# Report from the 2<sup>nd</sup> Float and CTD Technical Workshop University of Washington, Seattle, September 2017

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# Executive Summary and Key Recommendations

The technical performance of profiling floats in the global Argo program is highly variable across platforms and the teams deploying them. Float technology is also evolving, as are the CTD sensors being deployed on them. The last float technical workshop was in 2005, and given the changes in technology, new teams involved and drive for efficiency demanded by sponsors, a second technical workshop was convened.

The goals of the workshop were to

- Increase the overall efficiency of profiling floats in the Argo program by elevating float reliability across all groups and suppliers
- Better mitigate the risk and exploit major changes (e. g. controller boards, buoyancy engines, CTDs) being made to technology used in the global array
- Facilitate better communication between float deploying teams and suppliers

Over 5 days, float and CTD users met with each other and the manufacturers to share experiences, report on technical performance, and discuss future improvements. The key actions arising are listed below. Other more platform specific actions can be found in the main body of the report.

#### 1. Float acceptance testing

The most successful float-deploying teams carryout extended pre-deployment testing. Improved performance is likely to follow the implementation of more stringent post-shipping and pre-deployment tests:

RECOMMENDATION: The community asks that float manufacturers facilitate this by supplying:

- Tools to drive a thorough post-shipping check out that exercises all systems (e.g. tests buoyancy engine, air system, seals, etc.).
- Make it easy to compare post-delivery check parameters with pre-shipping (factory) parameters
- Tools to complete a quick check before deployment (on dock or at sea) red light/green light (stop or go guidance)

RECOMMENDATION: user groups take advantage and apply these tests, feedback their utility to manufacturers. Request such tests in procurement requirements.

Other best practices include:

-weighing floats on arrival and comparing with factory supplied weights

-for floats in the lab for a long time, check parameters regularly (perhaps weekly) - wireless communication is helpful for this.

### 2. Pre-deployment sensor checks

Independent checks of sensor calibration and stability are extremely valuable in tracking manufacturing issues and the quality of the Argo data stream.

- Pressure checks are extremely valuable and easy to do such a check captures a bias, and finds some number of sensors out of specification (cold temperatures and high pressures, for example)
- CTD salt check is worthwhile 1-5% are found in error could trigger an acid rinse or return to manufacturer

RECOMMENDATION: Teams that carry out such checks should continue and contribute to global meta-analyses as being carried out by Steve Riser on pressure biases. An urgent need to characterize the accuracy of Kistler pressure sensors used in Argo. All teams are encouraged to do these tests and log the data, where resources allow it, to further build the community data base.

### 3. Battery choice, health and performance

Most float types do not work well on alkaline batteries for deep profiling – wherever avoidable, alkaline batteries should be used for core Argo floats.

It seems possible that all float buoyancy engines damage lithium batteries in some way on a core cycle (deep profiling with 10 day pauses). For nearly all float types with regular lithium battery packs, we are not accessing all the stored energy. For SOLO S2As the issue is so acute it is severely restricting realized lifetimes.

RECOMMENDATIONS: Some work is required to define the problem/solution

- Check that required measurements are being returned in engineering data to assess battery health (V while under high load after drift (start of ascent ~ passivation impedance), V after passivation layer has been burned off (second pump -basic cell impedance) and V open circuit. Return results to users. [Manufacturers, Lee Gordon]
- Generate **a fleet wide view** of the issue. Our current view is that S2As are badly impacted, NAVIS somewhat, and APEX less so. [Lee Gordon] *See battery report authored by Lee Gordon.*
- Test Tadiran battery packs in S2As and other float models to see if lifetimes are better this will need to be done in numbers [SIO, WHOI and other teams]
- Improve how the data system labels the loaded energy and battery configurations [Bec Cowley and ADMT]
- Carry out a 'mixed' vs 'lithium only' battery source longevity analysis by float and communication type. [Brian King]

Remaining questions include

if it is feasible and worthwhile to capture voltages from each battery pack individually?

 Is battery orientation an issue? Manufacturers recommend positive up, but this is not implemented in most float cell packs (which alternate cell orientation)

#### 4. More accurate meta/technical data capture

Argo tracks the array's technical performance via a common meta- and technical data dictionary. Ensuring these are uniformly applied across teams and platforms is essential to allow global analyses of performance or to search for failure modes.

RECOMMENDATION: Float and sensor manufacturers adopt the Argo technical data/syntax and dictionary, ideally in their float manuals and, even better, in provided decoders, to ensure a more accurate and complete transference to the Data System.

User groups can work with manufacturers on these tasks. NKE – done via EuroArgo; S2A- John Gilson; APEX/APF11 – Bec Cowley; NAVIS-Elizabeth Steffen.

RECOMMENDATION: To facilitate accurate capture of technical data (e.g. serial numbers, firmware revision, manufacture dates), manufacturers should provide to users the information electronically in a machine-readable file.

#### 5. Float failure modes

Several types of early failure modes were discussed during the meeting. Apart from early battery failure, other modes included leaks, grounding, failed CTD sensors, etc. Early detection of increase or new modes of early failure can prevent large scale failures.

RECOMMENDATION - Manufacturers and float users should work together to document canonical failure modes and the typical engineering data behavior associated with grounding, leaking, passivation, etc. Select engineering experts from platform user groups to work with manufacturers to produce a cookbook of failure modes and diagnostic techniques.

### 6. Aged float retrieval and post-mortem? A new project?

Consideration was given to retrieving a sizeable (~20) number of aged floats for platform and sensor post-mortems.

Target issues:

- Battery aging what is the state of the batteries? How much energy is left in each cell?
- Hardware aging corrosion/wear and tear
- Sensor aging can we understand the mysterious drift to high salinity in ~5% SBE41s, pressure and temperature stability?

RECOMMENDATION: Form a small group to identify candidate floats, explore feasibility and possibly propose a project to the Argo Steering Team and funders. Partner with manufacturers to understand how best to do this and extract the most value from post-mortems on hardware and sensors [Steve Riser, Susan Wijffels and John Gilson, and others]

RECOMMENDATION: Teams to provide CTD serial numbers/WMO IDs of floats that are returning salinity that is slowly drifting high to Susan Wijffels.

Subsequent work on corrosion has been carried out by Dana Swift. See related Report.

### 7. How do we capture major changes in float hardware/software being used in Argo?

Manufacturers are improving and changing hardware and software continually. Some of these changes can be major enough that the Argo community should be aware and track in the data system. What is the most practical mechanism to achieve this?

RECOMMENDATION: propose to the IAST that they request a short <u>annual update</u> from manufacturers on any changes to their platforms – changes in the past year and near future plans

- Major controller changes
- Major mechanical changes
- IAST/ADMT to decide if naming vocabulary should change

[Wijffels and King]

### 8. CTD sensor testing/vetting for broad-scale use in Argo

The users were highly appreciative of efforts by both Seabird Scientific and RBR on better calibrations and on reducing dynamic errors in their CTDs. Excellent progress is being made.

RECOMMENDATION: In response to community identified biases, SeaBird Scientific will soon improve their pressure calibration practice from a 2<sup>nd</sup> order to 3<sup>rd</sup> order temperature fit. This should be captured in metadata. e.g. pressure calibrations and by a serial number transition point [Wijffels to raise with ADMT]

This change in the correction of pressure values will introduce a systematic bias compared to earlier measurements. To minimize this bias error in long term heat content trends, a methodology needs to be developed to make a gross correction to pressures from the earlier generation CTDs [Wijffels, Owens, Gilson].

Further independent validation is also desirable to better bound errors, particularly for dynamic errors and for this we might consider further ship-based comparisons.

RECOMMENDATION - users to explore opportunities for ship-based comparisons

- Ideally use a heave-compensated CTD system or work in a low swell environment to allow us to slow the lowering rates down
- Need high quality bottle salts

- Ideally in region with staircases and strong thermoclines
- Engage industry partners to assist with instruments and analysis

RECOMMENDATION – **manufacturers** – where possible to supply an internally recording versions of their float CTDs to put on a ship-based rosette, and collaborate on the intercomparison analysis [RBR and SBE are both willing]

[groups interested or able to contribute contact Wijffels, who can facilitate this]

#### 9. Piloting/testing the new RBRargo CTD for core Argo

Laboratory and limited field data suggest the newly re-engineered RBRargo CTD has the potential to meet Argo accuracy and stability requirements. A larger set of global pilot deployments is suggested.

#### **RECOMMENDATIONS:**

- encourage Argo teams to deploy RBRargo equipped floats across a wide variety of regimes (polar through tropics), and with an iridium SBE41 equipped buddy where needed (e.g. in a region largely populated by low resolution Argos floats). Ideally ~20 could be deployed over the next year or so.
- Argo community will monitor and analyse the pilot data to help establish quality and DMQC resource needed. Eventually a peer reviewed article might be developed to document the sensors/data stream.
- Explore the possibility of building a few dual CTD equipped floats for a tighter side-byside comparison. This would require some extra development/testing funds.
- To facilitate this next stage of pilot deployments, prepare a proposal to the **Argo Steering Team** and the **Argo Data Team** to allow the distribution of RBRargo CTD in the Argo data system [Annie Wong to lead]
  - 1. how to label them (QC=3 in the interim?)
  - 2. appropriate engineering and metadata (will need help from RBR)
  - 3. alert users: post a notice that Argo is distributing these pilot data and that they are in an evaluation mode, similar to the warning sent out for SBE41CPs used below 2000db. Data will be DMQC'd and qualified later

# **Detailed meeting report**

Note that links to the talks are embedded throughout.

### Day 1-morning: Introduction, APEX floats - users

After local logistical and welcoming remarks were made by Steve Riser, Susan Wijffels discussed the <u>goals and rationale for the workshop</u>. A key focus is on improving efficiency and reliability, as well as facilitating better communication between teams and with manufacturers.

*Float performance*: Brian King gave an <u>analysis of reliability</u> across the Argo array by team and by platform. Large variability can be seen. A discussion about float warranties and their efficacy ensued. However, it can help in tendering where 'value' is defined by the cost per profile returned and not simply the upfront capital cost. Discussion started on the different practices among teams with respect to testing before deployment. For floats that test extensively e.g. UW group, up to 5% of floats are sent back to the manufacturer for repair or checking. It was unclear whether failure modes differ across teams. Mathieu Belbeoch noted that overall, floats in Argo are getting less reliable in recent years, which is concerning.

APEX Evolution: Steve Riser presented the <u>history of use of APEX at the U. Washington</u>, from 1998 – through to the present. Dana Swift was central to the development of the APF9 controller, developed to overcome the limitations of previous versions. This controller is now no longer available, being replaced with the TWR APF11, which is relatively untested. U. Washington is also developing its own version of the APF11 focused on the core Argo mission.

Dana Swift <u>presented</u> on several technical problems identified in APEX, particularly energy-flu in battery packs, reemphasizing that use of alkaline batteries in APEX, particularly iridium equipped versions, is not recommended. Dana noted that few APEX floats appear to exhaust all of the loaded energy in the battery packs, meaning that other failure modes kill the floats before the batteries are exhausted. Possible reasons, supported by a few individual examples could be:

- deep profiling increases failure risk floats that profile deep only occasionally (every 3 or 4 profiles) can last well over 10 years and do appear to access most of the loaded energy
- 2. there is some other cause of sudden death, with no apparent anomaly in the engineering data: AWOL floats. What could cause this? Catastrophic hull failure? Sudden leaks? Corrosion? Dana noted one retrieved float that was surprisingly badly corroded.

*APEX Testing*: Rick Rupan demonstrated pre-deployment testing done at U. Washington, where floats are assembled from a parts kit. Every float goes through a gross buoyancy test. Typically they find ~5% have an issue that need attention such as loss of vacuum (bad seals), pinched

cables and air lines, and pneumatic system problems. All floats go through several tests after assembly, before and after shipping to the deployment vessel.

Elizabeth Steffen noted that the NOAA PMEL team logged these test results every time a float was queried into a database, and this has helped identify drifts in sensors or key indicators such as the internal vacuum.

A key need identified was for a GUI or equivalent interface to allow users to drive either a comprehensive or quick system test, allowing the data to be logged and also compared to results from when the float was tested before being shipped from the factory. Such a system is available for NAVIS and is very useful.

Ben Briat presented <u>a failure analysis of the Australia float array</u>. Less than half of these could be seen to survive long enough to exhaust their batteries. A mixture of causes of early death could be detected (e.g. grounding in floats using Argos communication), but ~10% were 'AWOL'.

Susan Wijffels <u>presented</u> a summary of user feedback and the morning's discussion. Some key items desired are:

- a simple version of the APF11 focused on the core Argo mission simpler means easier to debug and maintain free of failure modes
- better testing interface for both an extensive all-system test and a simple 'stop/go' predeployment check.

## Day 1-afternoon: APEX floats – users and suppliers

Susan Wijffels briefly revisited the meeting goals and welcomed the float and sensor manufacturers into the discussion.

Peter Furze, APEX product line manager from Teledyne Webb, presented an overview of the different versions of APEX floats, including those equipped with biogeochemical and EM sensors. He also introduced the TWR team attending the meeting.

B King raised the issue that since a certain percentage of APEX floats were purchased by non-Argo customers, these customers should be made aware that purchase of an APEX float did not automatically ensure entry into the global Argo program.

The Webb team demonstrated the APF11 controller user interface and self-test system. S Wijffels suggested that some of the mission configuration parameters could be set to core Argo specifications as the default. Wijffels communicated that there was appetite amongst user groups to run pre-deployment self-tests, both the thorough version and the simplified version with a graphical interface. The Webb team acknowledged that need and also stressed the importance of running the self-test on receipt of floats. Some users requested the following features be added to the Apf11 controller:

1. A tool to estimate remaining life of a float.

2. The ability to store a number of profiles onboard, for retrieval of incomplete profiles during telemetry. (The Webb team communicates that this feature already exists.)

There were discussions on how Webb could help ease the transfer of data from APEX floats, especially with the new APF11 controller, to the Argo data system.

Some suggestions are:

- Technical, engineering, and metadata from floats could adopt the syntax and nomenclature that are currently used in the Argo Data System. This will reduce the resources needed to map float output to Argo names. Errors in interpretation of new output will also be reduced.
- 2. Webb could provide a single-code (e.g. Python) set of decoders to bring source output into a consistent intermediate format, such as csv. Argo DACs can then work from this csv file and transfer the data to Argo netCDF format. Code-sharing among Argo DACs will become more viable.

ACTION: Select members from the ADMT to work with the Webb APEX APF11 team on:

1. Standardizing output nomenclature, especially regarding technical, engineering and meta data.

2. Trial a standard decoder and an intermediate output format.

About 25% of floats do not reach normal end-of-life (AWOL floats). There were discussions on how to reduce these catastrophic failures. Proper failure analyses need to be conducted in order to identify failure modes, and several suggestions were put forward on how Webb could help APEX users conduct their failure analyses.

1. Compile a cookbook of canonical failure modes, with examples of plots of vitals that can be used to diagnose these failure modes. User groups can then follow the cookbook and produce these analyses. Results can then be shared with Webb to identify problems.

2. Share cost in recovery of inactive floats, for inspection of parts to identify problems.

3. Communicate a clear interpretation (or expectation?) of the float energy budget.

ACTION: Select engineering experts from APEX user groups to work with Webb in producing a cookbook of failure modes and diagnostic techniques.

### Day 2-morning: SeaBird CTDs on floats – users

Steve Riser <u>presented</u> a history of the development and use of SeaBirds's 41CTD – made specifically for the profiling float application.

Dana Swift <u>presented</u> laboratory testing data aggregated from several Argo teams showing clearly a high pressure, cold bias in Druck pressure sensors in SBE 41 and 41CPs, which needs to be addressed. The data shows the errors are a linear function of pressure (a gain error), and that this might vary in time. A float would need to be recovered to assess this.

Shigeki Hosoda <u>described</u> the tests JAMSTEC have been carrying out. JAMSTEC has developed a simple SBE41 CT sensor calibration system. The advantages of the simple system are to conduct CT calibration without dismounting the CTD head from the float body, which enables us to maintain warranty policy, and to shorten testing time, keeping the accuracy as nearly the same as the formal SBE's calibration bath system by using SBE3 and 4 as reference sensors.

Based on JAMSTEC's long-term experience with the SBE's calibration system, one point calibration is conducted at 22°C (formally 7 points in the process of the SBE calibration, maintaining water temperature using some adiabatic material and tools). At this time, we have calibrated 29 SBE41 CTD with the simple calibration system. JAMSTEC also conducts a pressure sensor calibration using dead weight testing to screen out of spec sensors (±5dbar at 2000dbar) and investigate whether any systematic pressure sensor biases exist. Up to now we found some failure pressure sensors and these have been repaired by SBE. We will evaluate calibration accuracy to improve the simple CTD calibration systems. Out of 516 sensors tested 21 were sent back to SeaBird.

Rick Rupan showed the audience the U. Washington salinity checking rig, which used a reference SBE41 CTD sampling in line with a pump with the candidate sensors. Care is needed to avoid bubbles and contamination, but this is a useful tool to find batches of poorly calibrated or fouled cells.

Annie Wong <u>presented</u> SBE41 performance in the UW fleet, noting that 10% drift to salty as they age, with average adjustments around 0.03 by profile number 250. The mechanism for this drift remains unknown, despite a great deal of work on it. There is no obvious batch or geographical patterns in these. John Gilson <u>noted</u> that SIO SOLO floats exhibit a fresh drift (associated with fouling) but SOLO2 floats are salty, some by 0.3 psu over cycles 40-60, likely a batch of bad sensors.

Grigor Obolensky noted that EuroArgo tank tests 50-80 floats per year. 10% are found to have a fresh bias (tank contamination?). These were returned to Sea-Bird and received back with a new calibration. They still find a consistently fresh bias in SBE41s, particularly for float launched after 2010.

John Gilson <u>showed</u> that the surface offset behavior of Kistler and Druck pressure sensors is different, with Kistlers showing a bias to negative values (0.6db) over time. Kistlers also appeared noisier in both surface offsets and in the 1Hz data reported by SOLO floats near the surface. PMEL have noted that Kistlers have a strong transient thermal response.

It is unknown if these biases reflect a depth-dependent (range) error or an offset. If there is a deep bias in either or both Druck and Kistlers sensors, this is of great concern. Dean Roemmich noted that a 0.1% change in pressure bias is equivalent to 1 year of global warming in heat content change. Again, we can only check for this error by recovering floats.

Obolensky noted that pool-testing at IFREMER revealed some Kistler sensors installed on ARVOR floats to have large biases – up to 5db at 20db (delivered in September 2016). These were found to have a bad solder on the CTD board. More information on Kistler calibrations is needed.

ACTION – groups that do dead-weight pressure checks on Drucks should begin to check Kistlers so that we can build a cross-Argo data base on these.

Elizabeth Steffen noted that NOAA PMEL does simple salt checks, but this takes around 1 hour to set up. They have found errors in batches. Breck Owens suggested that for major fouling or cracked cells, the dry cell frequency check is also very useful, as suggested in SeaBirds '<u>best</u> <u>practices' application note</u> that was recently developed.

Susan Wijffels <u>presented</u> a summary of issues identified plus those sent in before the workshop. Most DACs show a similar number of floats need adjustment suggesting this is due to the equipment and not the deploying teams. As noted for UW, the most common drift is a slow one to salty, though fresh drifts and offsets are also found.

#### General Discussion:

Regarding salinity thermal lag error, we need more testing. Greg Johnson (PMEL) believed that SBE is tweaking their impellers, trying to keep flow rate constant, in order to reduce power consumption, but we don't know when these changes occurred. Can we get metadata from Sea-Bird when changes are made?

Can a test be done to examine a zero-order thermal lag correction on board on core floats, or better account for changes in pump speed for 41CP?

An example of a NOVA float delivering a vey noisy profile – this was a T and S misalignment? Greg Johnson noted that a faulty pump affects time constant.

ACTION: Those groups that have identified salty drifters, please provide WMO numbers and CTD Serial Numbers to Susan Wijffels. This might assist with finding any batch issues, geographical patterns, or possible candidates for retrieval.

### Day 2-afternoon: SeaBird CTDs on floats –users and suppliers

Users were invited for a SBE factory tour after the meeting.

Jochem Klinke presented the history and status of the SBE41 Argo CTD.

This talk only covers the 41 family tree with two general types: the spot sampling SBE41 with no internal memory, and a fixed pump rate, and the SBE41CP, which can do spot samples below 1000 m and continuous profiles above, at varying pump rates. The SBE41 was originally built at for PALACE floats and later adopted for Argo. The 41CP came as standard version or Coriolis version, which differed only in size of the head cap. Later-on another 41CP was developed with surface temperature and salinity with a free-flushed sensor with a shorter cell. Hardware consolidation was started in 2006 and now a single instrument can be used in both fashions.

There is now a new CTD engine for Navis, which is called 41N. A second round of hardware consolidation followed, and instruments are now denoted as ALACEplus or 41+. In 2015 there was also firmware consolidation, with one version for spot sampling and 3 versions for the CP. Last year SBE had problems with Kistler sensors and switched back to the Druck sensor. SBE is performing intense screening of the sensors to find micro-leakers. Currently 85% of SBE41s have Drucks and 15% have Kistlers. This is controlled by SeaBird's access to good Drucks to add to their inventory.

Long-term stability of CTD has been examined (see Janzen et al. in Sea Technology). They found essentially very little drift from post-calibration of six Argo floats. Best practices are given in AN97 (Annotation note). Metocean has its own version of the firmware with a hardware interface, which also seems to be used with NKE Arvor and Provor.

The question arose as to whether the pump rate was/is same on all firmware? SBE answers it can be set, and batches with different settings could exist. Can these different pump rates be documented through the Argo data system?

Peter Furze wanted to know when new firmware will be available. SBE responds that is not yet known.

Brian King inquired as to what changes should be captured in the Argo data system? SBE suggest that we record firmware revision. Mathieu Belbeoch remarked that we did not realize there were different firmware version for different floats. Is serial number a mandatory property in our files?

ACTION: Check in the Argo data system to see whether all floats have serial numbers recorded. Should we make that mandatory in our files, because that is the one number needed for APEX floats to get all the information retrospectively. Record firmware version in files, check what existing firmware information is files (decoder version vs. firmware version of TWR)

Kristi Anson presented a 2K Druck pressure calibration update.

In 2010 SBE was notified by Dana Swift about a pressure bias error at cold temperatures and high pressures. SBE replicated UW findings, looked for patterns, and came out with correction method. A new project was initiated to calibrate this out at the sensor level. It took a large effort and time – capital, hardware and software engineers. The <u>new calibration process starts</u> <u>with Serial number 41-10085</u>, now shown on the new calibration sheets with 3 different temperatures. In total, 15 sensors have been run through the old and new process and show a reduction in error.

Questions from Breck Owens: Why is there still 1 dbar error for the cold points? Answer is because of temperature differences between the board and the sensor. Breck again: This morning we have been worried about time-dependent pressure errors and with the new procedure we have eliminated this error. How do we make sure that our entire dataset does not suffer from inhomogeneities?

Susan Wijffels asked if SBE could help us to understand what that pressure bias in old Druck data was. SBE answers that for a small number of old sensors they could make us a histogram. However, Dave Murphy from SBE says that this temperature dependent response is variable across the sensors, thus the need for an individual calibration. SBE is asked how to identify if the new procedure is done. Answer is by the added parameter on the calibration sheets. At the moment, this procedure will only be done for 2K Druck.

Will there be enough Druck sensors for the array? It seems that we are dependent on the sensor manufacturer supplying SeaBird with an adequate quantity of sensors.

Greg Johnson (PMEL) asks why the new process of calibration are only showing positive errors. Answer: maybe reason lays at board level and not at sensor level.

Question to SBE: Have both sensors been used side-by-side on the same float? The answer was that there is no way of integrating two pressure sensors.

Susan Wijffels thanked SBE for this new and better calibration effort. Brian King wanted to know why the performance of this analysis has consumed so much electrical power? Answer: to keep the room cold. It is not clear at the moment when the new sensors go to the end-user.

ACTION: Work with SBE in order to understand the pressure bias in old floats and get some error estimates on that. [Riser/Wijffels]

Kim Martini presented on new work on dynamic errors and their corrections for 41CP CTDs

Stratified tank experiments are needed as Argo field data are too heavily averaged. The tank has a sharp thermocline and halocline. A 41CP is modified and samples at 16 Hz to be able to monitor that gradient. Three corrections are applied: thermal mass of thermistor, alignment, and conductivity cell thermal mass.

Corrections performed are:

- Fit for thermal mass is using symmetric form
- Fit for alignment is based on correct interfaces to same depth
- Fit for conductivity thermal mass could not rely on the above two corrections.

The latter parameter is adjusted to meet two conditions - no overshooting and no curviness in the lower part of the tank that would be unfeasible. The two parameters are then found. All corrections are found at sampling at 16 Hz and not as 1 Hz (the Argo float sampling rate). 16 Hz data are subsampled to the 1Hz sampling rate.

The SBE CTD samples sequentially across a 1 second interval – T then P then Pressure T then C. Thus C is sampled 200ms after T! This is why negative lags can appear in conductivity.

Breck Owens was confused about the vertical axes and remains confused. At the end new corrections are proposed and it is proposed to do this onboard the floats. But what about less ideal situations than the stratified tank?

A key question is: Do we want the corrections performed onboard? Does there need to be additional tests for applying this to 1 Hz data? Can the corrected values be sent as an additional variable? SBE tried verification with overlap from STS sensors and or raw data from SBE61.

Greg Johnson (PMEL) wanted to know what has been optimized in the fits. Answer is overshoots.

Breck Owens wanted to know if more experiments would be useful – say, to use staircases. He offered to talk with SBE about these experiments.

ACTION: Continue discussion with SBE on float measurements in staircases and perform further experiments. Test floats could be deployed where there are known staircases and the original and corrected salinities can be distributed in the raw and adjusted salinity data channels. Or 1Hz data could be return from staircase regions in the profiles, by deploying Solo2 floats in these regions.

John Gilson noted that S2A floats have raw 1Hz data available to examine. although it is frightening because it is noisy. Susan Wijffels suggested to use these data to see what could be done on board to see what the ideal coefficients for a float are.

ACTION: Give SBE access to 1 Hz data from the SIO and WHOI S2A floats (these should be in dimension 2 of the core netcdf files already from most S2A floats).

Susan Wijffels emphasized that we are interested in engineering out the thermal mass errors, and that this work by SBE is appreciated and important.

Annie Wong mentioned offline that we have a parameter called firmware version in the metafile that seemed to be copied into the profile files. But that may be different things - SBE firmware or decoding firmware.

<u>A general discussion</u> was held about areas of concern raised in the morning.

- dynamic temperature driven errors in Kistler sensors
- that frequency of ageing sensors resulting in salinity drifting high are increasing. Also there remains the question why around 8% drift salty?

#### Response from SBE:

Salinity drift comes from either minute amounts of leaked antifouling agent(TBTO) or another cause.

In an SBE41, TBTO causes a **fresh drift** if the liquid gets into the cell components: glass tube, electrodes and material that goes around the electrodes. SBE works hard to keep the TBTO from migrating. But if there is heating during transport it can creep into cell. However, it generally washes out quickly, ~10 profiles, though some seem to wash out over much longer periods, ~100 cycles. Could this be silicone oil? Dana mentions o-ring lubricants as a possibility.

**Drifting salty** is harder to understand. One mechanism is if a cell gets larger due to the dissolution of silica, but SBE doubts it happens. Salty drift appears more often in warm water. Electrode contact resistance could fall, but that also seems unlikely. A third mechanism is change in material that surrounds electrodes. This is being tested on a mooring but instruments are returned only once a year. So, work has indeed been done on this, but no explanation can be given right yet.

Dana Swift asked if it could be potential temperature drift, but this is not seen in postcalibrations. Steve Riser asked about changes in materials on the boards, or ageing. SBE also thinks that this unlikely because of their long-term tests in the lab.

#### Is retrieving floats useful? Under what conditions?

If we are willing to collect old floats, we should be fastidious how to prepare a float for postcalibration. Under what conditions and how fast would a 'aged' CTD need to be returned to SBE to be useful? Their advice on this will be crucial to whether float/CTD retrieval would be useful.

SBE has past experience from recovery of deep floats. It is best to have a technician aboard if possible. SBE insists that they have had better luck with the recalibration of recovered floats than with mooring equipment due to biofouling. SBE will provide best practices document.

Should we disassemble float or ship whole floats? Timely return is asked for to reduce the chances of the mechanical recovery of materials.

Steve Riser wanted to know if we really need the TBTO and had that been tested. JAMSTEC had 2 floats with no TBTO and won't do more. But those had no quality issues.

ACTION: SBE to develop a best practices document/guideline on how to handle recovered float CTDs for post-calibration and analysis.

Dean Roemmich mentioned the higher instances of drift and wants to know what has changed. Nothing, is the answer from SBE. SBE thinks the fast drifting cells may be due imperfect cells and suggests that this needs to be better understood. John Gilson has informed them about an uptick in the slow drifting to salty CTDs in recent years.

Susan Wijffels wanted to know why warm waters should matter if most of the time the float is at cold temperature days. Degree days is offered as index by SBE, with days above certain thresholds.

#### Pressure dynamic errors

What does SBE knows about this in Kistler pressure sensors? Do we need to mount Druck and Kistler together? SBE explains that these errors are artefacts of temperature gradients across the silicon chip. Drucks do have a lower magnitude response than Kistler. Drucks have a temperature sensor next to pressure chip while in Kistler measurements are separated. Norge Larson presented an assessment a few years ago at an Argo Steering Team meeting: it is a linear relationship and could be corrected. SBE offers to propose nominal corrections. They could bound the errors.

ACTION: Work with SBE on nominal corrections for thermal pressure errors in Kistler sensors [Wijffels and SBE]

#### Sampling closer to the surface

SBE is telling us we should not pump our CTD through surface films. Brian King reports on experiments in the Indian Ocean to test that. But there seemed to be a firmware issue with a range check. SBE offers to turn that off, but needs check on firmware revisions. Set the range to negative. Dean Roemmich asked again if 1 dbar is a fouling hazard? Do we want a pulse sample? Bin sample 1-2 dbar and 0.8 and 0.6 lowest points in profile?

The issue of an energy budget is brought up. SBE wants to know what we mean by that. Susan Wijffels talked about continuous profiles and spot sampling. Breck Owens mentioned migration to new electronics, and asked if that decreases the consumption. Answer by SBE is 'yes a bit'. Dean Roemmich talked about the philosophy for rise rate and how much of the profile could be continuously sampled. SBE responds they could provide some philosophy there.

ACTION: Continue discussion with SBE to improve energy budget and get their recommendation [Owens]

Breck Owens asked about longer-lived floats and will the sensors still will be reliable. SBE is advising us to recover some aged sensors to find out what is happening to them. The sensor that worries us the most is pressure, since we have no independent data for this and we need to determine what happens as the sensor ages. SBE offers their calibration database for Druck and Kistler sensors that have been used in different applications.

ACTION: get in touch with SBE to make use of their calibration data base [Riser]

Brian King came back to the issue of having two pressure sensors on a CTD. Can we mount a CTD pressure sensor on a float alongside the regular sensor? Two issues are brought up by SBE: One is power consumption, the second is the additional cost for the extra sensor and extra weight that could be an issue. Brian King mentioned the BGC-Provor, which would have no problem with that. SBE seems to agree it could be done.

ACTION: Engage SBE to explore if a Druck and Kistler sensor can be mounted on the same float [Grigor Obolensky]

### Day 3-morning: More float types-users

#### <u>SOLO 2</u>

Dean Roemmich and Breck Owens <u>presented</u> the History, experience, and performance of SIO and WHOI with SOLO-2/S2A floats

#### General information

Following SOLO, development of a next-generation ARGO float was undertaken to:

- Increase buoyancy adjustment capacity for operation to 2000m anywhere in the world.
- Decrease float size and weight for energy and cost savings and easier deployment.
- Eliminate latitude-dependent ballasting.
- Eliminate the air-bladder.
- Modernize electronics, CPU, firmware.

#### Characteristics:

- Float is 18 kg
- Reciprocating pump for size reduction and efficiency
- Pumping energy < 6 KJ per cycle (versus ~7 for SOLO)
- Deploy in biodegradable box 15" x 15" x 65"; ok for high speed deployment
- Iridium communications, many adjustable parameters
- Instrument self-test is ~ 30 minutes, can be done by non-expert w/data telemetered

With three battery packs, the float is expected to reach around 200 cycles. The next challenge is to reach 300 cycles with lithium batteries. The main technical issues are to increase the battery energy.

History:

- Prototype deployments, 3 floats off S. California Feb 2010 March 2011
- First "batch" deployment, 15 floats in April 2011, bladder problem shortened lifetimes.
- 10 Argo-equivalent SOLO-II floats deployed by Mirai in Aug 2011; 8 provided > 200 5-day cycles
- First MRV S2As deployed by SIO in Sep 2011 as part of technology transfer
- First WHOI MRV S2As deployed in May 2012 (STRATUS)
- Switched from 2 Electrochem lithium battery stacks to 3 in 2013
- Switched to Tadiran hybrid lithium batteries in 2015 2016

Performance:

- Initial reliability is high; 98% active after 10 cycles
- Failure rate about 4% per year for 3 years for SIO SOLO-II
- Main technical issue is battery passivation (high current drain under load at 2000 m)
- Lifetime limited by passivation, but capable of > 200 cycles with 3 Electrochem batteries; use of Tadiran batteries should increase this number to > 300



JCOMMOPS survival rate for SOLO-II floats deployed by RV Kaharoa in 2012 and 2013. The (20 deployed) 2012 floats had 2 Electrochem battery stacks. The (44, 39 still operational) 2013 floats have 3 battery stacks.





Tadiran batteries

Green: Voltage at surface

Red: Voltage at deepest pressure and high load (nominally 2000dbar). Averages include only cycles with deep pressures greater than 1750dbar.

ElectroChem batteries

Blue: Voltage at surface

Black: Voltage at deepest pressure and high load (nominally 2000dbar). Averages include only cycles with deep pressures greater than 1750dbar.

The upper figure shows the recorded voltage (V). The lower figure normalizes the voltage by earlier values (Cycle 5 for the surface voltage, and Cycle 9 for the deep voltage

SIO SOLO-II, Kaharoa deployments, 2011 – 2017 (355 floats total)



SIO MRV S2A (tech transfer), Kaharoa deployments, 2011 – 2012 (44 floats total)



Floats deployed in 2013 or later, all nations: APEX, ARVOR, NAVIS-A, SOLO-II, S2A



For the first 4 years, SOLO2 floats have a very high survival rates (90% are still active), better than the origin SOLO with less energy. SIO makes no difference between its model and the commercial version. No groups operate SOLO2 outside the US. That was mainly due to a license

fee policy (20%), but there are now several changes so they could be available outside the US soon. An advantage of SOLO2 is that the speed of the float is very regular (ascent rate ~9 cm/s), Allowing the the CTD sensor to work better.

#### Passivation and early death

The S2A floats appear to be greatly impacted by <u>passivation</u> or some other kind of battery damage, which prematurely causes the float the fail. This may be related to the relatively high current draw of the S2A's oil pump under high pressure compared to other float types. Currently the two teams using S2A's are managing this passivation in deployed floats in two ways. The WHOI teams stops profiling deep, while the SIO team is reprogramming pump times as detailed in the talks.

The teams believe the ultimate solution is to switch to Tadiran battery packs, which match large lithium cells with small rechargeable but high current cells. The large lithium cells trickle charge the small cells, which in turn supply high power to the buoyancy engine and other float needs. Several Tadiran equipped S2A's are now in the water and working well. Only time will tell if this solves the problem and the floats reach their potential maximum life.

#### Energy consumption

Tadiran battery packs: each pack can stock 1.7 MJ. S2A can get 3 packs and S2H (Alto) up to 4 packs.

For each cycle, the consumption has several sources:

- SBE CTD : 4.5 kJ
- ✤ RBR CTD : 0.5 kJ
- S2A hydraulics : 5.5kJ
- S2H hydraulics : 3.0 kJ
- Remainder : <0.5 kJ

Energy per profiles for different combinations is S2A / SBE : 10kJ (~510 profiles with no self discharge) S2H / SBE : 7.5 kJ (~906 profiles) S2H / RBR : 4 kJ (~1700 profiles)

A long discussion on passivation and its impacts across all float types ensued. A key issue is whether the engineering data being returned allows a useful analysis to answer this question.

What are the measurements of voltage that are available? Timing is a key aspect, because there are quick changes of voltage through the different parts of a cycle.

NAVIS APF9: measurements of voltage are available.

APEX APF9: measurements of voltage are available. The parameter names have to be explained in order to make sense. There are different measurements for each pack in several models:

that's a really useful thing to do.

APEX APF11: there is a constructed measurement from all the different voltages. But which are the relevant ones? There should be a time series of voltage.

Once the measurements are available, they still need to be explained, and many results are still unexplained (such as the drop off from 15V to 12V).

ACTION: For each type of float, an assessment of passivation is required [Lee Gordon].

John Gilson then <u>took the group through</u> the features and programming options for the SOLO II, including the dockside test which includes a satellite link test.

#### <u>General Discussion – SOLO II</u>

Passivation was discussed at length and how to diagnose it (see Appendix A by Lee Gordon).

Buoyancy engines do use different technologies:

• Ballscrew + air: float volume is more precisely known via the piston position, but the  $\Delta V/V$  is limited by the screw length and diameter.

- Pump: pressure dependent flow rates, so internal & external oil volumes not precisely known. However the  $\Delta V/V$  capacity is very large.
- Pump + air: improved efficiency over oil pump only. But still same problems as above.

Alex Ekholm discussed measuring surface waves through integration of an inertial motion unit.

#### <u>NAVIS</u>

Greg Johnson (PMEL) <u>presented</u> the experience of the NOAA PMEL team in using NAVIS floats, which is a relatively new platform. Many early failure modes were discovered and corrected via collaboration with SeaBird. These include

- Oil pump aviation in cold regions (12 floats).
- Apparent slow leak (20 floats).
- ✤ Air/oil separator issues (25 floats).
- Air bladder burping (17 floats).
- Quick catastrophic leak (5 floats).
- Miscellaneous causes (21 floats).

Many of these early failures were replaced via PMEL's warranty arrangement with SeaBird.

Given the loaded energy in the lithium packs, NAVIS expected lifetime should theoretically be ~300 profiles. However, voltages drop after ~180 profiles, suggesting death by ~225 profile.

Elizabeth Steffen gave a hands-on demonstration of the setup and mission programming of Navis floats, and went over the PMEL testing regime, which is relatively comprehensive:

- Check weights on arrival
- Confirm correct CTD serial number is installed.
- Quick transmission checks.
- Short workout (oil move, CTD).
- air bladder test (2h and 16h inflations).
- salt checks using simple rig
- mini mission (minimum 3 profiles).
- Periodic quick checks (oil, vacuum, pressure).
- Final checks before shipping.
- Shipboard predeployment checks.

This regimen has identified many different problems including:

- Leaks:
  - loss of vacuum.
  - holes in bladders.
- ✤ Air solenoids that fail to toggle.
- Oil system issues:
  - HP valve.
  - High current draws.
  - Sticky oil bladders.
- Transmission problems.
- GPS issues.
- Firmware incompatibilities.
- Spontaneous restarts due loss of internal comms with the CTD.

Several tests can be done on the ship before deployment:

- Confirm GPS and Iridium works
- Check mission programming
- Confirm bladder inflation, oil moves
- Check trends in vacuum, pressure

#### Automatic testing equipment:

There is a self-test rig that initiates a float testing cycle without having to connect to the float via a computer. It has been developed for inexperienced operators. If all tests are passed, there is a green light; if not, a red light shows. The current challenge is that the NAVIS firmware is changing so quickly, self-test packs are almost impossible to keep update.

ACTION: ask the manufacturers to maintain the self-test for each new firmware.

Several short talks covered other teams experience with Navis: CSIRO and JAMSTEC.

Bec Cowley reported that of 49 floats deployed by CSIRO:

Test floats profiled quickly to natural exhaustion (8 floats): all natural end of life and reached 200-250 profiles.

Bio float failures (4 floats): 3 natural + 1 leaked on deployment.

Shigeki Hosoda from JAMSTEC reported that of 71 deployments from 2012 to 2015, 24 have been declared dead. The failures are due to

- Buoyancy control failure: 27 (16 are dead)
- CTD communication error: 1.

Of these, 7 or 8 have been replaced via the warranty.

Brian King reported that 6 deployed out of 8 received by the UK Argo have performed well. The remaining 2 showed predeployment errors: a failed air bladder detected in Southampton and another failed a test on the ship (but had passed in Southampton).

It was noted that when a team discovers these errors and gives feedback to a manufacturer the information is not well-shared among other users. There is a real need to better collaborate between laboratories to alert the most users as possible.

ACTION: re-establish a means of faster communication among float operational teams about failure modes and technical errors.

At this point the fire alarm went off and we all had a nice break outside.



## Day 3-afternoon: Other float types – users and suppliers

#### MRV on SOLO and Alamo floats

Neil Bogue from MRV <u>discussed</u> the history of their company and the floats they manufacture – the SOLO II (S2A), ALAMO, 'hybrid'/Alto (ALAMO internals, S2A hull), and they are just beginning to manufacture deep SOLOs, replicating the SIO methods and design.

Locations: San Diego (financing, float finishing, shipping), Chicago/Itasca (Manufacturing), Seattle (Software)

The goal is for there to be little or no intervention by users to deploy: fan-tail ready S2A floats are now available for international sale, as the licensing contract was rewritten. A Bluetooth link makes querying and programming floats easier.

Lee Gordon discussed Tadiran battery technology and its benefits for use in floats, as they avoid passivation/de-passivation cycle damage to cell chemistry. He contended that if the float is in the water more than a month, Tadiran batteries (2 cell hybrid) are more efficient than the current single cell type battery packs used. The secondary rechargeable cell should hold at least as much energy as necessary for a cycle. For S2A/SOLO-II/Deep the secondary cell holds 2-3 times that energy. He noted that Tadiran packs need to be stored upright or on their side, not upside down.

Another discussion on battery passivation ensued. The questions discussed were:

- What is the right way to diagnose passivation? Best would be for a measurement of first and second large current pull after the drift phase.
- The apparent efficiency at accessing loaded energy across the array looks roughly like: Navis 60%, SOLO 50%, Apex 70% - why? It could be that passivation increases the cell self-discharge rate?
- Would it be helpful to recover floats for diagnosis? It wouldn't hurt to find how many Joules are left if the battery packs.

ACTION: Carry out an analysis of passivation across float types using reported engineering data and provide guidance on how to diagnose battery passivation [Lee Gordon]

Anthony Massa (MRV software engineer) was asked if MRV can help with decoders, and could MRV adopt the Argo technical data vocabulary? This will be explored.

Can MRV supply a testing graphical interface and a set of self tests (short and long)? Possibly. This hasn't been implemented yet as the present user base are experts.

Could they supply an energy counter? Best if this is based on numbers for energy used measured on the bench, as a true Coloumb counter is energy hungry.

Via a collaboration with WHOI, for both Antarctic and Arctic (probing with bumper), MRV is developing ice-avoidance capability.

#### SeaBird on NAVIS:

Daryl Carlson presented NAVIS history and developments.

Extensive field testing has occurred – all from Hawaii. After the early PMEL failures, the air system was redesigned – NAVIS EBR - 'External Bladder Redesign' which improved the air system reliability, cowling shape and vent hole placement

SBE is trying to limit the number of firmware versions to deal with. There will be one for core Argo and with oxygen. BGC floats have a different firmware branch.

SBE is developing a new float controller, the N2, due to parts obsolescence. It has an onboard humidity and tilt sensors and can store all profiles on the float – the float is not able to transmit these data but can get them back if float is recovered. It also has a Coulomb counter but has not implemented or fully tested it yet. The N2 will be supported until 2024. It is more power efficient with a 6mA controller compared to the old one which was 12mA. It also has USB capability that has not been implemented yet.

Ice avoidance has been tested on SOCCOM NAVIS floats, and is about to be available on core floats.

Failure mode detection algorithms are being developed, and SeaBird is willing to share them with the community – possibly through some web-based tools.

Updating the energy use models for the new float design and the N2 controller will help understand further options to reduce energy use.

A pH sensor is being integrated into BGC sensor packages, developed for Navis, Webb and NKE floats. The pH sensor looks promising after ocean testing but has a static offset at the start only.

N2 NAVIS uses firmware and software based on Dana Swift's APF9 controller. In addition, SeaBird has developed a MS software package on top of the firmware. This allows mission configuration, pre-deployment and mission changes after deployment.

#### Discussion

The issues of version tracking and battery experiments/passivation (trying new battery types) were raised again. SeaBird were keen to assist the community in these efforts.

Availability of a SBE supplied decoder was brought up: Decoder is based on flat files, matlab scripts are available. Mathieu Belbeoch suggested SBE put this on the Argo github

Brian King asked about how we can do a better job of keeping track of major firmware or hardware changes (e.g. EBR versions; and the SBE controller change from N1 to N2)?

Peter Furze queried as to what level of detail is needed? This is likely a judgment for the Argo Steering Team to make and Argo Data Team to manage. This discussion has led to one of our recommendations – that on an annual basis, suppliers give a brief update to the Steering Team on major changes and an outlook.

For questions about energy budgets and passivation, SeaBird noted that their model of energy use is accurate for fast cycles but at longer cycle times is not, consistent with possible battery damage by longer passivation periods.

Dave Murphy then reported on the SBE61 production. To date 81 have been produced, 8 for R&D, the rest for sale. Design has been stable since initial debugging.

Forecasting future plans by PIs was requested to allow curing time of sensors in the factory (6 months or more is needed) – it takes a while before the calibration stabilizes, and their stringent screening and calibrations means that they are expensive. SBE is ramping up to meet the deep Argo program needs. They welcome further opportunities on GoShip lines for testing.

ACTION: To obtain more stable sensors on SBE61 CTDs, PIs should provide a forecast of sensor needs, ideally 6-9 months before acquisition is needed.

#### NKE on ARVOR/PROVOR

Jerome Sagot <u>presented</u> on the current status of NKE floats. NKE is a fairly small company. It has a long partnership with IFREMER, and now LOV and UPMC.

#### ARVOR – is the core Argo float.

Its mass is 20kg, and it should deliver up to 250 cycles at 10 days and 300 CTD points per profile. Iridium versions are just now being deployed. The syntactic cube at the top of the float helps with stability, compressibility, and buoyancy.

Mission and Technical parameters are now better-organized and labeled in line with the Argo vocabulary. Ice detection is enabled based on temperature and pressure changes and satellite non-communication. This is user configurable before and during deployment.

#### PROVOR have the additional BGC sensors.

Architecture is built on two boards, one for float and one for additional sensors. The float has pH electro-chemical sensor. Optode in-air measurements for Aanderaa 4330 is now a possibility. The Optode is mounted on an aluminium mast for PROVOR & deep ARVOR, and overmoulded cable in ARVOR. An Optode can be added to all NKE floats. PROVOR returns two technical packets instead of one. Profiles are stored in memory to allow delivery later- up to 15 profiles. They are trying to increase this to 1 year's worth of data. Argo variable names are now included in the manual and decoders! A free matlab decoder developed by Coriolis is available.

Transmission via RUDICS has been optimized. SBD transfer is also available. CLS has a RUDICS server available.

These are self-ballasted floats with an oil bladder of 1L total – the can be adjusted for any location. They employ magnet startup and a Bluetooth module. No pressure activation mode is available.

There is an extensive 'expert' users <u>testing routine available</u>, with simple command line commands. Upon request, a user can set up float to start when a magnet is removed. This is done at factory with user configuration. A float can be delivered directly to the ship, ready to be deployed.

Deployment auto-test checks communications, valves, voltage, vacuum, sensors, upon removal of the magnet. An audible buzz is given to indicate the float is ready to go. Deployment checklist and deployment documentation are written and available. For SBD mission changes – send email to the Iridium system with the new configuration. Floats need to be stored vertically. Cardboard box deployment is possible.

Some Italian floats cycling on 5-days have reached ~350 profiles. IFREMER now have a large fleet of ~80 floats, and while they are still very young, they seem to have good reliability.

The first Arvor-Iridium float was deployed in 2010. Euro-Argo has deployed 110 ARVOR (Argos) and of these 2 are dead. IFREMER is just deploying Iridium Arvor now.

Jerome Sagot did not think passivation is a big issue, but was not sure. Battery voltages are stored during the cycle, so an analysis should be possible. The question of passivation needs investigation in ARVOR/PROVOR.

Serial numbers are more detailed now – is easy for the manufacturer to identify what firmware/part configuration they have. NKE keeps track of that now.

Brian King then presented a summary of the two key issues raised-More detailed and easier testing by users:

- Easier and increased acceptance testing on delivery (long test) and before deployment (short red light/green light)
- We need better documentation on what is the correct 'test' results. Can the new values be compared to past tests done after manufacturing? How this could be done and who pays for this (users, manufacturers) was discussed. What is the cost/benefit? Dean Roemmich noted that sending someone to start up floats and check floats at the

dockside is good practice for reliability reasons, but also makes a human connection with the deployers and shows that we care about our floats.

Battery health and efficiency:

- 1) We need to identify the correct moments to measure battery voltage/current
- 2) Telemeter that data
- 3) Capture consistency across Argo floats and do a fleet-wide analysis

Peter Furze noted that floats die for many reasons and the best way to really know is a postmortem upon recovery. All agreed, and that we need to be looking into the possibility of float recoveries for this purpose.

### Day 4-morning: More CTD types

Breck Owens presented the history of inductive cells in Argo.

Inductive cell advantages:

- No need for pumping, uses only 10% of the energy (typically 0.5 kJ per profile as compared to 4.5kJ for pumped CTD)
- Easy integration on float's head (compact, light, low volume)

Inductive cell disadvantages:

- Precise temperature measurement collocated to C measurement has to be done
- Sensors have to be calibrated accurately while on float's head; there are no unified calibration procedures across the various manufacturers, and even within each float manufacturer calibrations are head-dependent
- Thermal mass effects have to be strictly assessed
- As the inductive cell measurements are strongly affected by the cell geometry, biofouling has been an issue Argos telemetry with long (18 hours) drifts on surface was not good

First FSI attempts were on P-Alace floats and showed large stability problems, and accuracy of measurements did not compete with SBE pumped CTDs. The technology was not mature enough for early Argo deployments with Argos telemetry.

These floats also suffered from a programming bug: bins measured from bottom to surface during ascending profiles, but computed from surface to bottom when transmitted to shore, thus inducing computational errors on the reconstructed profiles

Susan Wijffels <u>summarized</u> the past experience with RBR CTDs in Argo.

The first RBR CTD tested in the Coral Sea had separated T and C measurements, which suffered from flow-related mismatches between these channels, inducing large errors in salinity (>.05)

and unrealistic inversions in the density. However, the Coral Sea RBR CTD shows excellent stability as compared to nearby SeaBird CTD, though it has a constant fresh offset. Based on this and tank testing, RBR re-engineered their CTD to create the RBRArgo CTD. There is also a deep version of this - the Deep RBRArgo CTD. Improvements include:

- T and C sensors are now collocated
- Hydrodynamics of the newly designed cell ensures much better C and T alignment, and thus the sensors have a better dynamic response

The only field data we have are from RBRArgo equipped ALAMO floats deployed recently in the Atlantic. These have sampled double-diffusive stair cases, and the results look extremely promising, even without further post-processing.

IFREMER has new results from a GOSHIP cruise at 36°N Atlantic which are promising; the sensor has been qualified on CTD Rosette shipboard casts. These quality of these data has not yet been assessed.

Future developing and testing that we are aware of include:

- Brian King to deploy 2 RBR/Apex soon.
- Guillaume Maze is working on the intercomparison with GOSHIP ship board data.
- RBRargo integration into MRV's S2H (Alto) floats is nearly done. A deployment in the Pacific is suggested, in an area chosen for its deep water mass stability.

### **Discussion**

JAMSTEC is about to deploy Apex RBR floats, but data policy not clear at this moment (public use or private to PIs).

Can we deploy dual CTD floats for an intercomparison? B King has a Deep Apex float for which this might be possible. IFREMER is working on a dual head RBR/SBE61 deep Arvor float At INCOIS, the RBR APEX deployments failed - likely due to an APF11 issue. NOC deployed 2 RBR floats off Iceland and preliminary results are that a few of profiles show large bio-fouling events – this occurs in SBE 41 data as well. It is exciting to get profiles as close as 25 cm to the sea surface.

Birgit Klein proposed to deploy more RBR floats in the Nordic seas, where the climatology is well-assessed, and there are many cruises and deployment opportunities.

In summary the new RBRArgo results are few, but very promising. What are the next steps? Suggestions included:

- more pilot deployments needed in stable water masses e.g. Pacific Ocean
- paired deployments rather than single ones for data intercomparison during the first profiles
- some deployments with dual head highly desirable, but may be hard to avoid issues with external measurement volume for inductive cells.

• shipboard deployment of RBRargo standalone sensors for intercomparison with SBE 911 high precision measurements to assess P, T and C

Brian King noted that the RBRArgo CTD has to be deployed intensively and not sparsely for a decent sensor assessment.

Annie Wong asked how to accept the data in the Argo data management system? We need to be prepared for these pilot studies with clear advice to the ADMT.

How do we notify a RBR float at the Argo Information Centre? M.Belbeoch noted that this is already possible and reminds us that it is mandatory to declare floats for international data handling.

It was noted that for the Deep APEX floats, the APF11 allows the user to plug in a standalone RBR CTD, though calibration might be difficult, as the manufacturer has to calibrate the sensor on the float.

Teams where encouraged to think about funding sources to participate in a global pilot study.

Steve Riser gave a <u>brief summary</u> on the new NOSS CTD and its potential use in Argo. NOSS uses changes in refractive index to estimate density, which is then inverted, using temperature and pressure, to obtain *absolute salinity*, not practical salinity (linked to conductivity). To date, only a few sensors have been constructed, but these are commercially available from NKE; a few have been tested at sea (only one deployment documented). There is an unexplained offset in the absolute salinity compared to practical salinity. First results are promising, but there were some pressure effects on the glass cell. The SHOM and NKE are trying to quantify the effects of pressure now. How much of the variation can explained by other (non-conductive) dissolved species in seawater has yet to be verified.

NKE are ready to lend the NOSS sensors out for testing during field campaigns. The technology is promising but it is too early to say if this will be used as a core sensor for Argo in the near future.

## Day 4-afternoon: Other CTDs – users and suppliers

### RBR on the RBR ArgoCTD

Greg Johnson (RBR) gave an <u>in-depth talk</u> on the history and status of the RBR and its Argo CTD. He presented the target accuracy of the RBR CTD, and the characteristics of the pressure sensor and conductivity cell. He described the calibration and testing, including aging of the CTD and pressure sensor, and individual linearity check of the conductivity cells. Drift can be generated due to changes in the electronics, electrical system, and the geometry of the CTD cell. Greg recommended using measurements at the surface for long-term assessment of the drift in the conductivity cell. Susan Wijffels addressed the need to update the firmware to access raw data for thermal mass correction before the implementation of large-scale deployments.

Greg Johnson (RBR) showed the RBR CTDs available for operation at 2000 m and 6000 m. The 6000m version, which is a slightly bigger than the 2000 m, is being tested on Deep NINJA, Deep Arvor, and Deep APEX. An MRV version for Deep SOLO floats is under development.

Greg presented the characteristics and power consumption of the ODO optode. He described two types of calibration using (i) a given value of salinity, and (ii) "live" salinity correction with ODO mounted with the CTD.

Greg presented the features of the new L3 platform: low power consumption, wide input voltage, faster sampling rate (up to 32 Hz), energy consumption (accumulates "sleep seconds" and "samples"), provides Joule count at any time, and individual power management.

Plans for the future include *in situ* processing and compression, the option to turn an onboard thermal mass and time constant correction on and off, and per-channel sampling schedules.

RBR will provide notice of revision and of firmware upgrades.

#### Discussion of the RBR CTD

1. What are the values for  $\alpha$  and  $\tau$  for the thermal mass correction? RBR plans to provide them, although these behave differently from SeaBird conductivity cells.

2. Is there a worry about the modularity of the end cap?

RBR works as joint engineering team with Teledyne Webb on the design of the end cap.

*3. Currently, 5-10% of Seabird cell drift in a mostly correctable way. Do you anticipate that there might be a drift in the RBR CTD?* 

RBR: We don't have a good characterization of the drift at present (not enough data for reliable statistics).

4. How do we get real confidence that we are meeting the target accuracy of the instrument? Would it be feasible to do testing on two-headed floats or side-by-side comparison on a shipboard CTD with good heat compensation system? Our goal is to improve the quality of the pressure measurements and decrease thermal pressure error.

RBR: Laboratory experiments including sampling in pressure tanks would provide useful information. The worry is that *in situ* comparisons with shipboard CTD would introduce too many variables.

5. The possibility of deploying two-headed floats (for testing only, won't go in the global data stream). This test would be informative of the performances of the SBE41 and RBR. Potential deployments in the North Atlantic and North Pacific Basins, and the HOT station could be

# explored. The goal would be to try to estimate dynamic error. Understanding relative fouling rates between regimes would also be helpful.

RBR suggested mounting an additional pressure sensor on the floats used for testing. Such an experiment would need at least 80 floats (10% of the 800 Argo floats deployed each year) either double-headed or with RBR CTD/additional pressure sensor to build reliable statistics.

Jerome Sagot, NKE, commented on the value of the absolute salinity variable for measuring in situ density. The NOSS sensor is a new tool for monitoring in situ absolute salinity and density of seawater. It is currently rated to 2000 m. According to Jerome, a deeper version could be developed. Jerome showed absolute salinity measurements using the NOSS sensor in the Mediterranean Sea, and comparisons with the SBE41 CTD. NKE plans to improve the accuracy of the algorithm in pressure and temperature, and perform direct measurements of absolute salinity.

#### Discussion on the NOSS Sensor

#### 1. Is the NOSS sensor susceptible to fouling?

NKE: The optical sensor not very sensible to fouling. We need longer deployments to assess fouling effect. NKE is working on anti-fouling solutions to implement in the future.

#### 2. Cost of the sensor?

NKE: Probably more expensive than a regular CTD. This price could be reduced as production rates ramp up.

#### 3. Interface in term of data logging?

NKE: Can be installed using any type of logger. So far, this sensor has been installed on Provor floats only.

#### 4. What is the depth limitation of the sensor?

NKE: Currently, 2000 m. They could develop a sensor rated to higher pressure. They would need to develop a new housing.

#### CLS on satellite communication services:

Brice Roberts <u>presented</u> on services provided by CLS and their future development. He presented the status and evolutions of Argos telemetry services for Argo profiling floats. A major upgrade occurred in 2016 and continued in 2017. There is strong collaboration with float manufacturers.

The Future: transition to Iridium Next. Should begin by the end of 2018 to beginning 2019.

Updates on Argos:

A new pricing is currently reviewed by OPSCOM, and a new Argos 3/4 chipset available for integration that is more power efficient.

Argos 4 will provide a better link and power budget, capability of larger messages (up to 625 bytes per message), and higher data rate (up to 4800 bits/s).

A new Argos constellation is currently being designed by CNES. This constellation should include nanosatellites to be deployed in 4-5 years, with a constellation of 15-20 satellites.

Recommendation from Brice: The Argo community may want to keep a proportion of Argos system floats operating in case of Iridium failure. The possibility of combining Argo and Iridium dual telemetry on expensive multi-sensor platforms (i.e. gliders, BGC floats) is attractive. Argos is a robust system for providing positioning and could be a valuable backup in case of Iridium transmission failure.

Backup link on APEX and Navis floats: The general rule is to switch from RUDICS to CSD in the case of 5 failed attempts to reach the RUDICS server. This was relevant when RUDICS could only handle one call at a time, but now there can be thousands of calls at the same time (if a server is properly maintained and monitored, it should be up and running 24/7). This scenario could happen during float testing, and if 5 failed call attempts due to bad weather. Maintaining analog phone lines is more and more challenging (obsolete technology). One solution: modem to modem calls.

### Day 5-morning: Deep Argo - users

Nathalie Zilberman presented the current status of Deep Argo deployments, which are in a pilot phase. In total 69 deep Argo floats are operating now spread across several regional arrays in different ocean basins. Overall most are working well, though sensor accuracy remains a work in progress. We don't yet know how best to use a mix of 4000m and 6000m sampling floats. Greg Johnson (PMEL) noted a newly funded deployment in the South Atlantic, supported by the P. G. Allen Philanthropies and NOAA.

Dean Roemmich presented his team's experience with Deep SOLO and SBE61 CTDs

History of Deep SOLO Deployments:

Jan 2013 and June 2014 prototype deployments

Jun 2014 compared SBE61 with SBE911 CTD casts on board RV Tangaroa.

Jan 2016 7 SOLO's and 1 APEX deployed in SW Pacific Basin, but there were issues with SOLO electronics.

Jun/Jul 2016 recovered 4 SOLO from the ocean and serviced with software upgrade and redeployed. 1 Unit had broken antenna on recovery by ship. Others that could not recovered, are staying down for extended periods.

RV Investigator deployed Deep SOLO's on P15S and along 26N in the Atlantic.

#### Deep SOLO Performance

25kg Float in 13" Sphere, similar to SOLO 1, 20KJ energy is needed just for pumping. 30 deployed, 29 active, 1 broken antenna.

Battery passivation is a major issue for Deep SOLO floats. The older versions have Electrochem batteries, but SIO is making the change to Tadiran batteries. Expectations are to obtain 200 cycles, with concurrent plans to increase the number of battery packs.

Several Deep SOLOs have done about 60 profiles, parking at 5000 dbar. Profile data are collected on the way down, and the float parks on the way up. SIO is exploring measuring on the way up. The float has a 3 m wire hanging below for passive bottom detection, which seems to be working well.

SBE61 Performance To date 30 deployed, 29 in operation. Goals are: Temperature +/- 0.001 Pressure +/- 4.5 Dbar over 6000DBars Salinity +/- 0.005 SIO has found salinity biases in the SBE61 and this needs further work (fresh by 0.003/6000). Salinity scatter has decreased in SW Pacific basin. Drift is less in the North Atlantic fleet but the record is short.

They have only recently started using full-scale dead weight tester to 6000dBars. There appear to be errors of up to 4.5 dbars at 6000 dbars. The testing has been done at room temperature and 4°C. Only 5 instruments have been checked checked to date.

Summary: further laboratory testing is required for deep CTDs. We should recover Deep Floats as well.

Charlie Parker <u>discussed</u> SIO deep SOLO setup and mission programming. These are similar to SOLO 2s, but Deep SOLO also has a wireless connection. Magnet swipe (blind) can initiate a system self-test. Wireless communication (XBEE) is like bluetooth and enables 'spying' on the floats to see all the engineering data.

There is also a guided checkout of the float for the more experienced user. Last test to be performed is always the magnet swipe with spying. Systems included are the high-pressure pump, valve, battery voltages, checksum values, communication with CTD's, GPS and modem.

#### Questions:

Is the XBEE communications reliable? Yes, most of the time. They have flashed firmware via XBEE. Usually only one float at a time, not two.

Deployments from ships of opportunity? Yes, in boxes and without. Cardboard antenna guard is used for naked launches.

How quickly could DEEP ARGO program ramp up? Manufacturing, 6-month lead time for CTD's Can SBE ramp up production? MRV construction can be ramped up, expansion is not a problem, but a long lead time required. CTD is the longest lead time for all parts.

SBE61s are cherry-picked for deep systems due to the aging of the systems. SBE has not yet started building SBE61s for stock purposes, waiting for forecasting of orders.

John Gilson presented further on the programming and behavior of the Deep SOLO. General mission setup: 15-day cycle, data profile on descent. 4 regions in the profile can be targeted. Descent is uncontrolled, ascent is controlled. The CTD is turned on right before descent, so that the surface data is reported. Floats drift at 5000dbars, but can target about 300 to 500 dbars above the sea floor.

#### Questions:

Why profile on descent? CTD is on the bottom of float, so it was decided to profile downwards, also have to park on the way up and there the profile would have been split. Thinking about profiling upwards after park phase, upper ocean profile.

Could profile in both directions, yes, very interesting idea to pursue.

How long to profile downwards? About ½ a day.

No passivation mitigation, no ice algorithm, no surface interval algorithm.

Float slows down descent rate at it approaches the bottom, and uses wire line to detect bottom.

Can you adjust the pump speed for CP. Perhaps? John would have to get more information.

The passive bottom avoidance system was discussed, and how the SIO team is constantly updating the profile depth for each float to avoid a bottom crash.

Where should the array going to go from here? Dean Roemmich is reluctant to start more pilot arrays. He is happy with current locations, so will continue to populate those areas. Also, they are working on how to ramp up the funding level. Likes the SW Pacific as well-studied and they look to replace floats in the array.

A general discussion was held on how deep Argo floats should be missioned and how to manage an array of 6000 db and 4000 db profilers. Much is still to be learned from the regional pilot studies before we can progress these issues.

Breck Owens <u>reported</u> on a test of the RBR Deep CTD being done by Guillaume Maze, IFREMER. JAMSTEC also has one for trial testing. The analysis has not started. Brian King notes that the new British RV has heave compensation on the CTD winch, which would be useful to test new RBR instruments. There is a need to test pressure with a digiquartz for satisfactory comparison. JAMSTEC also have suitable opportunities to perform testing.

Brian King presented on user's experience and issues with Deep APEX.

Various floats had internal hydraulic oil leaks, seawater leaks, some have died, and some have been recovered. Of the UK floats, Deep #8 died after 50 profiles. Deep #7 has done 120 profiles, but is now doing shallow profiles due to energy usage concerns and was recovered. They found that an extra oil filter had microcracks which allowed oil to seep into the float. Another 3 Deep floats were deployed in Drake passage and all showed leaks and were recovered after only a few profiles. Water was leaking through the pins of the cables. TWR has since changed the cable penetrations into the spheres.

Deep #7 will have a RBR CTD fitted alongside the existing SBE61 CTD. Future deployments are planned for Drake Passage and Atlantic 24S. Japan also deployed one Deep Apex but it had early seawater leak and died. TWR was able to do some at-sea testing before it disappeared. UW had four floats but lost one early on. The other three are working well. TWR did some extra work with modifications and electronics changes.

#### Discussion:

Deep APEX has no bottom avoidance. Failures have been seawater and hydraulic links. CTD performance has been problematical, too, with salinity starting fresh, but withare varying differences in drift. These were early built SBE61s, and Dave Murphy of SBE is working hard to fix SBE61 issues. The Deep APEX samples at 2dbar, and this is considered to be affordable up until now. UK floats are doing 3 day cycles, U. Washington are doing 10-day cycles.

Is the pump speed programmable? Should we be concerned about being able to correct the thermal lag error? Is there spot sampling being done? Yes, they are running in CP mode. Dean asked about the Deep SBE41. No information was available at this meeting

A general discussion followed on how to distribute and label pilot deep Argo and RBR data in the Argo data system. We can use the QC labels here: Peter Oke noted that most people will see and note the QC=3 data and not use it.

Acceptance of new sensors for core Argo has to be via the Argo Steering Team, based on pilot studies and demonstrated achievement of meeting Argo quality needs. Good data return, with the requisite quality, needs to be seen across different ocean regimes. Already 5 RBR Floats have been slated for deployment, and more groups might be willing to be involved in a global pilot study.

### Day 5-afternoon: Deep Argo – users and manufacturers.

#### <u>Deep Apex</u>

Peter Furze (TWR) <u>presented</u> on the present state of Deep APEX. TWR have made a substantial investment in the Deep APEX. Over the first set manufactured, a great deal has been learned, and several failure modes have been found and fixed.

The Deep APEX has a leak detection system. Leak behavior is demonstrated in park drift data — continual adjustments to return the float from deeper to the shallower park pressure might indicate a leak. Leak detect volts will drop to around ~1 volt (from 2.2) with the APF11. When a leak is detected due to leak detect voltage or humidity increase, the recovery mode is initiated. Humidity detect goes up to 60-70% from 10%.

In addition to the SBE61, T/W has integrated both the Aanderra and Rinko oxygen sensors on deep APEX. Electrochem lithium cells are used at the moment, but TWR will be evaluating use of Tadiran batteries.

The engineering data did help diagnose some failure modes. They showed a pump motor problem when oil leaked into the motor; a bladder leaked on shipment on one of the float; an air bladder in a Japanese float failed, but the float was able to stay at the surface. Hull penetrator leaks have been fixed – new floats have the new connectors.

#### Deep SOLO

Neil Bogue commented on MRV plans for building the Deep SOLO.

The first order has been received from Greg Johnson (PMEL), and the first build is about to start. There are a significant number of similarities in parts between the SOLO II and Deep SOLO. Testing will be taking place at Scripps. MRV would also like to get RBR integrated onto the deep SOLO. MRV Deep SOLOs will be available nationally and internationally.

#### <u>Deep Ninja</u>

Tony Escarcega presented results on TSK and the Deep Ninja.

The deep NINJA is 2m tall and weighs 50kg. About 22 Deep ninjas have been made and deployed so far.

The float can carry a large payload, and it has ice detection and bottom detection (no change in pressure) software. Other integrated sensors include a turbulence probe in collaboration with Rockland Scientific (requires fast ascent), and a Rinko oxygen sensor.

Future plans for Deep NINJA include increased battery life, higher reliability, and additional sensor capabilities. The float currently uses Electrochem batteries.

#### Questions:

The floats only have SBE41 on board at the moment. Will the SBE 61 be available. TSK is willing to look at this.

Under-ice float success rate? Average of 17 profiles per float under the ice for Japanese floats.

#### <u>Deep Arvor</u>

Jerome Sagot <u>presented</u> results of the Deep Arvor. Development by IFREMER since 2010 and commercialized in 2013 by NKE. This 26kg float can profile to 4000db. No pre-ballasting is required for the float and it can be deployed at any density. Currently it uses the SBE41.

Other features include:

- DO sensor option (Aanderra 4330), including an air measurement.
- Ice detection
- Zonal operations option (as for all other floats)
- Auto mission alteration and ground detection
- SBD data transmission
- On board data storage

Deployment status – 2 floats have reached more than 140 cycles, but many have failed early. There have been around 20 deployments in total. Spain, France, Italy, UK have all deployed them. Not all cycles are to 4000 m, due to grounding and then alteration of the profiling depth. Grounding detection and compensation has an energy cost. There are no plans to develop a ground detection device.

Salinity drift has been seen up to 0.25 PSU, but no clear temperature drift (very hard to see unless very large). To reduce the possibility of cell contamination, NKE now follows a cell cleaning procedure on all sensors before delivery using Triton X. Also, they have started hydraulic engine failure investigations and have a final testing in pressure chamber to check efficiencies.

Deep Arvor has been modified to do bottom tracking with a Doppler sensor. The goal to is to measure the bottom current in the Weddell Sea. This float has been deployed and completed 44 cycles (JB Sallee PI).

### Meeting summary and outstanding issues

Susan Wijffels led a discussion of the key issues, recommendations, and actions from the meeting. These are captured in the Executive Summary.

Overall, many found the meeting of great use and suggested these occur more frequently, such as every 2 -3 years.

We thank all the participants for their strong engagement and contributions, the efforts of the chairs and rapporteurs, and particularly the U. Washington team for being excellent hosts. Megan Scanderbeg helped with meeting logistics. This meeting was partly supported by the NOAA Climate Program Office.

### Appendix A: Agenda

Float/Sensor Workshop Ocean Sciences Building, Room 425 University of Washington Agenda (9/7/17)

[Items in Red: Float users only; Items in Black: All are welcome to attend]

Meeting registration fee: (everyone): US\$75, paid in cash; receipts provided To everyone: please bring slides relevant to the presentations listed even if you are not listed as a presenter.

#### Day 1 (9/11/17) (General theme: APEX floats)

Morning Chair: Breck Owens; Rapporteur: John Lyman 0830: Meeting begins, welcome, local arrangements, introductions (S. Riser) 0845: Rationale for holding the meeting (S. Wijffels) 0915: The present state of profiling float performance (B. King) 0945: Teledyne/Webb APEX floats: basic history and operation (S. Riser) 1000: Break 1030: APEX evolution: old and new controllers; communications; batteries (D. Swift) 1100: Examples of pre-deployment checking of an APEX float (D. Swift, R. Rupan) 1130: APEX user feedback: what are the most common failure modes, what predeployment checks are done, what needs changing? (S. Wijffels) [Responses solicited from various groups prior to the meeting]

#### 1230: Lunch

Afternoon Chair: Nathalie Zilberman; Rapporteur: Annie Wong 1300: Review of meeting format (S. Wijffels) 1315: Present state of the Teledyne/Webb APEX float (Teledyne/Webb representative) 1400: Mission programming options of an APEX float with T/W APF-11 controller (hands-on activities with T/W rep) 1500: Break 1530: User questions and issues with APEX; the future of APEX development (Users and T/W reps) 1730: Adjourn 1800: Welcome Reception (Ocean Sciences Building Lobby)

#### Day 2 (9/12/17) (General theme: SeaBird CTD units)

Morning Chair: Peter Oke; Rapporteur: Kristy McTaggart 0830: SeaBird41 and 41CP CTD units: basic history and operation (S. Riser and D. Swift) 0900: SBE41 calibration and laboratory checking (D. Swift and R. Rupan) 0930: SBE41 performance and data quality (A. Wong) 1000: Break 1030: Kistler/Druck sensors; thermal lag correction (D. Swift) 1100: Discussion of recurring issues with SBE CTD units on profiling floats (Users and S. Wijffels) [Responses solicited from various groups prior to the meeting]

1215: Lunch

Afternoon Chair: Shigeki Hosoda; Rapporteur: Birgit Klein 1315: Present and future states of the SBE41CP (SBE representatives) 1430: Break 1500: User questions and issues with SBE41 and 41CP (Users and SBE reps) 1645: Adjourn 1700: Bus leaves UW for tour of SBE and dinner (float users only)

#### Day 3 (9/13/17) (General theme: more float types)

Morning Chair: Susan Wijffels; Rapporteur: Ben Briat 0830: History, experience, and performance of SIO and MRV SOLO-2 floats (D. Roemmich, B. Owens) 0900: Setup and mission programming of SOLO-2 and Alamo floats (J. Gilson) 1000: User issues with SOLO-2 (J. Gilson, B. Owens) 1030: Break 1050: History, experience, and performance of Navis floats (G. Johnson/PMEL) 1120: Hands-on setup and mission programming of Navis floats (G. Johnson/PMEL) 1200: User issues with Navis (G. Johnson/PMEL) [Responses solicited from users prior to the meeting]

1230: Lunch

Afternoon Chair: Steve Riser; Rapporteur: John Gilson 1300: Present state of MRV SOLO-2 and Alamo and user issues (MRV representatives) 1400: Present state of SBE Navis, and user issues, plus SBE61 status (SBE representatives) 1500: Break 1530: Present state of NKE Arvor/Provor and user issues (NKE representatives) 1630: Summary of float performance and user issues (Users and B. King) 1730: Adjourn

#### Day 4 (9/14/17) (General theme: more CTD types, etc.)

Morning Chair: Brian King; Rapporteur: Grigor Obelensky 0830: Inductive CTDs: past, present, and future (B. Owens) 0900: The RBR CTD and its use in Argo (S. Wijffels) 1000: The NOSS CTD and its use in Argo (S. Riser) 1015: Break 1030: Breakout discussions with vendors (floats; CTDs; other issues; rooms TBA)

1200: Lunch

Afternoon Chair: Pedro Velez-Belchi; Rapporteur: Nathalie Zilberman 1300: Discussion of the present state of RBR CTD (G. Johnson/RBR) 1330: RBR CTDs on an APEX, Alamo, and SOLO-2 floats (G. Johnson/RBR) 1430: User questions about RBR CTD units 1515: Break 1530: Discussion of the present state of NKE floats and NOSS CTD (NKE representative) 1630: User questions concerning NKE floats and NOSS CTD [responses solicited prior to the meeting] 1645: The future of ARGOS use on profiling floats (CLS America representative) 1730: Adjourn

#### Day 5 (9/15/17) (General theme: deep Argo floats)

Morning Chair: Susan Wijffels; Rapporteur: Craig Hanstein 0830: The present state of Deep Argo planning (D. Roemmich, N. Zilberman; G. Johnson/PMEL) 0930: User experience with Deep SOLO and SBE61 CTD (D. Roemmich, N. Zilberman) 1030: Break 1100: RBR deep CTD status (B. Owens) 1115: User experience and issues with Deep APEX (B. King)

1200: Lunch

Afternoon Chair: Dean Roemmich; Rapporteur: Rebecca Cowley 1230: Discussion of the present state of Deep APEX (Teledyne/Webb representative) 1300: MRV plans for Deep SOLO (MRV representative)1400: Deep Ninja (TSK representative)1500: Deep Arvor (NKE representative)1600: Meeting summary and outstanding issues (S. Wijffels)1630: Adjourn, meeting ends



# Appendix B: List of Attendees

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			÷.,	

Work City

Seattle Hobart Stennis Space Center

Ottawa Southampton Hamburg

San Diego

Seattle San Diego

PLOUZANE

Woods Hole LA JOLLA

PLOUZANE

Yokohama

Hamburg

Woods Hole Seattle

Yokohama

Santa Cruz de Teneri

North Falmouth

hennebont Hangzhou

Villefranche sur mer

Seattle US RAMONVILLE-St AGNE FR

N. Falmouth Hobart Seattle Bellevue

Stennis Space Center

North Falmouth

Dartmouth Yokosuka Yokosuka

Woods Hole

North Falmouth

Santa Cruz de Tenerife ES

No Falmouth La Jolla Seattle

Plouzané Seattle

Work Country

US US FR US

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