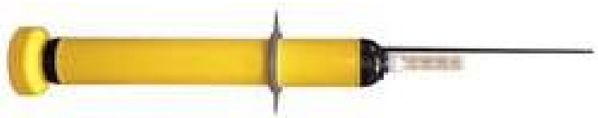


REPORT FROM THE 1st ARGO TECHNICAL WORKSHOP
September 19-21, 2005
University of Washington, Seattle, USA

[prepared by S. Riser and S. Wijffels]

1. Meeting Summary

- If prepared and used correctly, APEX floats can meet the Argo specification of profiling for 4 years to a maximum depth (pressure) of 2000 dbars.
- The cause of 80% of past failures of APEX floats are known, and most failure modes have been eliminated.
- Battery performance and battery quality issues are the largest source of float failure – strategies exist to deal with these problems.
- Experience cautions against wholesale adoption of new features or design changes before they have been well-tested – it is best to deploy floats with new features in small numbers and to increase the number of deployments slowly as the performance is shown to be favorable.
- SeaBird CTD sensors generally meet Argo requirements; over 80% of the data returned are of high enough quality that they require little or no delayed-mode corrections.
- There are several common sensor failure modes which are not understood. Recovery of floats with these symptoms is encouraged whenever possible so that the problems can be diagnosed in a laboratory setting.
- Thermal lag errors are the most significant source of salinity errors in Argo CTD data. These are bias errors (not random) and need to be taken seriously. For the present, these could be partially corrected during the delayed-mode QC process. APEX users need to work with SBE to discuss software and/or hardware changes that will reduce the size of these errors.
- Argo APEX users need to supply information to the Technical Files in the Argo data stream in a consistent manner, so that analyses of the technical performance of the entire array can be carried out in a simple fashion. The Argo Data Management Team needs advice on names and information to insert into these files.
- The Argo community needs a clearinghouse for routine analysis of APEX float failures and anomalous behavior, so that batch manufacturing problems are quickly identified and fixed, and so that a clear picture of the array's performance is available on a timely basis.

- Argo APEX users should strongly suggest to the manufacturer that 5-day averages of hourly temperature and pressure data be collected while the floats are in their drift phase (ie, between profiles); these data should be included in the telemetered profile data.
- A simple set of instructions for procedures to be carried out with grounded/stranded floats needs to be developed with the float hardware manufacturers and made available to the Argo Technical Coordinator.

2. Current Status of APEX

The Argo array consists of over 2000 floats (at the time of the meeting), and APEX floats manufactured by Webb Research Corporation (hereafter WRC) comprise about 70% of the global array. Thus, high reliability and efficiency of these floats are vital to the success of the program. Nearly 100% of the APEX fleet are equipped with CTD sensors (conductivity, pressure, depth) manufactured by SeaBird Electonics (hereafter SBE), and the success of Argo is similarly highly dependent on the universal accuracy and stability of these sensors.

In March 2000, at the second meeting of the Argo Steering Team, the following technical specifications for Argo were agreed upon as goals for the array:

- 90% of floats attain a 4 year useful lifetime (~ 150 cycles at 10 day cycling)
- 2000 m profiles everywhere
- temperature accurate to 0.005 °C
- pressure accurate to 5 decibars
- salinity accurate to 0.01 (PSS-78)

How well have we achieved these aims?

When considering **float lifetimes**, we have several examples of floats that have lasted 5 years (although these profiled only to 1000 m). However, many early Argo floats failed within their first year or second year. We believe that we have identified and fixed the causes of many of these premature failures. The problems found include

- Motor backspin, when back pressure on the electric motor induces large currents that damages float electronics (found in 2002, fixed in 2003)
- Loss of energy due to manufacturing defects with internal float electronics (found and fixed in 2003)
- The snowflake effect – failure of the Druck pressure sensor (found and mostly fixed in 2003)
- Failure of individual alkaline batteries, causing entire battery packs to fail prematurely (problem known since 2001, cause determined in 2004, possible fix has been implemented)

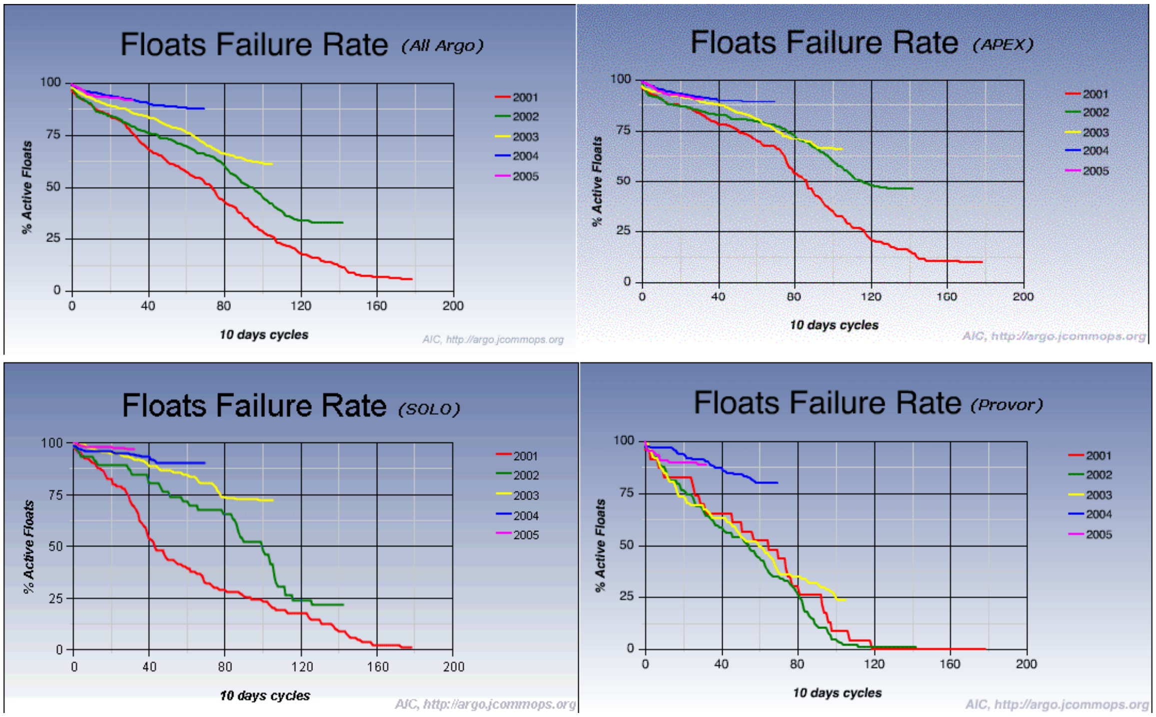


Figure 1: Float reliability (number of profiles delivered as a percent of the number expected) as a function of time and deployment year for APEX, SOLO, and Provor floats (this figure was provided by M. Belbeoch; an earlier version was shown at the meeting).

Due to the problems listed above, only 60-70% of early APEX floats (those deployed in 2001-2003) were operating after 1-2 years (see Figure 1). APEX floats deployed by the University of Washington (hereafter UW) during these years were substantially more reliable (over 80%), most likely due to UW floats parking at 1000 m and profiling to 2000 m only every fourth profile. This practice greatly reduced the loss of floats due to the motor backspin defect, which was only a problem on floats profiling to 2000 m on each cycle. While it is desirable to collect as much 2000 m data as possible, in this case the choice of conservative missions that limited deep data collection to occasional profiles clearly had the effect of increased float lifetime.

Collecting data from 2000 m on each profile is still a challenge: alkaline battery life is adversely affected (see below), and until recently it has not been possible to profile to 2000 m everywhere in the world ocean due to buoyancy limitations (these limitations are most severe at low latitudes with very low density surface waters). Recently, WRC has offered floats with the N_2 buoyancy feature, whereby a mechanical compressee assists the float ascent from dense deep waters through the higher stratification in the upper ocean. This feature has been tested on floats in the Bay of Bengal (one of the most difficult sites for 2000 m profiling in the world ocean due to low density surface water) and has worked well on the floats that have been tested so far. This simple addition to the APEX buoyancy engine appears to have removed the buoyancy limitation on 2000 m APEX profiling. Float hulls made of various carbon fiber composites are undergoing testing at the present time and may offer another method for extending profiling to 2000 m globally at a reduced energy cost.

CTD sensor stability has been definitively examined from several recovered floats. JAMSTEC has successfully recovered 4 floats, and a fifth has been recovered by UW. Post-recovery recalibration showed that the SBE CTD sensors were remarkably stable [see the table below], well within stated Argo goals. Delayed-mode quality control of 132 UW long-lived floats also showed that 95% required no salinity corrections, while on 7 floats the sensors drifted by 0.01 to 0.02 (PSS-78) per year.

FLOAT	TIME (days)	Δ*T* (°C)	Δ*S* (PSU)	Δ*p* (dbar)
4 (Japan)	840	0.0014	– 0.006	4.7
5 (Japan)	730	0.0015	– 0.005	5.9
6 (Japan)	900	0.0010	– 0.012	0.7
063 (UW)	1096	0.0003	– 0.006	0.6

Table 1: Results of recalibration of recovered floats by UW and JAMSTEC groups.

In summary, APEX floats generally work to Argo requirements until they cease operation; the main challenge at the present time is to increase the mean time to float failure. Good progress is being made towards this goal. Over the last few years float reliability has dramatically increased, and the CTD sensors on floats are generally quite stable and operate within Argo specifications.

However we have not yet reached the stated goal of 90% of APEX floats achieving a 4-year lifetime. A more coordinated, community-wide effort to monitor and improve the performance of APEX floats in Argo is required.

The meeting goals are thus to

- Suggest methods to monitor float performance
- Assess the performance of APEX floats in Argo, and suggest solutions to the remaining problems in order that floats provide reliable data for ≥ 4 years on average; to identify the remaining problems and how can they be fixed
- Examine new technology and features to be added to floats in the near future
- Suggest ways for increasing communication with WRC and SBE so that floats can continue to improve.

3. Failure Modes of APEX Floats

A long-term analysis of a group of 860 APEX floats, originating from UW and many other national programs, has been carried out with the goal of identifying the predominant modes of APEX failures. Of the 860 floats, 366 have already failed. Analysis of their failure modes based on the scientific and engineering data returned by the floats indicates that 5 problems caused 80% of float failures, as listed here:

1. Energy flu (36%), consisting of alkaline battery pathology (31%, fix underway), and motor back-spin defect (5%, fixed).
2. Float grounding (21%), consisting of silt collection in the cowling (17%, fixed), and drifting ashore (4%).
3. Symptomless failure (usually termed AWOL floats) (10%).
4. Druck pressure sensor defect (7%, generally fixed).
5. Motor back-spin defect (7%, fixed).

Appendix A contains a more detailed explanation of these failure modes and their diagnostic signatures in float data and engineering parameters.

As noted, several of these problems have been fixed. Yet the largest source of failure by far, alkaline energy flu, generally remains as a problem. Several fixes for this problem have been suggested, but it is not clear that these remedies have yet been successful (see Figure 2).

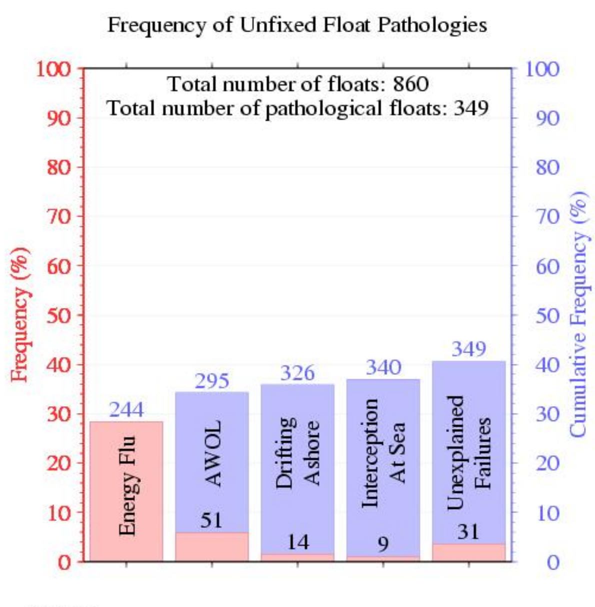


Figure 2: Frequency of float failure due to currently unfixed problems based on the analysis of the failure of 366 APEX floats (supplied by Dana Swift., UW).

Based on this analysis, the following steps are recommended in order to improve float lifetimes:

1. Use the *Park and Profile* feature (ie, do not go to 2000 m on every profile), particularly if using alkaline batteries (see below).
2. Deploy away from islands and coasts.
3. Monitor the engineering data from each float on each profile (this can be automated).
4. Avoid deployments of large numbers of floats with of new features until the performance has been documented (the motor backspin problem is an example of this, where large numbers of floats profling to 2000 m were deployed before this capability was fully tested by the manufacturer and the user community).

(a) Energy flu/Battery Failure [Addressed but not yet fixed]

Roughly defined as the premature discharge of the float's alkaline batteries, this failure mode has had several causes: alkaline battery energy flu, which is the dominant cause, with some low incidence strains such as motor back-spin, APF controller pathologies, APF firmware defects, and SBE41 pathologies.

Based on laboratory testing done at UW, an APEX float with alkaline battery packs should achieve 300 shallow (1000 m) profiles, 220 park and profile cycles (to 1000 m on three out of four profiles, and to 2000 m on the fourth), 160 2000 m profiles. Note that one reason for the larger number of shallow profiles is that a lighter weight hull can be used, allowing an additional battery pack be carried by the float. However, many floats are not meeting these theoretical projections. An analysis of the battery voltage records from the float ensemble clearly shows that floats with alkaline batteries that profile to 2000 m on every cycle consistently showed premature battery failure, and failed prematurely in greater numbers than floats that only profiled to 1000 m (see Figure 3).

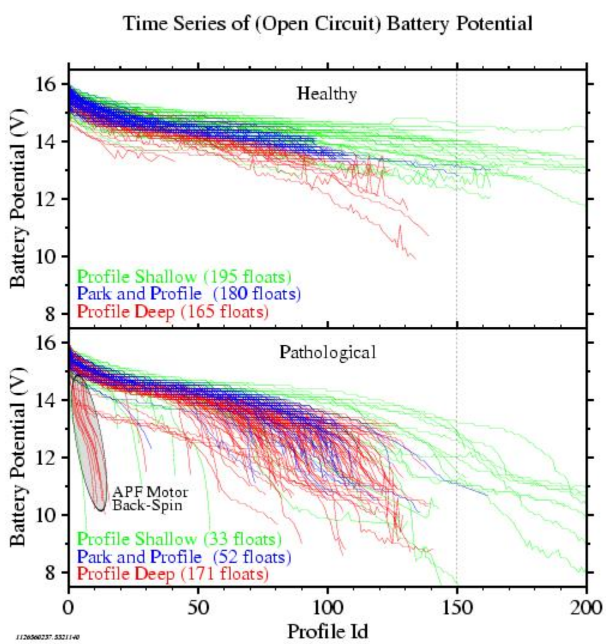


Figure 3: Battery voltage as a function of profile number. Top – floats operating normally. Bottom – floats exhibiting energy flu (from D. Swift, UW).

It is now believed that running the float pump at high pressure results in high peak currents drawn from the battery packs. These currents are thought to cause individual alkaline cells in the battery packs to fail; once a cell fails, its high impedance breaks the circuit in the battery pack and the energy in the pack becomes inaccessible to the float.

Once the energy flu was recognized as being associated with alkaline batteries (n.b. Duracell alkaline batteries), WRC installed bypass diodes across all cells within a battery pack (this was initiated in February, 2004). In theory, this should prevent failed cells from preventing the energy in entire battery packs to be accessible.

	Leakage Proof	Adding Shunt Diode	Parking depth	Number Deployed	Energy flu	%
APF7	No	No	2000	16	12	75
APF8	Yes	No	2000	77	8	10.4
APF8	Yes	No	1000	44	7	16
APF8	Yes	Yes	1000	117	4	3.4

Table 2: Statistics of number of JAMSTEC floats that failed from energy flu. All floats profiled to 2000 m on every cycle (supplied by N. Shikama, JAMSTEC).

Subsequent experience at JAMSTEC (Table 2) clearly shows that diode protection has greatly decreased the early occurrence of energy flu in alkaline powered floats, reducing failure rates from 10-15% of floats down to < 5%. This is very encouraging.

However, this problem is not entirely solved, for several reasons. First, diodes do not prevent cell failures, they simply reduce their impact. Secondly, and of great concern, is that 7 UW floats with diode protection still exhibit energy flu. JAMSTEC has also observed energy flu in four floats with diode protection. This suggests that despite diode protection, failing cells are still somehow affecting other cells in battery packs, resulting in rapid float voltage drops over 4-5 profiling cycles. Finally, it is distressing that cell failure and energy flu have never been reproduced in the laboratory, despite many tests on hundreds of cells having been performed by Dana Swift at UW. Thus, we still do not understand the single most important cause of premature float failure as of the time of this meeting.

We can conclude that energy flu is still not really understood and we need to continue to investigate its cause. Alkaline battery manufacturers have not responded to inquiries about cell failures. However, we suspect that the batteries are aimed for a mass market and a low price (indeed, most traditional users of these batteries can simply replace a failed cell with a new one). Attempts to find alkaline batteries made to a higher reliability standard have so far proven unsuccessful. Thus, other actions must be taken to limit float mortality due to this problem, as described below.

Short-term fixes for Alkaline Energy Flu:

1. **Do not profile deep as often.** Deep profiling requires pumping at high pressures and causes high peak currents to be drawn from the battery packs. By reducing the frequency of deep profiling, damage to alkaline cells is reduced. This is clearly indicated in D. Swift's analysis showing higher longevity of alkaline powered floats that do not profile deep frequently. Hence, if alkaline battery packs are to be used alone, we recommend that floats park and profile to 1000 m, with a 2000 m profile only every fourth cycle.
2. **Install lithium batteries.** Lithium batteries do not suffer from failure under high peak currents and do not exhibit energy flu. CSIRO has been replacing two alkaline packs with lithium batteries since 2000. Among 61 APEX floats powered by such mixed packs, none have shown evidence of energy flu, even the 18 which have profiled over 80 times to 2000 m. Similar results have been obtained by UW and PMEL in younger floats. UW now uses lithium batteries exclusively.

Actions taken to address alkaline battery flu by the various groups represented:

CSIRO, UW, and PMEL open the floats and replace 2-3 alkaline battery packs with lithium batteries.

JAMSTEC will likely move to installing lithium batteries within the next year.

The Canada, China and Korea Argo programs currently do not routinely open floats but will consider changing to park and profile sampling, or eventually to change to lithium batteries.

Every national Argo program represented at the meeting strongly urged WRC to offer lithium batteries as an option that can be purchased directly from WRC.

Advantages of lithium batteries:

Lithium batteries feature many advantages over alkaline batteries:

- They are more reliable, as they are manufactured to a higher standard
- Their higher energy density means the floats will last longer or can profile deep on every cycle, thus saving costs in delayed-mode QC and increasing data coverage
- Alhough lithium batteries are initially more expensive (there is an incremental cost of approximately US$800 per float), the increase in float lifetime of 1-2 years easily justifies the increased cost

However, there are some serious disadvantages in using lithium batteries:

- They are considered to be *Hazardous Material* by shipping companies and so are more difficult and expensive to transport. The float deploying agency must transport the floats using a shipper specifically certified to handle hazardous materials
- Purchasing the batteries and opening the floats add costs and complications to float operations, making the operation too complicated for some float groups

Regarding mixing battery packs: Lithium batteries do undergo passivation during the 10 day drift of the float when little energy is drawn from them. Passivation means a "skin" forms in the cell which increases the cell's initial impedance. It is unclear how this effect interacts with the float electronics, especially during the first wake up after the drift phase, when the CTD and controller board are active and require small currents, but the float pump is not yet turned on.

Once the float pump is switched on at the beginning of a profile, the passivation layer is burnt off and the lithium cells become active again. In mixed battery pack floats, it is possible that the alkaline batteries could provide energy to the float electronics before the passivation layers of the lithium cells have been dissipated, a possible advantage to the mixing of cell types.

General Discussion of Batteries/Energy Flu:

P. Whitely (UKMET) asked whether alkaline energy flu could be due to the fact that a single battery could be supplying much of the energy earlier on and thus failing. Could more careful construction of battery packs avoid this, such as matching impedances?

Whitely noted that new lithium battery technology was available that was intrinsically safer than previous types. Would these remove some of the shipping restrictions?

Another source of premature energy loss could be variable efficiencies of the floats motor/piston system. Papij and Mantel (CSIRO) have noticed in the laboratory that the current drawn by the motor pump cycled high/low (~30%) with each rotation of the piston. This current cycling increased in amplitude as the back pressure was increased on the bladder. A misalignment between the piston and motor will generate precession in the mechanism, and thus variable float efficiency. Others in the group noted that some floats are noisier than others, and some have variable pitch during pump operation.

Whitely wondered whether one could listen for this problem, note it, and later correlate it with rapid battery discharge. That is, are the noisy floats more inefficient?

(b) Grounding/Silt Collection [Fixed]

After alkaline energy flu, the next most significant known APEX failure mode is grounding. Of the UW analysis group, 17% of float failures were associated with grounding; with JAMSTEC floats, 7% of failures were due to grounding.

In theory, floats that touch bottom should not have higher failure rates than those that do not. However, JAMSTEC has demonstrated that about 25% of grounded floats do not resurface after grounding. Engineering data suggested that the float's mass was increased after grounding (see Appendix), and indeed, retrieval of a float that had grounded revealed that sediment had accumulated inside the float bladder cowling (Figure 4).

Cowling had 8 small holes   Silt weighed 13.4g

Figure 4: Cowling (left) and cowling interior (right) of a recovered JAMSTEC float showing significant sediment load acquired during grounding (supplied by N. Shikama, JAMSTEC).

Once this problem was recognized, WRC began plugging all but 7 of the holes in the float cowlings to reduce this hazard. JAMSTEC noted that failure due to grounding is now reduced to only 1% of grounded floats.

Sealing all but 1 hole in the float cowling has one drawback. On deployment, float cowlings are air filled, and with only one small hole for the air to escape, flooding can take a long time; during the float will not be oriented upright with its antenna out of the water. This means that the initial float test messages might not be received. Solutions include drilling smaller multiple holes near the top of the cowling (UW group), or flooding the cowling before deployment (Canada Argo).

(c) Snowflake Effect - Druck Pressure Sensor Failure [Generally fixed]

A large source of float failures has been the malfunction of the pressure sensor. Since the float controllers rely on pressure measurements to navigate the float through the water column, gross malfunctions in the pressure sensor can result in float death.

D. Swift, working with SBE, determined the source of malfunction of the Druck pressure sensors installed on SBE CTD's, was due to internal shorting by the growth of carbon 'snowflakes' in the oil-filled cavity in the sensors, resulting in the measurement going to full scale (~3000db). Initially, this problem often occurs only intermittently, but eventually it does not go away, resulting in float death (see Appendix C).

For the float ensemble analyzed by UW, Druck sensor failure accounts for 7% of current float failures, though many more floats presently deployed are at risk from this problem. At JAMSTEC, this problem accounts for a much larger 52% of all failures. This has been a significant failure mode for APEX, and other float types using SBE sensors as well.

Having identified the problem in August 2003, SBE was very prompt in recalling affected CTD's. Druck and SBE have implemented changes to reduce the occurrence of shorts in the sensor, though complete elimination of the problem is seemingly impossible. Since the problem was fixed, a few newly deployed floats (about 1%) have continued to show the Druck problem, but its occurrence is clearly greatly reduced. Many floats deployed before 2003 are still vulnerable to the development of snowflakes, leading to float failure. Hence, we expect to see continued occurrence of failures due to this problem into the foreseeable future.

(d) Motor Backspin [Fixed]

In early 2002, A. Papij and P. Mantel (CSIRO) repeatedly noticed damage to some electronic components due to intermittent high current surges during routine laboratory testing while floats were operating at high pressure. After investigation they realized it was due to "motor backspin" – with high external pressures on the bladder, the float piston would "slip", driving the motor backwards so that it acted as a generator, thus sending damaging high current surges through the electronics of the float. They alerted the float community to this design flaw in July 2002, and WRC quickly responded and fixed the problem. However, motor backspin resulted in the early failure of significant numbers of APEX floats, although the signature of this problem is less clear than for other failure modes. Rapid early voltage drop is one symptom (usually during the first 10 profiles), though floats may just suddenly disappear if satellite transmission circuits are damaged, as happened to both CSIRO and UW floats in the laboratory.

Of the UW analysis ensemble, motorbackspin accounts for 5% of failures.

(e) AWOL/mysterious symptoms

We believe that only about 10% of float failures remain to be explained. Of the UW group, 6% failed with no symptoms at all, and 4% failed with single occurrence, mysterious symptoms. For JAMSTEC, about 17% of failures were attributed to unknown causes. Several groups also reported floats disappearing on deployment. Diagnosing the failure mode in such cases is very difficult.

Another possible failure mode involves a leaking air system on the float. UW carries out a overnight air bladder test, and several floats have failed these tests due to cracked hydraulic hoses or bad valves (usually there is dirt in the valves). Similarly, PMEL has returned 5 air systems to WRC before the floats were deployed after noticing problems with hoses. WRC is now doing an air bladder test for several hours, though UW/PMEL recommends an overnight test to check for slow leaks.

Prof. Xu from China Argo showed a recovered float that operated seemingly normally at sea for 289 days. The butyl rubber of the bladder appeared white and eroded on its bottom end where it contacts the cowling, suggesting a possible weakening of the material. This float has now been returned to WRC for analysis of the bladder.

4. Seabird CTD Performance

D. Swift found, based on the UW analysis ensemble, that 90% of data returned by the SBE CTDs on the floats is good, with the remaining 10% affected by “drifts, jumps and Drucks”. Data loss was 4% due to Druck sensor problems, 2% due to salinity jumps, and 4% due to salinity drifts.

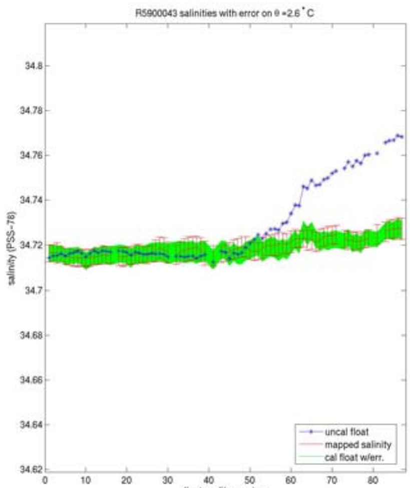


Figure 5: An example of a salty drift error in salinity reported by an SBE41 on an Australian float. Salinity is shown on a deep isotherm, with red showing climatological values and green for corrected values at the float (supplied by T. Tchen, CSIRO).

While most conductivity sensor problems will cause the salinity to drift to low values, a significant number of SBE41s on APEX have drifted *high* – sometimes by as much as 0.1 (PSS-78). In the UW ensemble, 22 floats exhibit this behavior. Australia has 5 floats with clear drifts to higher values of salinity. Physically, this can only occur if the conductivity cell is bored out (the volume of water in the cell is increased) or becomes coated with a substance more conductive than seawater; both of these scenarios seem somewhat unlikely. Alternatively, these errors could be generated by a warm drift in temperature of between 0.1 – 0.01°C, which would not be easily detectable in the data. Appendix D contains a table of examples identified with a slow salty drift error. We believe that these errors are correctable in delayed-mode analysis, as they appear well behaved – that is, constant for each profile and slowly changing in time.

Jumps in Salinity: In the UW study ensemble, 26 floats exhibited large (~1 PSU) jumps in salinity during their lifetime, as shown in Figure 6. Presently, we have no understanding of the possible causes of such an error. As the salinity jumps are very large and the shape of the potential temperature/salinity curve changes, these data are currently deemed uncorrectable.

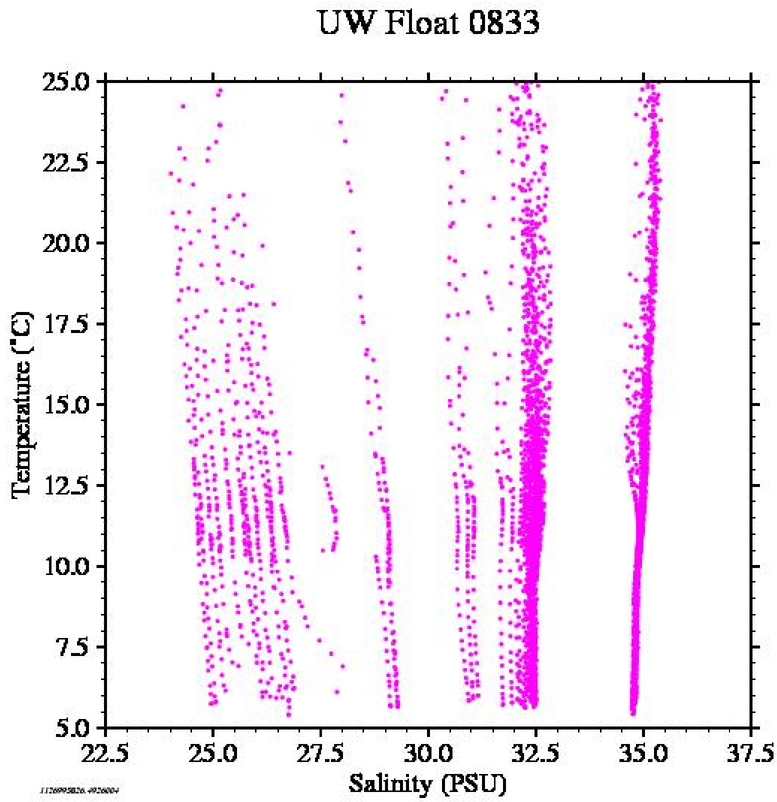


Figure 6: Example of large jumps in salinity reported by an SBE 41 over a number of profiles (D. Swift, UW).

Druck Errors: As discussed above, 88 floats have experienced the snowflake effect (shorting within oil-filled Druck sensor). Data is lost due to confusion by the controller in these cases and the returned conductivity and temperature data are useless without accurate pressure.

Pressure Sensor Drift : APEX floats record a pressure reading just before they "dive" to their park pressure, which is termed the "surface pressure offset". If the float is at the surface, this reading gives an estimate of the stability of the float's pressure sensor, since at the sea surface the sensor should read 0 dbar. Three types of pressure sensors have been used on the SBE CTD units since the beginning of Argo: Druck, Paine and Ametec. N. Shikama of JAMSTEC has found that Druck sensors are quite stable (compared to drifts seen in Ametek and Paine sensors), with nearly all offsets at the sea surface less than 1 decibar. Typically, Ametec and Paine sensors can drift by 5-10 dbar, sometimes more.

A discussion ensued about the wisdom of applying the surface pressure offset automatically in software onboard the float, as requested by both the JAMSTEC quality control group and B. King from UK Argo. However, several in the group cautioned against this as it trusts the pressure sensors too much. D. Swift showed examples of floats which were "stuck" at depth and thus recorded a very high "surface pressure offset", and others with 10-20 dbar spiking due to the snowflake problem. In cold regimes, ice can also cause the pressure sensor to read 1000 dbar at the sea surface. It was thus concluded that corrections for pressure drifts should continue to be done during post-processing rather than in real-time aboard the floats.

It was also noted that the current version of APEX controller boards cannot return negative pressures – the software will truncate negative pressures to zero, so a drift to lower pressures (less than 0 dbar) will be hidden in the "surface pressure offset". This problem will soon be addressed by SBE.

Thermal mass errors in the SBE CTD: G. Johnson lead a discussion of errors introduced into the salinity measurements due to mismatches between the temperature measured by the CTD thermistor and the temperature inside the narrow glass cell in which conductivity is measured. This small temperature difference is due to the thermistor having a smaller thermal mass compared to the conductivity cell.

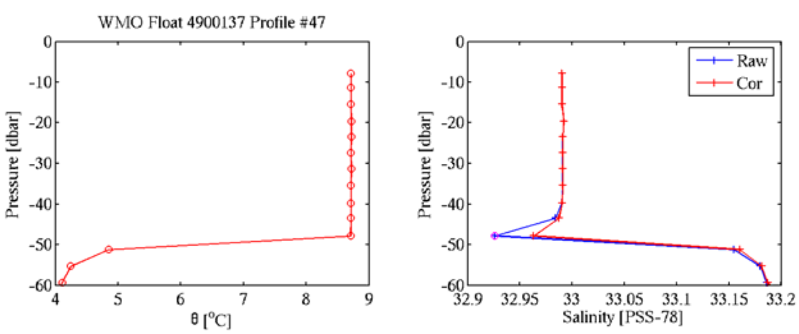


Figure 7: Temperature verses pressure (left) and salinity versus pressure (right) for a float exhibiting a thermal lag error. Note the 0.05 PSU fresh spike at the base of the mixed layer.

On APEX floats, we typically only profile when the float is rising, which means that the conductivity cell is usually colder than the water entering it. During its passage through the cell, the water is cooled by thermal diffusion at the cell wall, resulting in lower conductivities (a difference of 0.001°C leads to a salinity error of 0.001 PSU) and thus lower calculated salinities. The salinity error scales with the rate of change of temperature with time. Thus, errors will be largest when a float is passing through very strong temperature gradients, such as found at the base of the mixed layer (Figure 7) producing spikes in salinity of over 0.05 PSU. Also of concern is that this error is a fresh BIAS error that exists all through the profile. While for most of the water column the error will be very small (< 0.001 PSU), in the tropical thermocline bias errors can be as large as –0.005 to –0.01 PSU. G. Johnson showed that this error is correctable to some extent, and he showed examples of how this might be done. The accuracy of the correction relies on knowledge of temperature change with time. For continuously sampling CTD units (the SBE 41CP) a correction could be made on board in the instrument software, while for the more common burst sampling done by SBE41 units, the correction will have an error due to imperfect knowledge of temperature changes over the seconds before a sample is taken. It is recommended that we routinely do this correction in delayed mode. This problem and its potential future solutions were discussed in more detail with SBE.

Floats found out of calibration: UW and PMEL perform a simple salinity check before deployment, whereby conductivity is simultaneously measured by the float and a reference CTD unit. They have found 5-10% of floats to be out of calibration (ie, larger differences than factory specifications). Often a repeated flushing or a weak acid rinse will bring the cell back into calibration, suggesting that coating of the cell wall by the anti-foulant has occurred during shipping. JAMSTEC has a highly accurate calibration facility identical to the one at SBE, and they check every CTD. JAMSTEC found 5% of CTD's are out of calibration.

5. Monitoring the Performance of the APEX Argo Array

Discussions on how to best monitor the performance of the APEX Argo array occurred at several junctures through the meeting. A. Papij and V. Dirita showed a web site where indicators of the health of UK and Australian Argo floats were displayed and the associated technical data was available as plots (see *http://www.marine.csiro.au/argo/tech/*). When working on this problem they found it difficult to access the technical data, and found inconsistencies in naming conventions for certain parameters. D. Swift maintains fairly comprehensive plots of APEX technical data for a large number of APEX floats associated with the UW program and a number of other national and Argo-equivalent programs (not publicly available). Dan Webb commented how very useful such graphical displays are in diagnosing float problems quickly. Several groups are vigilant in examining float technical performance in real time,

Currently, a regular assessment of the global APEX Argo fleet is lacking, which may leave us vulnerable to batch manufacturing problems not being identified early or other float problems diagnosed only slowly.

It was recognized that pooling a large part of the technical float information through the Argo data system was useful (though it will be impossible to capture it all) and a pre-requisite for any analysis of the engineering data and float performance from the entire Argo/APEX array. Both the metadata and technical data files in the Argo data system allow engineering data to be easily shared and archived. Issues of naming conventions and which data are stored still require group agreement. D. Swift also pointed out that floats using Iridium communications will have very large engineering data sets and it will have to be decided how much of this should be inserted into the Argo data system.

Actions:

1. It was agreed that regular analysis of the APEX engineering data and a consistent approach to designation of float failure modes is required. This would allow us to learn whether changes improve or erode the fleet performance, help us prioritize which failure modes are common and need attention or which are rare, identify new failure modes more quickly, and better estimate float lifetimes (and thus the cost of carrying out Argo). Group members agreed to pursue methods of funding a person to carry out this work.

2. The APEX technical and meta data files need to be examined for consistency of names and how well these files are being populated (some DACs don't even generate technical data files!).

6. New APEX Developments

APEX floats are undergoing new developments/improvements and are being used as platforms for new sensors. A considerable amount of development work is underway at both UW and JAMSTEC. Other groups are experimenting with new sensors.

A new controller board and Iridium communications:
A new, more flexible controller board has been developed – the APF9. UW has been deploying APEX with this board since 2003, and soon 60 will have been deployed and are operating successfully.

The important advantages of the APF-9 over the APF-8 (present version shipped by WRC):

- APF-9 is programmable in C, allowing more user control and knowledge of the mission
- APF-9 has several RS232 ports and 2 analog A/D ports, making it easy to add other sensors
- APF-9 has areal-time clock – profiles can be scheduled to occur on real dates/times

The primary downside of the APF-9 is its complexity. The basic controller software consists of 40 thousand lines of code, and thus the potential for software errors is much larger than with the APF-8. UW has used extensive data simulators to test any code changes.

The primary advantage of the APF-9 (and the reason it was developed by UW/WRC/SBE) was to implement *Iridium communications* on APEX floats. Iridium allows two way communication, which means we can change the mission in real time. Its much higher bandwidth (180 vs <1 byte/sec data rate) means only 6 minutes is required on the surface to receive a 2000 m profile sampled at 2 dbar intervals, compared to 9 hours using Service Argos with only 70 vertical points. The APF-9/Iridium system can also accommodate new sensors with high resolution profiles.

Implementing Iridium requires choosing between two modes of data transmission: dialup or short burst messaging (SBM). Dial-up Iridium is probably not feasible for large-scale applications like Argo as only about 100 floats can be hosted by a single phone. SBM is also possible, but presently quite expensive. TCP/IP implementation might be developed in the future that will make the data transmission more affordable. At present for UW, the cost of Iridium communications is comparable per profile to Service Argos, but the profiles are fully resolved (2 dbar sampling).

WRC makes an Iridium patch antenna for APEX. UW believes the antenna needs to be reconfigured to move its wake away from CTD. This can be done by angling it to the side (the so-called Mai-tai configuration). This new configuration will be deployed in early in 2006.

Deep drift sampling:
With the greater bandwidth of Iridium, data can be collected during the drift phase of the float. The APF-9 is programmed to do hourly temperature and pressure samples during drift, which will resolve the deep tides. Salinity sampling is possible in principle, but impractical as it requires too much energy, since the CTD pump would need to be run.

Additional sensors:
Several examples of new and additional sensors deployed on APEX were shown such as an acoustic rain gauge and wind-speed sensor (UW float 0006). Two types of oxygen sensors (from SBE and Aanderaa) have been deployed by several groups (UW, AWI, CSIRO). Southampton Oceanography Center is experimenting with chlorophyll on APEX. TSK has made a small float that drifts at 50m and profiles to 5m which has worked well for a 6 month period as demonstrated by a Japanese fisheries science group.

Tom Sandford at UW has made a float that measure relative velocity using an electromagnetic sensor.

Floats under ice: Currently APEX with APF-8 can be configured with ice-avoidance ability. However, profiles terminated under ice are lost. Some floats with APF-8 have the ability to store these under-ice profiles, but these floats must spend up to 5 days transmitting using Service Argos. With the APF-9, storing under-ice profiles will be easier. Floats have been tethered on wires under drifting ice (as demonstrated by the JAMSTEC Arctic group in the POPS-Arctic program). John Toole and collaborators at Woods Hole Oceanographic Institution have developed a float-like vehicle that crawls up and down on a weighted cable under an ice-bouy.

7. A New JAMSTEC Argo Float

Masahira Yoshida of JAMSTEC described efforts to develop a new kind of float – based on a gear pump and a high viscosity oil. The design has some impressive advantages. The gear pump is short and so the float is smaller and lighter than current Argo float. This float will also have no buoyancy limitations. Thus is will be able to profile to 2000 m everywhere and have no need for precision ballasting.

The JAMSTEC Argo float will undergo engineering tests through December 2005, and a field test will be performed in January 2006. If successful, this float will be made available commercially by TSK.

8. Future Improvements Needed

There are several features that Argo APEX users would like to see available on APEX in the near future:

1. More reliable battery packs
2. Pressure activation on deployment. UW has worked with WRC to develop this feature and prototypes have been successfully deployed.
3. Drift measurements for P/T – reporting the mean and standard deviation of hourly values over two 5 day periods.
4. Nearer surface temperature. Current APEX floats cease measuring at 5 dbar. For meteorology and the calibration of satellite data (see discussion below with SBE), it would be useful to have true SST measurements from floats
5. Nearer surface salinity – this could be even more difficult and expensive than near surface temperature
6. Pressure bail out – come to the surface and send off all engineering data when problems are detected
7. The ability to reduce thermal inertia errors in salinity by sampling continuously in the upper 200 m with a SBE 41CP and doing on an board lag correction
8. Interlacing pressures in transmission messages so that large gaps in vertical profiles would not be lost when whole transmission blocks are lost. JAMSTEC have found several percent of profiles affected by this problem.

9. Pre-deployment Float Preparation

Argo groups using APEX vary in the number and types of pre-deployment checks/modifications they carry out. Below is a short summary of what some groups do.

PMEL- E. Steffen

1. Weigh the floats
2. Perform overnight bladder test – 15 hours at full inflation, check loss by monitoring the air bladder counts – a loss of 7 counts or more is deemed problematic. PMEL has found 6 cases of problems such as punctured tubing and solenoid problems
3. Open floats and replace two battery packs with lithium cells
4. Perform a salinity check – here air bubbles are a challenge, and so they use a peristaltic pump to get the air bubbles out. Often running cells for an hour can resolve problems
5. Perform a transmission test for a mini–mission. Program floats for 4 hours up, 7 hours descend, 1 hours ascend time.

Problems found:
Bad components on board – phantom current draw, dropping currents over several weeks
Erratic position readings, seen when moving piston

Unlatched potentiometer
Contamination on seals – loss of vacuum over the course of several weeks
There have been examples of several salinity failures which may be an error of the delta-sigma board in the SBE CTD.

UK – P. Whitely

1. Piston extension test
2. Check bladder inflation
3. Note time it takes for the piston to retract
4. Use WRC's Labview test procedure.

China (J. Xu) **and Canada** (M. Robert)**:**

1. Check battery voltage
2. Check bladder inflation

Australia – A**.** Papij

1. Weigh
2. Open floats
3. Visual inspection
4. Replace two battery packs with lithium cells and adjust weight to original
5. Outdoor transmission test

Japan – N. Shikama

1. Open and ballast
2. High precision CTD calibration
3. Battery voltage check (< 14V deemed problematic)
4. Check piston and potentiometer performance (counts should change when piston moves)
5. Outdoor transmission test

JAMSTEC has found that 3% of APEX floats have some malfunction and also reported that the number of malfunctions found have recently increased.

UW – S. Riser
UW purchases float components from WRC and carries out float construction in UW laboratories. Over 30 checks on float performance are carried out during the construction. All float systems are completely tested, including communications, CTD, the buoyancy engine, and the float controller. A 2-day dock test is carried out prior to final shipping and deployment.

10. Discussions with Dan Webb, WRC

Dan gave an overview of the status of APEX at WRC.

Production has increased recently from 10 floats/month to 60/month. The price has been steady. WRC has been integrating new sensors/features as requested by customers, such as ice detection, an isopycnal following capability, isothermal following capability, bounce profiling – rapid subsurface profiles, pressure activation, and the ability to return a full depth profile within 24 hours of deployment, and a compressee-assisted float for 2000 m profiling globally. In collaboration with SBE and UW, they have incorporated Iridium and GPS with the new APF-9 controller.

In addition, WRC are developing new a APEX design with a non-metallic composite hull which weighs less, allowing the battery and sensor payload to be increased. They also have developed an automated software system that a non-technically skilled person can use to test the floats that is available on the WRC ftp site.

Reliability improvements –

- Aug 2002 – Papij identified backspin problem that has been fixed
- July 2003 – Druck problems identified by Dana Swift and SBE
- Late 2003 -Premature exhaustion of batteries – problems with batteries were confirmed in recovered floats that contained failed cells. After examination, Duracell did not reveal the cause, but did report that the cells prematurely discharged. Despite numerous attempts, this problem has not been reproduced in the laboratory.

Steps WRC has taken to fix this:

1. Feb 2004 – shunt diodes were installed across all cells in every battery pack
2. Since high peak current loads seem to increase failure rates – WRC now always recommends to customers to use park and profile mode
3. Some customers install lithium batteries to fix this
4. WRC is starting a new series of discharge tests of float battery packs under partial vacuum
5. WRC is seeking an expert consultant to help investigate the battery problems
6. WRC *is not willing to install or sell floats with lithium battery packs* due to issues involving liability, shipping complexity, and safety.

WRC has looked at other battery suppliers and have carefully tested Panasonic batteries. The inability to reproduce cell failure in the laboratory remains an important problem in finding a solution.

Dan then commented on the new features desired by the group and specific questions:

1. Temperature near the surface – this needs to be discussed with SBE, concerning issues of what kind/where to put a separate sensor.

2. Drift measurements at depth – this can be done by a change to the firmware and should incur no extra cost. WRC says it can be easily done, but the Argo community needs to provide the specifications. These are two 5 day averages of hourly readings.

3. What is the future of APF8? This will be driven by the rate by which Iridium is adopted by the community. WRC will hire a software engineer to support the APF-9.

4. Should we still be transmitting pressure values? - Druck history suggests yes.

5. An interlacing scheme for pressure is possible. The Argo community needs to specify exactly how they want this done.

Action – canvas the idea of interlacing pressures at the next ADMT meeting

6. Agreed to the requirement for a list of dated technical revision information in a public place – that is make the family tree of firmware available. Dan agreed to do this.

7. Agreed to the requirement for a web-page, listing new float enhancements along with changes and new features with the date, feature description, number made, customer group.

8. Time stamps during a profile would be useful to help correct drift velocities. This is easily done but will increase the transmission time.

Dan Webb hoped that the Argo community could come to a consensus on some of the specifications for Argo so that they were more uniform. He also recognized the value and need of statistical summaries of float performance and thanked Dana Swift for his large contribution in this regard. WRC would be pleased to participate in designing metrics used to assess float performance.

Procedure for handling of grounded floats: The group asked Dan about how he thinks we can best deal with stranded floats. It was agreed that we need a user guide or set of instructions for individuals who find floats that are grounded on coasts. This guide should be available by fax or via the Internet. Elements to include in the instructions include

- Do not open the pressure case
- Remove the vent plug in a spark free area [need pictures that can be faxed – all that is needed is a pair of pliers]
- Store the float in shade/cool area outside
- Do not burn the float or its components
- Contact a local meteorological agency who can help find the float owner

For APEX floats with lithium batteries, the float owner should arrange for someone knowledgeable to remove the batteries. How do we safely dispose of lithium batteries? This will depend on the country and situation.

The Argo Information Center can help float providers find stranded floats. The float label needs to be redesigned, with warning symbols against opening or burning the float.

11. Discussions with Norge Larson, SBE

Dr. Norge Larson, head of SBE, met with the group to give an SBE perspective on Argo and discussed many technical aspects of the CTD sensors.

SBE has shipped 4000 CTDs so far and is now shipping about 1000 per year. Argo is their largest customer. Because we don't get floats back the normal SBE trouble shooting methods don't work (laboratory analysis) – hence the need to use the float data. Thus SBE must rely on the community to help with this. SBE needs quick, statistical and summary feedback – errors in a single float are not a productive thing to work on. SBE needs to know which are the 10% problems, not 1% problems. Once identified, SBE can establish class faults and mechanisms – they want to really understand what is going on. The proximity of UW and SBE has led to a good relationship where a great deal of information of this type has been exchanged. SBE would like to have similar arrangements with other float groups.

In SBE's laboratory, CTDs are achieving stability over 5 years of 0.002 °C, 0.005 (PSS-78), and pressure changes of less than 5 dbar. SBE thinks this level of stability is likely for 90% of the CTDs they manufacture. Several examples of data from floats left on the shelf over a number of years and recalibrated periodically revealed very good sensor stability. However, cleanliness is crucial, with the need to avoid oil coatings and biofouling by bacteria and algae. Avoiding ingestion of surface films is also crucial.

Several examples of extreme cold temperature cycling of sensors in the laboratory were described. SBE also worked hard to improve the antifouling plugs to prevent 'weeping' of material into the cells. How can we reproduce the great stability seen in the laboratory in the ocean? Norge believes that about 90% of deployed CTDs are meeting the laboratory standards, while there is a 10% set of CTDs that are not performing optimally in some way. Data quality control and analysis is the key to finding the malfunctioning CTDs and isolating them from properly operating group. SBE needs the Argo community's help to identify the floats that comprise this 10%. SBE's past experience is that by the time 10,000 units of a product are produced, SBE will have most malfunctions solved. Currently about 4000 Argo CTD's have been produced. SBE's goal is to get to 98% of units functioning in line with the quoted specifications for life of the floats.

Questions to N. Larson:

1. *Do your tests include pressure effects?* No. We have however checked for pressure effects on the anti-foulant pills – which showed no bad effect.

2. *US national environmental policy assessments might make tributyl tin oxide (TBTO) illegal to use. If so, what is the alternative*? SBE wants the use of TBTO to remain allowed for scientific purposes. The only ways the CTDs can meet Argo specs is if we can use some kind of poison to keep growth out of the cell; t is hard to find a replacement. We would argue that the use of TBTO in Argo is targeted use of a poison. For comparison, the amount of TBTO leached from a supertanker hull in 1 day is same as all the TBTO used in all SBE instruments in 1 year.

3. *Thermal lag mismatches are our next largest source of error in salinity measurements. How can this be reduced?* We would need one hertz data to correct this so that it be done on board the float. In a burst sampling instrument like the SBE-41, there may be some hardware fixes such as to pump faster or differently within current energy budget. The users could move to a continuous sampling SBE-41CP and we could apply the correction

on board, but this impacts the float energy budget. With lithium batteries this may not be a problem.

Action: D. Swift to supply estimates of energy required to run CTD continuously (SBE-41 CP) and whether 4-year lifetimes can be achieved with lithium battery packs.

4. *We have observed a significant number of floats drifting to more saline values, rather than the more common drift to lower salinities – about 5-10% of SBE 41CP show some evidence of this. What could cause this?* Can we establish which sensor is the cause? A 50 m°K drift in temperature or a 100 dbar drift in pressure can account for 0.05 PSU drift, though temperature and pressure have proven very stable in the laboratory. Electronics problems may be involved such as oscillator drift or capacitor drift. Two other candidates for the drift to high salinities are (a) if the internal surface of cell ablated or was etched by something as found in equatorial Pacific TAO/TRITON arrays; or (b) a conductive coating somehow added to the cell. Recovery of such a cell for laboratory analysis is the only means to diagnose the malfunction. Salinity jumps are electronic by definition. Correlated pressure and temperature errors (the analytic connection between pressure and temperature in the delta-sigma circuit) might also play a role here.

5. *Is the Druck snowflake problem a thing of the past?* No, SBE doubts that all Druck sensors will be snowflake free, but they expect that only 1/1000 will be affected after recent manufacturing and testing changes.

6. *Can pressure have a scale factor error?* Yes, and this would most likely be caused by a calibration error or an error in entering the calibration coefficients. These can be checked to see whether the calibration coefficients are correct.

Near Surface Temperature: With N. Larson, the group discussed the requirement for very near surface temperature from some user communities such as meteorologists and the Global High Resolution Sea Surface Temperature project (GHRSST).

GHRSST would like high resolution temperature profiles near the surface, especially in the upper 10 m at 10 cm intervals. It was recognized that this would require a faster response temperature sensor to be added separately. SBE could possibly add another *T* sensor to the CTD unit and mount the new sensor up and out of the conductivity cell. The strategy would be to use the larger stable thermistor used for salinity measurements and the smaller less stable thermistor for fine scale temperature near the surface. The stable thermistor could be used to calibrate the less stable one on each profile. This could be implemented in SBE-41CP right away, at an extra cost of a few hundred dollars. Integrating the new thermistor with pressure measurements is a task that needs addressing in this context. Larson pointed out that SBE is revising the 41CP circuit at the present time, so specifications from the Argo/GHRSST community are needed as soon as possible.

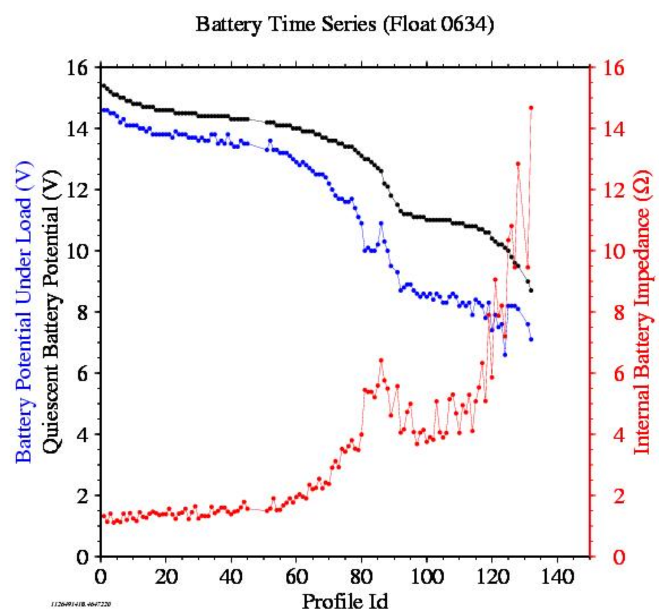
Action: Paul Whitely to discuss near surface temperature measurements with GHRSST and SBE.

Larson requested that the Argo community keep an updated table or web site listing CTD problems referenced by CTD serial numbers. It is generally the only way a batch manufacturing error can be discovered.

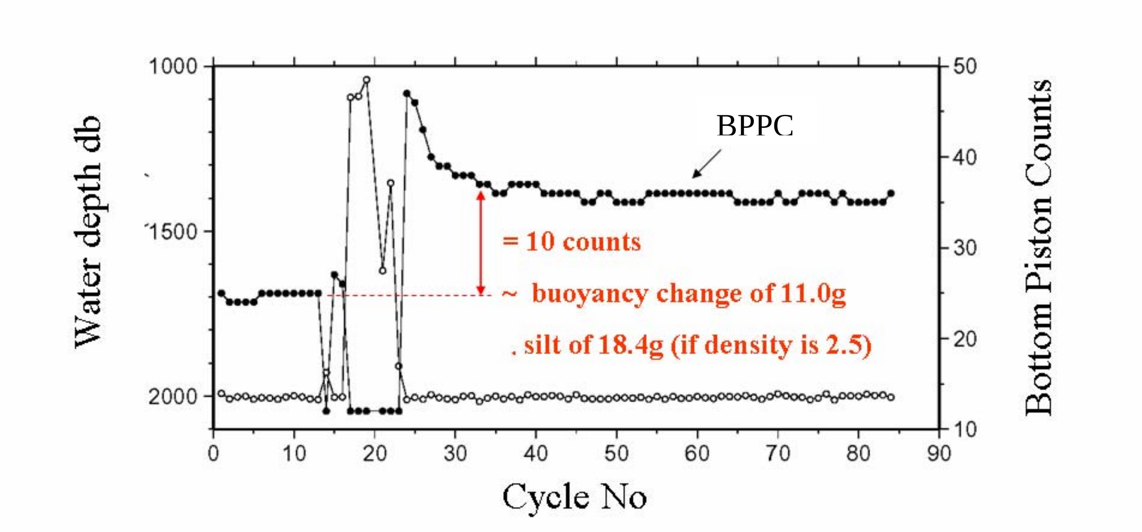
A final discussion resulted in a summary of meeting findings that appear in the summary at the beginning of this report.

Appendix A. Diagnostics for Alkaline Energy Flu

Alkaline energy flu can easily be seen in the voltage data returned by APEX floats. Voltage will drop quickly over 5-6 profiles and then plateau again. The plot below shows a typical example (from D. Swift).

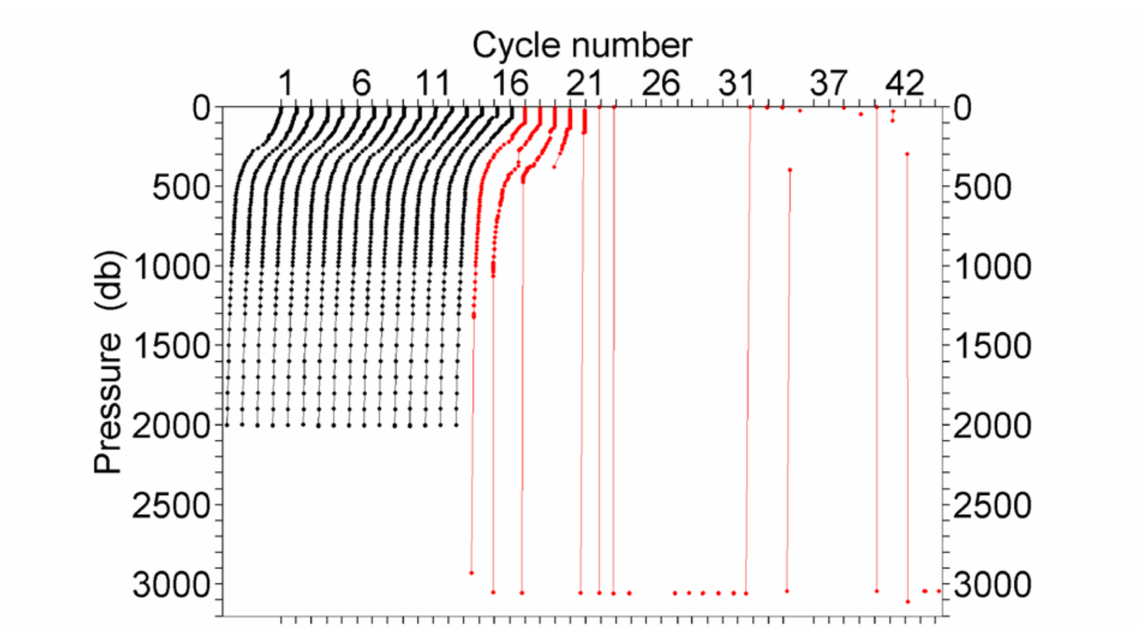


Appendix B. Diagnostics for a Float Grounding or Adding Sediment



Grounding can be detected both in the pressure data and also in the bottom piston position counts (BPPC). If the float collects sediment during grounding events, this will be detectable in an increase in the BPPC once the float has moved back into deep water. As the float is heavier with its sediment load, the float piston does not have to retract as far to reach the drift depth. Above is an example from N. Shikama of JAMSTEC.

Appendix C. Diagnostics for Druck Pressure Sensor Failure



This plot shows the temperature and pressure data returned by a SBE-41 affected by the Druck sensor failure (supplied by N. Shikama, JAMSTEC). The earliest manifestation can be seen in the full-scale pressure readings near 3000 dbar around cycle 16. The float continues to measure pressure correctly sporadically until cycle 21. Eventually the pressure reading remains stuck at full scale; the float tries to get to its park depth (1000-2000 dbar) by extending the piston until it becomes a surface drifter and ceases to operate.

Appendix D: Some SBE41 Sensors that Show Drift to a Saline Bias

PLATFORM S/N	WMO ID	GROUP	SBE S/N	DATE DEPLOYED
APEX 154	39030	UW	Not in meta file	2000 07 03
APEX 157	39033	UW	Not in meta file	2000 10 29
APEX 158	39034	UW	Not in meta file	2000 11 01
APEX 169	39035	UW	Not in meta file	2000 11 03
APEX 167	39039	UW	0185	2000 12 17
APEX 491	4900284	UW	0533	2002 09 17
APEX 428	5900230	UW	0527	2002 08 30
ALACE 057	53546	CSIRO	0126	1999 10 15
ALACE 055	53554	CSIRO	0128	1999 10 13
ALACE 223	56508	CSIRO	0131	2000 04 29
ALACE 225	56509	CSIRO	0223	2000 07 22
APEX 0613	5900043	CSIRO	0523	2003 03 07

Appendix E. Meeting Agenda

Monday, 9/19/05, morning
[S. Riser, chair]
0830 Introduction, logistics, meeting plan (S. Riser)
0835 APEX history, reliability, and known problems (S. Riser)
0850 APEX energy: alkaline and lithium batteries (D. Swift)
0915 Battery/energy discussion
1000 Break
[N. Shikama, chair]
1020 SeaBird and Druck sensors (A. Papij, D. Swift, N. Shikama)
1100 Pressure sensor discussion
1130 Other problems with APEX (grounding, unexplained disappearances) (D. Swift, N. Shikama)
1200 Summary and discussion of morning session
1215 Lunch

Monday, 9/19/05, afternoon
[G. Johnson, chair]
1310 Monitoring the state of the Argo array (V. Dirita, A. Papij)
1340 SeaBird CTD performance (N. Shikama, S. Wijffels, G. Johnson)
1425 Other APEX/SBE problems (contributions solicited from the group)
1450 Break
[J. Xu, chair]
1500 New technological developments: APF-9, Iridium, etc. (S. Riser, D. Swift, M. Yoshida)
1600 Additional new technological developments (contributions solicited from the group)
1650 Discussion of first day's results, summary
1700 Adjourn

1900 Dinner (logistics and transportation to be determined)

[Days 2 and 3 will consist of group discussions, with some contributed presentations]
Tuesday, 9/20/05, morning
0900 Discussion [S. Wijffels, chair]: how can we improve APEX reliability? (N. Shikama)
1000 Discussion [A. Papij, chair]: what new features would we like to see with APEX? (N. Shikama, P. Whiteley, A. Papij)
1100 Discussion [D. Swift, chair]: how can communication with Webb and SeaBird be improved?
1200 Lunch

Tuesday, 9/20/05, afternoon
1315-1500 Group discussion with Dan Webb (Dan will present his views on the present state of APEX and future developments, followed by group discussion)
1500 Break
1530 Discussion with Webb continues, with emphasis on group's conclusions from Day 1 and morning of Day 2

1700 Adjourn

Wednesday, 9/21/05, morning
0900-1030 Group discussion with Norge Larson of SBE (Norge will present his views on the present state of SBE CTD performance, followed by group discussion)
1030 Break
1100 Discussion with SBE continues, with emphasis on group's conclusions from Day 1 and morning of Day 2
1200 Lunch
1300 Summary discussion of meeting results
1530 Meeting ends

Appendix F. List of Attendees

M. Belbeoch (AIC, France)
V. Dirita (CSIRO, Australia)
K. Henize (UW, USA)
G. Johnson (PMEL, USA)
N. Larson (SBE, USA)
A. Papij (CSIRO, Australia)
J. Park (SNU, Korea)
S. Piotrowicz (NOAA, USA)
D. Ripley (UW, USA)
S. Riser (UW, USA) [Convenor]
M. Robert (IOS, Canada)
N. Shikama (JAMSTEC, Japan) [Co-Convenor]
E. Steffen (PMEL, USA)
C. Sun (SIO, China)
D. Swift (UW, USA)
D. Webb (WRC, USA)
S. Wijffels (CSIRO, Australia) [Co-Convenor]
A. Wong (UW/UH, USA)
P. Whiteley (UKMET, UK)
J. Xu (SIO, China)
M. Yoshida (JAMSTEC, Japan)