE (*www.NKE.com*). PROVOR carries Sea Bird type 41CP CTD sensor and has an important volume variation capacity. It can be used in a wide range of density gradient and can be launched from any vessel at low speed using only a rope and from a high speed vessel (20 knots tested) by using release kit and launching crate. Based on its self ballasting features, PROVOR is fantail ready, able to be launched in all seas by removing a magnet. Mission parameters can be modified by user before launching. During the first descent data are acquired in order to enable comparison with CTD cast (Conductivity Temperature Depth). Data are transmitted through Argos satellite system. PROVOR can complete more than the nominal four-year Argo mission, using lithium batteries (more than 250 profiles at 2000m depth, CTD pumping continuously, transmitting 110 CTD averaged levels). A model exists which carries alkaline batteries (150 cycles). PROVOR is a platform dedicated to carry various extra sensors like PROVOR_DO: dissolved oxygen, PROVOR_A: Sofar acoustic positioning during drift, PROVBIO: optical irradiance and transmittance (with Iridium telemetry).

2.2. ARVOR

The ARVOR float has been designed by Ifremer, by using an important know how in float activities and well qualified subassemblies. The purpose of this development was to get an optimised and specific float for Argo application: CTD measurements, lighter weight (20 kg), cheaper than Provor. NKE has achieved its industrial design. Argos telemetry is used to collect data and localize ARVOR when surfacing, and Iridium satellite communication option has become available in 2009, allowing high resolution profiles. ARVOR floats carry Sea Bird type 41CP CTD sensor and can perform up to 250 profiles from 2000 meters depth to the surface, with CTD pumping continuously and transmitting 110 CTD averaged levels. A profile is achieved during the first descent for comparison with a CTD cast. ARVOR float is self-ballasted allowing operation in a wide range of density conditions and gradients. Ballasting operation is not required. ARVOR can be launched by non-specialist crews, using a magnet to start the mission. Wireless connectivity using Bluetooth eases mission configuration and testing before deployment.

2.3. APEX

The present APEX design is an evolution from the earlier ALACE and PALACE designed in the 1990s. Based on the same 6.5 inch (16.5cm) diameter aluminum hull as its predecessors, APEX is rated to 2000 db operating depth and each float has a nominal mass of 26 kg. Virtually all APEX floats carry Sea Bird type 41 CTD sensor. (Floats using Iridium communication technology allowing higher vertical resolution use the type 41CP sensor). These are mounted on top of the instrument and make measurements only during the ascent phase ascent.

The functioning of the APEX float is governed by a controller that has been modified during the life of Argo to improve float performance and to eliminate problems as they have been revealed by extensive use and by detailed analysis of the data.

The standard maximum volume displacement of the (now superceded) 180ml and the present day 260ml floats does not allow floats to surface from 2000m in ocean areas with very low surface densities due to high temperatures and low salinities (for instance in the Bay of Bengal). In such cases an optional compressee (based on a gas spring) can be fitted. APEX floats can be specified to operate in either isobaric (pressure-following) or isopycnal (density-following) modes.

APEX with Argos telemetry can complete the nominal four-year (approx 140 profiles Argo mission using alkaline batteries. In order to extend float life several APEX float oparators have equipped floats with lithium batteries. Starting in 2010, WRC factory-installed lithium primary batteries will be available.
Floats are delivered to users ready to deploy and can be launched by non-specialist crews with minimal training. A user interface (20 mA loop with provided converter to RS232) enables easy testing or re-programming of floats when needed. APEX floats have been successfully deployed from aircraft.
APEX floats have been adapted for measuring variables other than temperature and salinity. The number of APEX floats operating in Feb 2010 include dissolved oxygen (180 floats), (Kortzinger et al, 2005) fluorescence (10 floats) (Johnson et al 2009). APEX floats have also been used to carry acoustic rain gauges (Riser et al 2008) and to measure current shear profiles (Sanford et al, 2007). A further modification to APEX floats allows them to collect high-resolution temperature profiles of the upper oceans.
By early 2010 approximately 5000 APEX floats had been delivered to 20 nations.

2.4. NEMO:

OPTIMARE (*www.optimare.de*) has developed the Navigating European Marine Observer (NEMO) Float for Argo. The NEMO design is based the Scripps Institution of Oceanography SOLO float, the design of which is openly available for manufacture by other parties. Like other floats NEMO ascends from a depths of up to 2000 meters in regular intervals to the surface and transmits the collected data via the Argos satellite system. The NEMO-Float has been particularly improved to allow the deployment under ice, positioning through GPS and RAFOS, as well as the integration of new sensors (nitrate, oxygen,…) and telemetries. Data transfer to a land-base is available via satellite communication.

3. SENSORS

3.1. CTD

3.1.1. Measurement accuracy

Existing technology
Provor floats are fitted with Sea-bird SBE41CP and APEX floats with the SBE41 CTD sensors (*http://www.seabird.com/products/profilers.htm*). Sea water is pumped through the SBE41 at a rate of 40 ml/sec for 2.5 seconds during which the measurements of T, C and P are made. The SBE 41CP(continuous profiling) is pumped at a rate of 30 ml/sec flow continuously during the profile. The specification for both SBE41 and SBE41CP are:

	Pressure	salinity	temperature
range	2000 dBar	0-40 PSU	-5°c at +35°C
Initial accuracy	+/- 1 dBar	3 mPSU	+/- 2 m°C
resolution	0.1 dbar	1mPSU	1 m°C
Observed stability	<5dbar / 5 year	10 mPSU / 5 year	2 m°C / 5 year

On all floats the CTD sensor unit is placed at the top of the float and is controlled by the main CPU of the float.
The CTD is used :
to get pressure measurements for controlling float behaviour, using specific "fast pressure" command. It consumes approx. 100 milliwatts.

to get triplets (Pressure, temperature and salinity) mainly for ascent, but also for descent and drift at parking depth. It consumes approx 300mW.

In all cases the pumping of the CTD sensor is turned off between 0 and 10m (adjustable) before the float reaches the surface. This is to avoid contamination (and hence degradation) of the sensor by pollutants at the sea surface.

Since Argo floats are not designed to be recovered at the end of their mission, calibration of the conductivity (salinity) sensors is achieved by comparison of salinity data with recent ship-based measurements and by comparisons between nearby floats. The method is adopted by all float operators and is documented by Owens and Wong, 2009, and is also kept under constant review by the Argo Data Management Team and the Argo Steering Team.

The measurement of salinity is fundamentally dependent on the accuracy of the pressure and temperature measurements. Pressure offsets in all float models can be adjusted by measuring atmospheric pressure when the float is at the surface. Temperature measurements have to be assumed to adhere to the manufacturer's or float operator's pre-deployment calibration.

A small number of floats have been recovered in full working order and have allowed the sensors to be recalibrated. A report documenting the sensor drifts for 3 Apex floats over periods between 2 and 2.5 years (Oka, 2005) showed salinity drifts in the range -0.0074 and -0.0125. Temperatures showed offsets of between 1 and 1.5 °C$\times 10^{-3}$ and pressures between 1 and 6db.

In 2009, pressure sensor (Druck manufacturer, sub-contractor of SBE) has been affected by a serious failings. The pressure sensor "microleaks" problem induces a negative drift of the pressure sensor. This pathology in Druck pressure sensors induces microleaks past the glass/metal seal. This oil leak leads to an internal volume loss, which then exhibits itself as an increasing negative offset at all pressures. This problem has led to stop float deployments in 2009 until the problem was resolved. Seabird has replaced failing sensors, some of them by Druck sensors that have passed screen tests, most of them by new Kistler pressure sensors.
In a PROVOR and ARVOR float (with Argos telemetry), the reset-offset function of the SBE sensor is used to reset the pressure sensor to 0 before each dive. The surface pressure value is thus a pressure offset relative to the previous profile. Any drift in the pressure sensor is thus taken into account for both the vertical positioning and the salinity estimate from the conductivity measurements. Truncated surface pressure values were then transmitted with a 1 dbar resolution , which was inadequate to detect any drift. The resolution of the pressure offset has been modified to 1cBar in 2009.
First generation of APEX floats are equipped with an APF8 controller that transmits positive values (when a negative surface pressure is measured, it is truncated to 0). APEX floats equipped with an APF8 controller also transmit positive values with 5 dbar added. When the control was performed, the 5 dbar was removed in the technical files of the Coriolis DAC. The new APEX floats equipped with an APF9 controller transmit positive and negative surface pressure without adding 5 dbar. The microleak problem can only be seen on recent floats equipped with the new APF9 controller.

Improvements-evolutions trends
At the first Euro-Argo users group (June 2008) there was interest in developing floats that would profile to greater depths (3000m was mentioned). The major limitations on such a development are a) pressure case strength b) energy considerations c) sensor stability and accuracy.
To achieve depth capability greater than 2000 dbar, SBE has proposed a titanium pump impeller housing, rather than plastic. This part is the same as used on SBE 49 FastCAT (adds about 255 grams to the weight).
At the end of 2008, the new SBE 41CP has been available. It consumes less than 180 milliwatts (against 300 mW today)

Other CTD sensors have been tested in the past (FSI) but its sensitivity to environment and its drifting caused by biofouling made us renounce to this technology. An alternative way could be the development of an optical density sensor which has started this in 2008.

3.1.2. CTD acquisition

a) Provor measurements and sampling method

During descent, if enabled by the user, measurements are done just after sinking detection (typical threshold 8 dbars). The CTD pump is then running continuously until parking depth is reached. During ascent, measurements are made from leaving start profile pressure until surface. The CTD pump is running continuously until 5 dbar is reached, avoiding to pump any dirty film at sea surface. The main CPU picks PTS samples every 10s, while the CTD delivers one sample every 2s.

At first descent, measurements are always done, enabling CTD on ship comparison.

At parking depth, the CTD pump is put on every time a measurement is programmed (min 1 hour).

Power consideration:

A profile from 2000m to surface spends 6.5 KJ , approx. 30% of the total power consumption of the float.

b) Provor data reduction

The profile is composed of 2 area named bottom area and surface area. Each of them is split into slices, enabling the user to program the number of transmitting points. PTS samples acquired into each slice are averaged in order to reduce amount of data to transmit: the result is a triplet approximately adjusted on mean pressure of the slice. On floats fitted with iridium transmission, standard deviation is also processed.

Improvements-evolutions trends

- On ARVOR float, if enabled by user, "economical" sampling method can be chosen. Instead of maintaining CTD pump always on, acquisition may be done by "spot sampling": the pump is only "on" around programmed pressure +/- 1 meter, in the middle of each slice. The "high speed" measurements (one every 2 second) are averaged on this 2 meters area, then the pump is put off until next slice. This can be applied to bottom area. On the other hand, pumping on in surface area is maintained to minimize thermal mass errors in the conductivity cell, which can be large in the thermocline. Like that, power is hugely conserved: 1 KJ instead of 6.5 KJ for default scheme. approx. 25% of the number of cycles can be saved.
- Arvor floats and Apex floats can be used with Iridium/GPS communications allowing high-resolution (2db) sampling throughout the profiling range. Around 150 such Apex floats are active in February 2010. The majority of these are operated by the University of Washington, USA with a smaller number by the Australian Argo project. In 2010, 2 Arvor floats are operated by Ifremer and 2 by OGS (Istituto Nazionale di Oceanografia e di Geofisica Sperimentale) in Italy for Mediterranean EuroArgo contribution.
- A recent development initiated by the UK allows Apex floats to make detailed near-surface profiles of temperature that are of value in allowing Argo data to be used in the study of surface mixing. The floats do this by continuing to sample temperature after the CTD pump has been switched off. This float’s firmware contains the Near Surface Monitoring feature. At depth greater than 20 dbar, PTS samples are taken as in the normal depth table. At 20dbar, 15 dbar, 10 dbar and 5 dbar cross-calibration samples are collected which consist of a non-pumped PT immediately followed by a pumped PTS. At depths less than 5 dbar, 12 non-pumped PT samples are taken at 6 seconds intervals. This time duration allows for sampling up to and including the surface. The near surface sampling option requires only one extra Argos message and has no significant power implications.
- In a similar way, in 2010, Ifremer has developped the Near Surface Measurement feature to the Arvor by adding one extra surface layer. Now, data (continuous sampled during profile) are averaged into three kinds of slices instead of two earlier. The surface layer (typically 10m to 0m) can be programmed into 10 slices of 1m thickness and the cut off pressure of the CTD pump can be programmed. This cut off pressure is taken into account in order to flag TS samples which are not

pumped samples. This feature has been tested in 2010 on Arvor operated by Ifremer in Mediterranean Sea.

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3.2. Dissolved oxygen

The measurement of dissolved oxygen from profiling floats adds greatly to our understanding of both physical and biogeochemical process and thus has been the focus of considerable technological development effort. To date 291 floats carrying dissolved oxygen sensors have been deployed of which 191 remain active. Most of these are in the Pacific, but a few are in the Southern Ocean and the tropical and subpolar Atlantic.

Sensor types: two different sensor types are used today on Argo floats, Seabird electrochemical sensor and Aanderaa Optode 3830. Each of these has pros and cons; while for response times and initial accuracy the Seabird sensors are thought to be superior, it is the long-term stability, the ability to measure in low O_2 concentrations, and the robustness against biofouling that speaks for the Optode.

Accuracy considerations: Probably the most demanding O_2-accuracy requirements are for climate related issues like the evolution of the oceanic oxygen minimum zones (OMZ). It will be one of the challenges to quantitatively resolve the changes in the OMZ's and both existing O_2-sensors have to be improved for long term stability, time constant, calibration etc., and some efforts are undertaken in that respect. For example a new version of the Optode with more exposed temperature sensor (Mk II) will likely reduce the mismatch of the optical and temperature measurements in the Optode (Beta tests are running).

Calibration issues: The Aanderaa Optode 3830 is used on various platforms, including moored fixed level instruments, moored profilers, autonomous gliders, and profiling floats. The instrument specifications claim long-term stability of measurements (more than one year) without recalibration. However, our comparisons with CTD measurements show that the factory settings require an instrument-specific calibration to satisfy the accuracy needs to measure oceanographically relevant signals. A sufficient pre-deployment calibration is therefore of great importance. Two possible ways are under consideration: First, factory calibrations with improved accuracy are underway in collaboration between manufacturer and the Bjerknes Centre (Bergen), and these will be evaluated soon. Second, an in-situ calibration of the Optode is presently under investigation – with convincing results. Comment: individual near-by $CTDO_2$ profiles are not sufficient for e.g. OMZ studies.

O_2-Float lifetime: Generally the lifetime of a profiling float is reduced by a significant fraction when O_2 sensors are implemented. It is too early to judge whether O_2 sensors are reliable for durations extending to the approximately 3-year float-lifetime of any of the O_2 sensor models; however, T,S sensors are used beyond that duration. Therefore, it must be investigated whether total float life time should be extended by the use of Lithium Batteries to assure that the Argo requirements could be fulfilled.

Sensor position on floats (on top of float?): O_2 sensors are mounted at different locations on floats; e.g. on top of APEX float, but at lower end of PROVOR float. However, it has been shown, that Optodes can measure in moist air, and surface measurements may be used for calibration purposes. Thus a careful evaluation of sensor position for both, electrochemical and optical sensors is necessary, and also necessary is the further evaluation of the potential for barometric pressure measurements from floats for oxygen sensor calibration purposes.

Long-Term stability and Quality Control (delayed mode): Compared to the effort with the salinity quality control (delayed mode QC) the O_2-QC is in its infancy; one of the problems is the availability of reliable historical oxygen data. Here, Euro Argo should encourage the research community to timely make their measurements available.
In parallel efforts should and will be undertaken to investigate the long term stability of available sensors on other platforms; e.g. moored stations, gliders, moored $CTDO_2$-profilers – this will allow detailed long term (2 years at minimum) investigations of sensor behavior and post deployment calibrations.

3.2.1. Dissolved oxygen

Provor - Existing technology on PROVORDO: 3830 Aanderaa optode

- The absolute sensor accuracy is today it is ±5 % or ±8 µM (whichever is greater). Factory settings and calibration is sometimes erroneous.
- 90 % response time is today around 40 s, that is too much.

The position on the float is not ideal (lower end cap) when profiling on the ascent and atmospheric measurements are not possible when the float is “parked” at the surface. It could also be a difficulty to compare measurements with CTD, eg. in presence of high temperature gradients .
Measurement is done every CTD sample (10s). The optode is switched on during 2s, and off 8s. Extra power for optode lead to consume ~8% of total float energy, so lifetime capabilities of Provor float could be maintained beyond 3 years.
The cost of an optode is around 4000€.

Improvements-evolutions trends

There are aspects of existing technology which needs to be addressed before it can be mass deployed in open ocean studies. The objectives of the manufacturer are to reach the following specifications:

- Absolute sensor accuracy of ±1 % or ±2 µM (whichever is greater
- 90 % response time of less than 15 s.
- faster T sensor for temperature compensation will be placed in the proximity of the foil
- the response time of the foil should be improved.
- Improve its calibration procedure.

The position of the optode seems to be better if it is close to the CTD. In this case, the raw data of the oxygen could be combined to CTD temperature measurement, which is faster. The interest of this aspect should be confirmed. This will have consequences on transmission: more data to transmit.

Dissolved oxygen on Apex floats

The performance of oxygen sensors on Apex floats has been described by Kortzinger et al 2008. Much of the development work has been carried out by Steve Riser, University of Washington who has deployed floats fitted with both Aanderaa Optode and SBE sensors. This results have not yet been reported in the peer-reviewed literature.

3.3. Ice sensing

Initially Argo was intended to observe the deep ice-free ocean in real time. However, during recent years, the ice-resilience of Argo floats has been increased. Today four different types of ice compatible floats are in use:
Two commercial float types

1.) NEMO (by Optimare Sensorsysteme AG, Bremerhaven, Germany)
2.) APEX (by Webb Research Corporation, East Falmouth, Massachusetts, USA)

and two non-commercial float types manufactured at,

3.) University of Washington, USA (Steven Riser), and
4.) Hole Oceanographic Institution, USA (Peter Winsor).

NEMO Float:
So far, NEMO floats are ice compatible within in the Southern Ocean only. Ice compatibility is achieved by NEMO floats through three modules.

1) Ice Sensing Algorithm (ISA)
The algorithm aborts the float's ascent to the sea-surface when ice is expected at the surface. ISA improved float endurance in ice-covered seas significantly from less than 40% to 80% percent. In particular, 70% (7 of 10 floats) of the 2003 generation of ISA equipped floats have now reached their 6th summer season, exceeding the 5-year endurance design criterion as originally established for ice-free oceans. This increased endurance is most likely due to the saving of energy when floats avoid data transmission during the ice covered periods.

2) Interim Storage (iStore)
With some areas being ice covered for significant periods of time, substantial numbers of profiles will be aborted and thus not transmitted immediately, although these profiles had been measured by the float. Hence, it is desirable to save these data until they can safely be transmitted at a later date. To overcome these difficulties NEMO-floats are able to facilitate the interim storage of ISA-aborted profiles. The data of the aborted profiles are transmitted during the subsequent summer season when ice coverage – and hence risk of damage – is minimal, even when extended surface periods are needed to transmit the larger data volume.

3) Subsurface RAFOS navigation
To optimally utilize interim stored profiles, the profile/float location (under the sea ice) must be known to an acceptable level of accuracy. Use of travel time measurements of frequency modulated underwater sound signals allows retrospective tracking of floats by means of the RAFOS (Ranging And Fixing Of Sound) technology with an accuracy of a few kilometers. A RAFOS array for subsurface positioning of Argo-floats was installed within the Weddell Sea during the past years, consisting of a set of 10 moored sound sources. First results prove the usefulness of RAFOS positioning even under sea-ice.

Descriptions of ice related features of the other floats types mentions above have been requested and will be included in future report (pending availability).

Underwater Rafos navigation on Provor
The Provor can be fitted with an acoustic Rafos receiver. This technology have been used on Marvor floats in the nineties. It has been implemented on 3 Provor profilers (called Provor-A) in 2006 and tested at sea. However, floats fitted with acoustic positioning are intended to stay for a long while at parking depth: they don't respond to the 10 day's cycle specification of an Argo

float.

3.4. Biogeochemical

Measurements of biogeochemical parameters was made from oceanographic vessels in the past. With the coming of new small sensors with relatively low power requirements, new measurements are possible on floats.

"ProvCarbon" float have a Wetlabs transmissometer CROVER (carbon-related properties) and an oxygen sensor (Aanderaa optode).

"ProvBio" float is equiped with Wetlabs and S-Atlantics sensors: a transmissometer, a radiometer (3 wavelenghts), an ECO3 (fluorescence, CDOM, backscattering). These floats can performed 3 cycles per day. They use Iridium communication to transmit more data in less time and programming of the mission can be modified by downlink capability.

In 2001 a WetLabs precision fluorometer (designated FLSS) was integrated to an APEX float as part of a NASA-funded effort, by University of Washington, University of Maine and Oregon State University. Ongoing development since then has led to multiple deployments of WetLabs combined fluorometer and turbidity sensors (designated FLNTU and recently FLBB) usually in combination with dissolved oxygen and CTD measurements. Other optical sensors carried by APEX floats include WetLabs CROVER transmissometer and SeaPoint turbidity sensor.

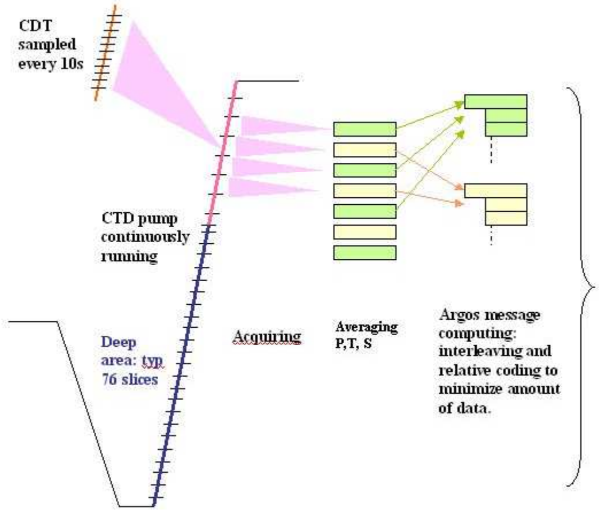
Improvements-evolutions trends
The demand for nutrient measurements is growing. Nitrate measurement should be implemented in 2010 on Provor, using new MBARI/S-Atlantic SUNA sensor. Trade-off between power availability and amount of data collected shoud be analysed.

3.5. Acoustic sensors

A detailed discussion on issues and requirements for acoustic sensors is given in Annex 1.

4. SATELLITE COMMUNICATION

a) Argos transmitted data on Provor
Data collected in float memory are gathered into Argos messages whose filling are optimised by absolute/ relative coding. Subsequent triplets correspond to alternating data points in the profile (for example, measurement numbers 1, 3, 5, 7, . . .). Interleaving data points are sent in another message. This technique minimizes the impact of the loss of any one data message.



To improve the probability of reception, data are transmitted several times. The number of repetitions depends upon the quantity of data to be transmitted, the transmission period and the programmed minimum transmission duration. Messages are sent in a random sequence in order to minimize the risk of accidental synchronization of one message with some form of transmission interference.
A "cyclic redundancy check" code (16 bits CRC CCITT) is added at the beginning of each message to make the transmission safer.

A technical message is generated which contains many informations to monitor the float motion. These one are used to make up more precise trajectories of floats.

Performance of transmission: for a typical 10 days Argo cycle (1000 dbars drifting, 2000m profile, 200m surface/ bottom pressure threshold, 10 dbars thickness for surface slices, 25 dbars for bottom slices), 112 PTS triplets are generated, approx 17 Argos messages, 6 hours transmission duration.

Argos2
Energy budget: 6h transmission duration → 4.75 KJ
transmission costs
15€ monthly fee + 2.25€ / 6 hours slice of transmission (CLS Argos 2008 rate).
→ for 3 profiles / month: 15€ + 3* (2.25€+2.25€)= 28.5€/ month.

The pros and cons of Argos are well known: global coverage, low modem/ antennas cost for the first, non permanent random access and poor data rates for the second.

Improvements-evolutions trends

Argos3 will give higher data rate, predictable tables of satellite visibility for mobile, acknowledgement transmission, downlink capabilities. Localisation of float will have the same performance of Argos2, If accurate fixing is needed, GPS should be added and the antenna issue should be resolved.

Argos3 performances (to be confirmed):

Energy budget: 10mn transmission duration, 2W mean power assumption, (1 Metop passing)→ 1.2 KJ
transmission costs:
15€ monthly fee + 3€ / 6 hours slice of transmission (CLS Argos 2008 rate).
Approx 1Kbyte / profile
for 3 profiles / month: 15€ + 3 *3€= 24€/ month,
→ 1 profile: <u>8€ / 1 Kbyte</u>

b) <u>Iridium satellite on Provor</u>

Iridium transmission has been successfully experimented on "multisensors" Provor, using short burst data (SBD) method. It has been used because of its higher capability then Argos2, to transmit a lot of data. The pros of this system are global and permanent coverage, good data transfer rate, simple and fast data access (email), downlink. The cons are modem and antenna costs, the poor capability of fixing (GPS is recommended).

Iridium transmission duration: a few minutes

Iridium transmission costs
15US$ monthly fee + 1$/Kbyte (approx.)
for 3 profiles / month: 15$ + 3$ = 18$ / month (~12 €)
→ <u>1 profile: 4€ / 1Kbyte</u>

<u>*Improvements-evolutions trends*</u>

For Argo applications, using Iridium will reduce staying at surface when transmitting data. This feature is very interesting in marginal seas by delaying beaching , so increasing lifetime of the float. More, remote control is possible with downlink.
Iridium could be a solution for higher amount of data transmission, increasing profile resolution.

Power budget:
power is saved, compared to Argos2 :
Argos2: 6h transmission duration → 4.75 KJ
Iridium: 3mn transmission duration (280mA modem mean current) → 0.5 KJ

Remote control permits to the user to optimise the mission of the float by modifying parameters such parking or profile depth, measurement sampling,… When designing this function, focus has to be placed on security in order to be sure that commands sent to floats will be not corrupted.

<u>b) Argos data transmission from APEXfloats</u>

ARGOS telemetry is the standard for APEX floats. APEX carries a Cobham (formerly Seimac) transmitter with nominal 1 Watt RF output.

<u>*Improvements-evolutions trends*</u>

Use of Iridium telemetry (combined with GPS) is increasingly common, based on Motorola 9522 modem. This enables high resolution bin-averaged CTD sampling, as well as greatly reduced surface time and optional use of bidirectional telemetry to revise float operating parameters.

Development of optional Iridium Short Burst Data (SBD) feature is planned for 2010.

5. FLOAT TECHNOLOGY

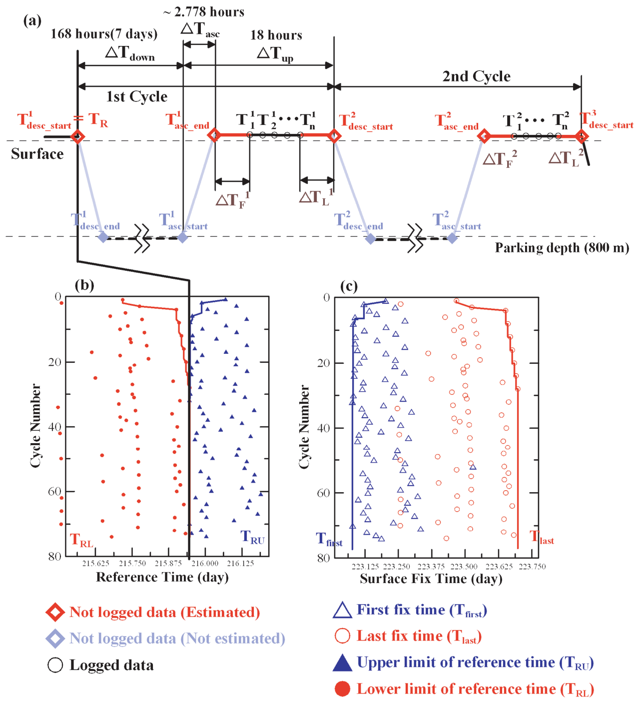
5.1. Float motion

The determination of subsurface velocities from the movement of the Argo floats is a fundamental objective of Argo and of Euro-Argo. The Argo cycle scheme is first, descent to parking depth and drift there, until time to descent to profile depth, and then rise to surface. Since, apart from floats that are tracked by RAFOS, the floats are only positioned when at the surface there are some inherent uncertainties in the estimation of the subsurface velocities.

These uncertainties are
a) the float displacement during the ascent and descent phases and
b) the determination from the ARGOS position fixes of the exact times and locations at which the float reaches the surface and starts its descent.

These positions have to be extrapolated from the data relayed by Argos. The method is fundamentally similar for all Argos-tracked float types and has been described in detail for APEX floats by Park et al (2004).

They concluded that the calculation of the surfacing and submerging positions could be done to an accuracy of order 1km and that this was dependent on geographical location (frequency of ARGOS fixes and shear between parking depth and the surface. (It should be noted that the global subsurface velocity Argo product YoMaHa'07 described by Lebedev et al. 2007, does not have these corrections applied).

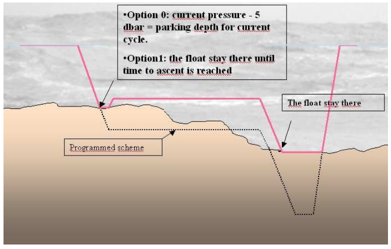


(a) Schematic diagram of depth vs time for a float cycle. (c) The time of the first and last fix for each cycle, mapped back to the first cycle by subtracting the float cycle period. (b) The times

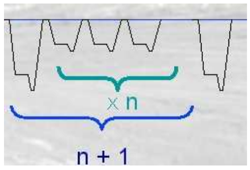
from (c) have been mapped around the initial dive, so that the reference time can be calculated. The units are Julian day (starting on 1 Jan 1999). (From Park et al 2004)

The following is a detailed description of the issues of position location for Provor floats. The Provor float is fitted with a high hydraulic pressure pump for ascent and electrovalve for descent. Depth resolution of a few meters are achieved in a 300-2000m gap. Descent speed is around 3.5 cm/s and ascent speed is accurately controlled at 9.5cm/s +/- 0.5 cms.

Grounding behaviour:
2 options after grounded, depending on whether you want to stay there waiting for ascent time or you want the float to escape and carry on with drifting.



One cycle every n cycle, the profile depth can be programmed different for CTD calibration at 2000m for exemple.



<u>Provor Improvements-evolutions trends</u>

- When descending, the time to reach the parking depth and then the profile depth could be shortened by controlling descent speed . Instead of lasting more than 15 hours to go to 2000m depth, the descent could last the same time than ascent (~6 hours). This could be useful to improve depth trajectories knowledge. This improvement has been already studied in the past, but not implemented (software) on float.
- One way to optimise hydraulic engine could be by coupling a secondary pump at surface to achieve emergence needed to transmission. Today this operation costs 9W power, which could be reduce by 10. This could lead to 10% more cycles. This improvement needs a consequent design work.
- Higher pressure operation: there should be many impacts on the design. First, the thickness of the hydraulic end cap should be checked; second, flow should be reduce to maintain power acceptable (or increased if higher power and higher flow is needed), according to batteries capabilities. May be, the capacity of the pump should be lower than today. This improvement needs a consequent design work

5.2. Batteries

Provor uses Lithium batteries which has high capacity, high current capabilities, low auto-discharge, high reliability, high price (~5% of total float cost). They are designed to supply the float to perform up to 250 cycles at 2000m, continuously pumping during profile and transmitting 110 CTD points to the satellite.

<u>Improvements-evolutions trends</u>
Higher capacities batteries exists (18 A.h instead of 13) and are available in the same volume, but with lower current discharge. These technology could be used for lower depth operation (eg coastal floats) or coupled to "super capacitors" to absorb peak current needed by engine (increasing price).

On the other hand, alkaline batteries could lead to reduce costs and simplify shipping rules (but reducing also performances).

Apex floats delivered from the manufacturer at present are only supplied with Mn-Alkali batteries. These are designed to provide sufficient energy for the floats to perform a 4-year (140 cycle) mission to 2000m.

Improvements-evolutions trends
Increasingly float operators have opted to fit lithium batteries to increase float life and thus provide a greater margin of error. Starting in 2010 WRC will supply floats fitted with lithum batteries.

5.3. Performance/lifetime

Lifetime of the float is determined on one hand, by how the mission is programmed by the user (it depends especially on the depth and the quantity of data to transmit), on the other hand by the available power embedded in the float. These features have to match the expected lifetime of the sensors to provide good data (i.e. it is not sensible to have a float that continues to ascend and descent and yet does not provide useable profile data). Some data about this drift shows that lifetime float, initially specified for 3 years, now leads to more than 4 years.

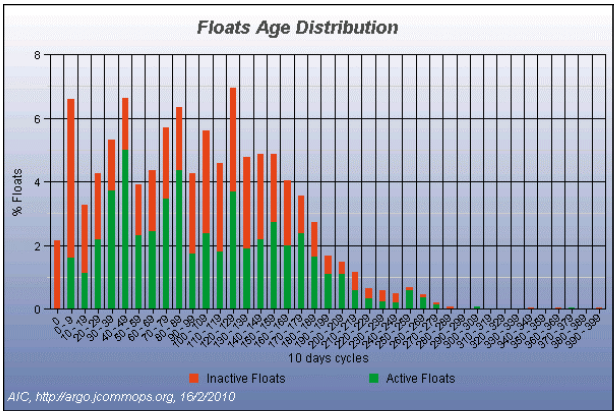
- Energy assessment.

Provor-CTS3 energy budget is calculated to reach 260 cycles at 2000m depth, 10 days cycle, 112 CTD data per profile, with 6 hours Argos transmission duration.
The Arvor, using less power than Provor, is able to do 250 cycles at 2000m.
As stated earlier in thios report the battery life of a standard (alkaline battery) Apex float is 140 cycles to 2000m.

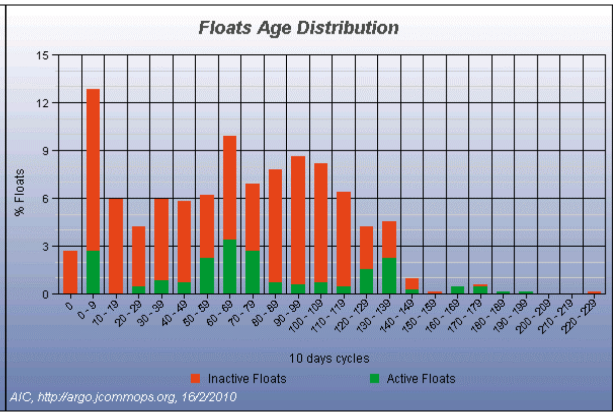
- Results at sea.

Today, some of Provor CTS3 have been cycling for more than 3 years. Those from JMA (Japan, 5 days cycles) have gone beyond 210 cycles at 2000m depth. The 2 first CTS3 floats deployed by Coriolis are cycling since 2005. To day, they are still cycling and have made 113 cycles at 2000m depth (10 days period).

The following charts show the age distributions (in terms of number of profiles performed) for the present active global array (green) and for those floats that are now inactive - floats that have failed for any reason (red). The graphs (for Apex and Provor floats) make no distinction between mission parameters (depth of profiling or parking depth) but do standardise to a 10 day cycle (e.g a float that has made 100 20-day cycles is represented as having made 50 10-day cycles. The charts do not distinguish between battery type (alkaline or lithium).



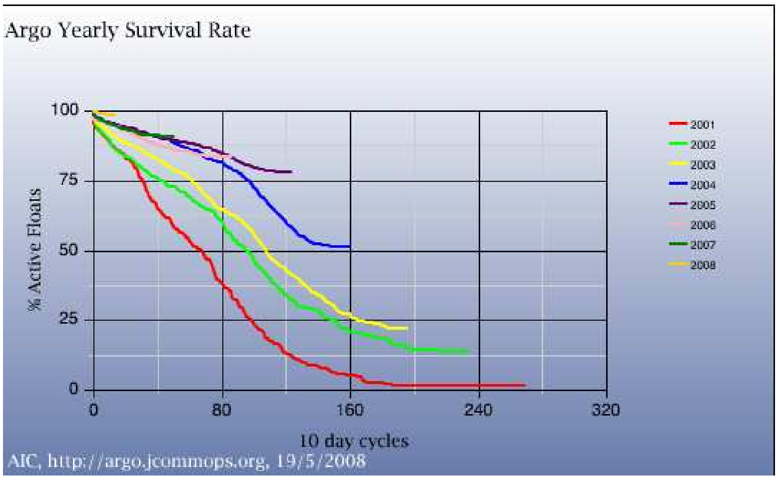
Apex float age distribution



Provor float age distribution

Both graphs show a drop off in the number of floats with a life longer than about 150 (equivalent) cycles showing that the 4 year planned lifetime is now being achieved.

This was not always so. Float lifetimes have steadily incleased during the 10 year lifetime of the Argo project as shown on the graph below.



Number of floats remaining active by year of deployment.

Improvements-evolutions trends

With higher efficiency communication (Iridium, Argos3) and reduced time spent at the sea surface the lifetime of floats will potentiually be increased (approx +20%).
Power of new CTD sensor will also decrease, resulting in ~15% extra lifetime.

6. SPECIFIC REQUIREMENT FOR MARGINAL SEAS

Desired technological developments for marginal sea floats

Floats

Lighter and easier to deploy vehicles like Arvor, but capable to profile as deep at 1000-2000 m.

Sensors

Improve oxygen sensor to be able to measure low values (characteristic of anoxic sea areas such a the Black Sea). Solve the problem of hysteresis (like with Optode sensor using slow-response time temperature sensor)

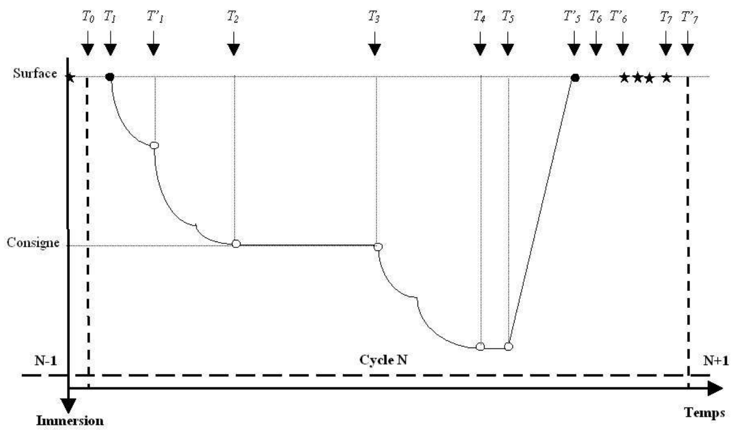
<u>Sampling</u>
Full resolution (1 m vertical resolution) profiles desired
Capability to profile as close as possible down to the bottom using pre-programmed bathymetry map (to avoid touching the bottom in shallow areas but to allow to monitor important deep water masses.

<u>Positioning</u>
GPS
Telemetry
Definitely Adeos3, Iridium or Globalstar bi-directional, with user-friendly management and dissemination.

7. OTHER ISSUES

7.1. Technical data transmitted

The technical parameters are transmitted for engineer analysis in order to have as many information as it is possible for understanding float behaviour. This is very useful to technical monitoring. Some information for decoding profile data are also contained in it. More recently, the construction of trajectories has taken advantage of these technical data, to be more accurate.



Technical data for trajectories

<u>Improvements-evolutions trends</u>
In order to improve Coriolis data decoding, some other informations could be added to technical messages such as current date of the float, current number of cycle, additional points of the cycle (time / pressure), parameters of mission programmed by user…

7.2. User interface

Provor programming interface needs a cable for float plugging and such as hyperterminal software.

Improvements-evolutions trends
A wireless link eliminate risks of plugging damage. Arvor is fitted with Bluetooth interface.

7.3. Initial testing and configuration

Provor doesn't need any ballasting preparation. It is ready to launch in any ocean.

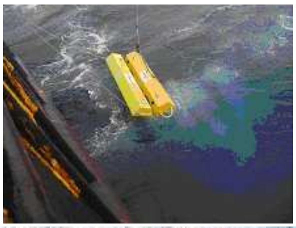
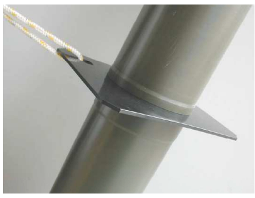
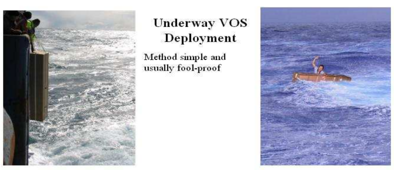
7.4. Handling / shipment

Mechanical features of the floats need to be very strong against harsh environment for Operational Oceanography, because these instruments are intended to be used by several operators before deployment. This include stocking, shipping and deployment conditions. Floats need to be certified for large environment conditions: temperature while stocking, shocks and vibrations during shipment and handling.
Provor specifications are:
Temperature storage: -20°C to 50°C, up to 1 year,
Vibrations: Sweeping frequency 0 to 55Hz, 3 axes,2mm peak to peak amplitude from 0 to 16Hz, 0.2mm from 16 to 55Hz
Shocks: 1/2 sinus, 15G, 20ms.
Hull made in hard anodised aluminium against corrosion.

Improvements-evolutions trends
To minimise costs, the using another hull technology should be benefit. Glass-epoxy or carbon-epoxy solutions, should lead to less cost and to lighter hull allowing more embedded pay loads.

7.5. Deployment

Provor mission start by simply remove a magnet that put the float on.
Many methods of deployments exists with sometimes, join tools to protect the float during launching.


Improvements-evolutions trends
The new Arvor float has been designed to facilitate deployment (its 20 kg weight makes easy handling by only one person). In many cases, no tools is needed to deploy it.
In VOS deployments, at high speed, a special launching cardboard case should be preferred.

Before first dive, Arvor will send a technical message on shore in order to control float just after launch.

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Annex 1

Technology of acoustic sensors for zooplankton measurements from floats

A large number of autonomous instrument platforms (drifters, floaters, AUVs, gliders, moored rigs etc.) for measuring hydrographical properties (salinity, temperature, oxygen etc.) exist today. When it comes to acoustic systems for measuring biological parameters, the assortment of platforms are much more limited. The main reasons for this are the high power consumption of most existing systems, large physical size and extensive need for storing and processing of the initial sensor data. Systems that do exist, has in general a very limited operation time or are physically large, enabling them to facilitate huge batteries.

To be able to map the current state of the art of low power acoustic systems, enquiries were sent to a number of companies worldwide. The same companies have also been asked to give an evaluation on the future advancements in technology. The results of this enquiry are elaborated more in detail in chapters “Existing technology” and “Likely technical evolution”.

Unlike more simple sensors (i.e. salinity, temperature etc.), acoustic systems can produce a large variety of output data depending on which requirements the user has for the acoustic sampling. Selection of requirements will severely influence what kind of equipment is needed. This does not only have an impact on the technical complexity, but does also influence issues like power consumption, physical size and cost. The end users of the acoustic data need to decide on demands and desires before a cost – benefit relationship is established. In this context “cost” is not necessarily a monetarily term, but might as well be other issues.

Requirements
This chapter contains elaboration around various issues concerning requirement of an acoustic system used to measure zooplankton from a new generation of Argo floats.

Aim of the acoustic data collection
To be able to select adequate acoustic equipment to be used in the Argo floats, it is important to define the scientific aim of this new instrumentation. The Argo floats are deployed throughout all the oceans of the world. Scientists might want to investigate different issues in dissimilar oceans. Even within European waters the ecosystems are diverse. To facilitate the possibility to perform

acoustic investigations with different scientific aims, it is important that the acoustic equipment is built up in a modular way. This should be done in a way so that transition from one setup to another can be done in a smooth way. Creating several different systems which do not build on a common basis should be avoided. Before acoustic instrumentation on Argo floats has become a reality, it might be difficult to foresee the scientific potential of this new sensor. As acoustic data from the Argo floats become available to the scientific community and analyses are performed, it might lead to a revision of the aims and potential of the data collection.

Biology

Different species of zooplankton play an important role in the ecosystems of the various oceans of the world. The size span of zooplankton species is large. In some European waters, small copepods of only a few millimetres are vital components in the food chain. In Antarctic waters, krill with a maximum size of approx. 60 mm is regarded as key species of the entire ecosystem. The acoustic challenges are very different between the smaller and the larger zooplankton species. This is the case both from a technical point of view as well as from a biological view. Some of the larger zooplankton is rapid swimmers which need to be monitored from a distance due to potential avoidance or attraction reaction to the Argo float. In most waters there will be a mixture of zooplankton species at varying densities and depths.

Acoustic properties

Based on the aim of the acoustic sampling and the zooplankton species composition of the investigating area, echo sounder frequencies have to be selected. It would be advisable to sample the zooplankton with more than one frequency to reduce the inherent vast ambiguity of the data. This will make it possible to distinguish between size groups as well. Multifrequency ($\geq$ 3 frequencies) observations and analyses are now used for species and size group determination, mainly on fish. The total frequency span will determine the total estimated size range of observed organisms. The number of implemented frequencies will generally determine the size resolution. This is exactly true for a mathematically determined estimation case while the number of size groups may be increased regardless the number of frequencies for an underdetermined case possessing other problems. Both figures have to be determined based on the overall aims of the buoy system, demands for accuracy, technical feasibility and cost.

The most applied method for size estimation of zooplankton from acoustic data is based on measuring the volume backscattering coefficient at all frequencies and put these data into an acoustic-mathematical model and running the size estimation through an inversion method. The main requirement in the inversion process is to explore the most nonlinear regions versus frequency of the scattering models of the prevailing zooplankton, e.g. the transition region between Rayleigh scattering and geometric scattering.

For instance a frequency of around 1 MHz might be preferred as the highest one covering the smaller zooplankton down to a minimum size of 0.5 mm. At this high frequency the range of the acoustic system is very short and the volume sampled will be low. For larger organisms up to a maximum size of 10 mm, a lower frequency will be preferred, maybe at 100 kHz or lower. Larger organisms than 10 mm may be observed at 100 kHz, but estimating their size distributions will inherently be of lower accuracy, e.g. due to lower signal-to-noise ratios. For instance by going for a 3-frequency system, the in-between frequency should be in the range 400-550 kHz. These elements have to be more closely investigated when it has been decided on the target zooplankton species and their belonging size ranges.

Instead of using several discrete frequencies a wideband system might be an option. If the acoustic system is to sample at frequencies far apart, the frequency range of the transducer might be a problem. More that one transducer will be needed or several transducers have to be built into one unit.

The beam width of the transducers has to be determined. All transducers should preferably have equal beam width and be mounted as close together as possible. This has implications for the quality of the multifrequency analyses. For ship mounted, towed or autonomous vehicle borne multifrequency acoustic systems, transducers with rather narrow beam widths, approx. 7º, are used. This is neither a requirement nor a necessity for a buoy borne system. Smaller transducers and wider beams will rather be a requirement for this kind of buoys both from technical, operational and cost reasons.

If the transducers are pointing horizontally, the system will have a larger sampling volume than a vertical looking system since a down looking setup only will cover a small area along the path of the float. Much of the acoustic work done on zooplankton is however based on dorsal aspect observations and thereby vertical looking transducers. The sampling aspect of all organisms has an impact on the acoustic backscattering in the geometric scattering region.

If a vertical looking acoustic system is chosen, data collection should not take place during ascend since the float itself might have disturbed the organisms as it passes by and thus influenced the acoustic recordings.

The selected transmitter power most be chosen with care. Higher power will increase the range as well as the power consumption.

The duration of the transmit pulses will also influence the power consumption. A short pulse gives higher spatial resolution and shorter range.

The ping rate has to be determined based on the need for vertical resolution (if the transducers look horizontally), sampling range and power consumption.

If there is a need for measuring single organisms (target strength measurement), a split beam system is needed. The transducer and the echo sounder electronics become more complex and expensive. The simpler single beam systems will measure the spatial distribution and volume density of the zooplankton and the data possess qualities for estimating size distribution when applying several frequencies.

The acoustic system should be calibrated according to scientific standards. This will ensure comparable data not only between different Argo floats, but also compared to other acoustic platforms. One option is that the floats are delivered with full system calibration from the producer. A challenge when it comes to calibration is depth stability of the transducer performance. Depth stable transducers or transducers with predictive performance are more expensive to produce.

Physical limitations

The Argo floats operate to a maximum depth of 2000 m. The high pressure does not only represent a problem for stable transducer performance, but might permanently damage the transducer if proper design measures are not implemented. Most transducers available on the marked could not tolerate the pressure at 2000 m.

The available space for acoustic instrumentation must be determined to clarify the size restriction which applies.

Electronics

The many aspects mentioned above in chapter “Acoustic properties” will have profound impact on the echo sounder electronics. Only when the sum of requirements for the acoustic system is known, details on the impact on the electronic design and solution can be given.

One of the main challenges for use of acoustics in the Argo float is the average power consumption. This figure can not be determined without knowledge of issues like sampling strategy (see below), ping rate, transmit power, number of frequencies and so on. For potential producers of acoustic instrumentation to the floats, an idea of instantaneous power consumption in passive mode would be useful. A realistic maximum value could be 1 W and preferably less than 0.5 W. The supply voltage has to be determined.

It has to be determined to which degree the echo sounder should be a stand alone unit which handles issues like sampling strategy, sleep functionality, data compression, data storage and remote communication. A central Argo processor might also handle some or all of these tasks.

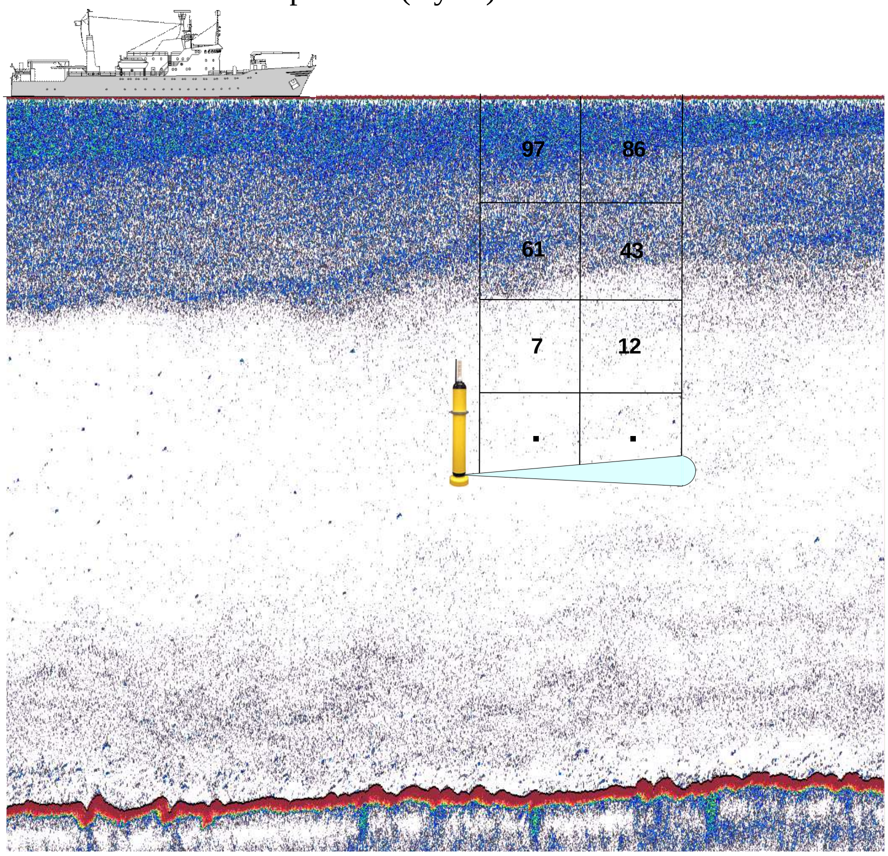
The choices made will have an impact on the electronic solution. Regardless of the choices, the echo sounder electronics must have some feature:

- Communication ports to send out acoustic data to be transferred ashore.
- The sounder should be able to read various types of remote parameters and requests to alter the sounder performance or inspect settings. The parameters might be sent from an internal Argo processor or via satellite communication from land.
- A sleep function should reduce the power consumption to close to 0 W.

Data processing

Acoustic systems tend to collect large amounts of data far beyond the capacity of the Argo communication link. The available baud rate and time span dedicated for acoustic data transfer via satellite has to be determined.

Various forms of data compression are needed. Standard data compression algorithms might be used on the final data. During data collection the amount should also be minimised. Data might for instance be averaged over a number of pings. If the aim is to produce rough vertical distribution data of zooplankton, the mean volume backscattering coefficient (s_v) can be calculated for a limited number of depth bins (layers).



The figure shows a possible way of collecting acoustic zooplankton data from an Argo float. As the float descends through the layers of plankton, a sideway-looking echo sounder collects data (the acoustic beam is indicated in cyan). Several ping returns are averaged as the float sinks (gives vertical/depth data compression) and the acoustic backscattering is calculated for a limited number of range bins (horizontal data compression). The result is a small matrix or table of zooplankton backscattering data for each acoustic frequency, well suited for transmission via satellite communication.

Remote commands and requests have to be handled. The messages might be echo sounder settings, processing algorithms, data transfer commands or sampling strategy parameters.

Depth information should be used to stop pinging when the Argo float is out of water, since transducers might be damaged if they ping in open air. Averaging of ping returns may be done based on depth data (gives data by depth layers) instead of a fixed number.
Information on sound speed from other sensors in the float should be input to the sounder system to improve accuracy of the acoustic sampling.

Sampling strategies

The chosen sampling strategy has a profound impact on total power consumption. Based on the scientific aim, the sampling might for instance only take place in the upper part of the Argo depth profiling. If the depth distribution of zooplankton is not known, sampling might stop if the density decreases below a set level.
It might be sufficient to only sample during ascend and not during descend like the Argo floats do today, since geographic and time difference is small between the two and it is probably unlikely that zooplankton distribution has changed a lot.
If the system detects deterioration in the battery capacity, the sampling strategy might be altered automatically. It is possible to imagine a number of factors which might influence the chosen sampling strategy; e.g. different sampling schemes during night than day, reduced sampling if the Argo floats geographical drift is small etc. The possibilities and demands for the acoustic sampling will first be reviled after the new Argo float have been used for some time, so modularity and flexibility in every aspect of the acoustic instrumentation is vital.

Costs

Several factors will influence the unit cost for an acoustic sensor. As mentioned above, the end user has to define the aim of the data collection and also specify the demand for data quality. Some choices will have a considerable impact on the unit cost.
Since it is most likely that development activities are needed to get an echo sounder system suitable for the Argo floats, development costs have to be divided between an expected numbers of units to be produced. All the companies contacted have found it hard to give a proper cost estimate. Assuming we are looking for an echo sounder with two frequencies and two single beam transducers, producing simple backscatter data in depth bins, a very rough cost estimate has been given by a few companies at a price of approximately 5000 EUR a piece. More frequencies will raise this price estimate.

Existing technology

A total of 13 companies worldwide, producing acoustic equipment have been contacted. Four of the companies have replied (see chapter "Presentation of potential provider" below), claiming they have the needed technology and interest to participate in the development of a modern low power acoustic sensor for use in the future Argo floats. They all have existing systems within the line of what is needed, but all companies need to develop the instrumentation to suit the demands of the Argo system. There might be other companies with the needed competence that has not been detected during this search.

Likely technical evolution

The advancement in technology for use in acoustic sensors has been large the recent years. There is no reason to believe that new improvements will not still appear in the time to come. By the time of realisation of the Argo float acoustic system, new technologies and new actors might arise.
A trend in the development of acoustic systems the last years have been to move away from hardware defined equipment. The functionally of the sounders are now to a higher degree determined by software, giving more flexible systems. Advancement of electronic components has and will contribute to smaller and more accurate echo sounders. This is valid for all modules of an echo sounder, from the processing units to the transceiver.
The use of composite technology for transducers has become more common. The transducers become more broad banded and an increasing numbers of depth resistant transducers will be

available. It is likely that it will become more common to include some of the echosounder electronics inside the transducer unit. This will reduce cabling and remove noise.

Conclusions

Scientific demands and aims have to be determined first by the end-user before technical solutions are chosen based on cost / benefit considerations. At the current stage an estimate of the trade-offs between the additional costs and increased power consumption is therefore difficult to perform. However, it is likely that only a minor part of the total Argo float cost is needed to implement an additional acoustic sensor. Such a sensor will attract other user groups and increase the scientific value of the floats.

It seems to be realistic to develop an adequate acoustic sensor for zooplankton sampling on Argo floats.

Presentation of potential providers

Below follows a short presentation of the companies identified as potential providers (in alphabetic order) of such a sensor:

ASL Environmental Sciences, Canada, *http://www.aslenv.com/*

The company already manufactures a single-frequency Acoustic Water Column Profiler (AWCP) for zooplankton monitoring. The average power consumption is approx 0.5 W with available frequencies at 125, 200, 460 and 800 kHz each with 6 to 9 degree beam angle depending on the (single-beam) transducer. The company is supplying additional echo sounders for use on Argo floats as part of the Damocles project to detect ice.

Marport, Canada, *http://www.marport.com/*

The company uses a new technology, SDS (Software Defined Sonar) for their very small (54mm x 45mm x 36mm), low power (2 mW standby, 2-10 W transmitting) acoustic sensor. The central USP (Universal Sensor Processor) can be programmed as an echo sounder at various frequencies without hardware modifications. Several frequencies can be accommodated by one USP in addition to other sensors (pressure, temperature, pitch, roll etc). Current frequency range is from 10 - 400 kHz and broadband transducers are an option. Dynamic range for the acoustics is currently 80 dB and the acoustic system can be calibrated to scientific standards. The USP can store 16 GB internally and has interface options.

Nortek AS, Norway, *http://www.nortek-as.com/*

The company produces low power ADCPs (Acoustic Doppler Current Profiler) in small housings for long time deployment. ADCP technology does not focus on accurate measurement of signal strength to the same degree as ordinary echo sounders, but the focus on power consumption, size and high accuracy is dominant. Nortek regards the development of an echo sounder variant of their equipment as very realistic and well inside their business area.

Kongsberg Simrad, Norway, *http://www.simrad.com*

This company, which is one of the world leading manufacturers of acoustic equipment has a fisheries research department supporting scientific demands. Recently, Kongsberg Simrad has developed a compact, low power, low cost echo sounder module (Simrad ES10) for use on buoys. Approximately 200 ES10 are sold yearly. Average power consumption is approx. 1 W and the dynamic range 96 dB. Currently one frequency of 190 kHz is supported, but multifrequency designs can be developed. Remotely, the sounder can be set up to average over several pings and backscattering data can be compressed in depth bins if required. The size is 10 x 11 x 4 cm. Development of a small external microcontroller card with storage has been discussed to facilitate advanced operations (survey strategy, data compression, mission plan etc.)