Development of Autonomous Underwater Profiling Drifter (AUPD) and field results

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Autonomous Underwater Profiling Drifter (AUPD) is developed by National Institute of Ocean Technology (NIOT), Chennai, India, for the vertical profiling of the ocean. AUPD is a free-drifting profiling platform for near-real-time in-situ observation of the upper 2000 m of the ocean column. It measures conductivity and temperature profiles with reference to depth. The AUPD transmits measured data through ARGOS satellite Platform Terminal Transmitter (PTT) to ARGOS regional centre as per the requirement of the International ARGO program. The AUPD ascends or descends due change in buoyancy (±250 cm³). While on sea surface (to transmit the profile data), the position of the float is derived using the Doppler shift method with an accuracy of ~100 m. NIOT developed AUPD and deployed in the Arabian Sea in 2013–2015. The AUPD is ballasted for a pre-deployment depth of 2000 m and pre-programmed for a typical profiling cycle of 2 days. The AUPD is designed with 32 bit Atmel micro-controller and a lithium battery bank provides power. It has endurance for 150 profiles. AUPD float is suitable to fulfil the demand for profiling floats for International Argo Program. This paper is focused on the development of AUPD. The paper also discusses testing and field deployment of AUPD float.

Keywords. AUPD; profiling float; variable buoyancy.

1. Introduction

The oceans play a crucial role in determining the climate of the planet. Thus, there is a need to monitor very closely the changes occurring in the ocean. There have been a variety of ocean observation platforms to monitor the oceans. Data buoys are instruments which collect weather and ocean data within the world’s oceans. Moored buoys are anchored with the ocean bottom. They have taken an important role in measuring conditions over the open seas. NIOT developed and deployed data buoys in the Arabian Sea and the Bay of Bengal since 1997 to monitor met-ocean parameters on real-time basis (Venkatesan et al. 2013). Drifting buoys (Hansen and Herman 1989; Perry and Rudnick 2003; Zacharia et al. 2014; Srinivasan et al. 2016, 2018; Zacharia and Srinivasan 2016), underwater ocean gliders (Manley and Willcox 2010; Jones et al. 2014; Zacharia et al. 2015; Schofield et al. 2015) and other autonomous vehicles (Desa et al. 2006, 2013; Gafurov et al. 2015; Maurya et al. 2016) provide temporal and spatial scale data (Rossby et al. 1986; Mizuno 2000; Roemmich and Owens 2000; Davis et al. 2001; Perry and Rudnick 2003; Gould 2005).

Autonomous profiling floats have advantages to monitor the ocean in extreme weather conditions at high latitudes. Several kinds of profiling floats
are in use over the globe by the scientific community for different target depths. The variable buoyancy float operates on the principle of either changing mass or volume (Rossby et al. 1986; Davis et al. 1992; Schwithal and Roman et al. 2009; Andre et al. 2010).

An international ARGO program, a collaborative partnership of more than 30 countries started in the year 2000, provide real-time data for climate and ocean science studies (Roemmich and Owens 2000; Riser et al. 2016). More than 3000 autonomous profiler monitors were deployed under the ARGO to measure the temperature and salinity of the upper 2000 m of the ice-free global ocean and currents from intermediate depths (Roemmich et al. 1999; Mizuno 2000). The data from these profilers enhance our understanding of the coupling between the oceans and atmosphere. The inferred drifts at the parking depth at 2000 m and at surface are utilized for deriving the flow patterns. India has been contributing to the ARGO International project for global ocean monitoring since 2002. As part of the International ARGO Program, India has deployed 459 ARGO float hitherto. NIOT, Chennai, indigenized technologies for ARGO program and developed an Autonomous Underwater Profiling Drifter (AUPD) (figure 1). The first sea trial of an indigenous AUPD float was conducted in 2008 in the Arabian Sea.

The technical challenges met in the AUPD development are developing the buoyancy engine, maximizing energy efficiency to achieve endurance of minimum 150 surfacing cycles and achieving reliable satellite communication. This paper describes the AUPD system, design specifications, performance and procedure for testing and qualification of AUPD floats and field experiment in 2013–2015.

2. Means and methods

2.1 AUPD system

The major components of the AUPD are variable buoyancy engine (VBE) to perform descend and ascend, CTD sensor to sample the ocean column, control electronics to schedule various phases of the mission cycle and a satellite telemetry system to send profile data to the base station. The technical specifications of the developed float are shown in table 1.

2.1.1 Physical

The AUPD hull is made of aluminium (Al Alloy 6061-T6). The dimension of the AUPD is selected from the standard seamless extruded tube. The hull and other wet components, such as CTD sensor, antenna and external bladder, are pressure rated for the target depth of 2000 m. Dry components of the profiler, which mainly include variable buoyancy engine, control electronics and batteries, are housed inside the hull (figure 2). The ARGOS antenna is mounted on the top hemispherical end cap. Payloads of the profiler, namely conductivity sensor, pressure and temperature probe, are mounted on the top end cap of the profiler.

The flooded bottom end cap of the profiler houses an external rubber bladder to vary volume of the float. The bladder is protected with a PVC shell. A damper plate near the top end of the profiler reduces the heave oscillations that the float experiences on the sea surface and also assists in achieving reliable satellite communication during rough sea conditions (figure 1). A fully integrated float weighs ~25 kg (dry weight). Inside the profiler, all the subcomponents are mounted on two sides of a frame plate, one side of which is the

Figure 1. AUPD float.
buoyancy engine and the other side is fitted with embedded electronics and batteries. Access to these subcomponents is through lower end cap of the profiler.

2.1.2 Variable buoyancy engine (VBE)

VBE allows the float to descend and ascend in the sea by retracting and pumping the hydraulic fluid from internal reservoir to external bladder, respectively. The total variable volume change of 250 cm$^3$ was chosen to compensate for the range of water densities the float may encounter in the water column (Gould 2005). Buoyancy engine mainly consists of piston and cylinder, ball screw and nut assembly and a twin chamber rubber bladder. Ascend and descend of the float in the water column are achieved by varying the buoyancy of the body without varying the weight. This is made possible by inflating and deflating a rubber bladder attached to the pressure hull using a fluid in a piston-cylinder driven by a geared DC motor (motor, gear box) through a re-circulating ball screw. The piston and cylinder are required to pump the fluid from the pressure hull to the external rubber bladder and vice versa. Maximum continuous torque provided by the motor is 8.826 Nm. The working fluid used for volume change is hydraulic oil with viscosity 31 mm$^2$/s at 40°C.

The external rubber bladder is designed to have two sections, one for hydraulic oil and the other for air. The bladder is made of nitrile material. This elastomeric rubber coating material has a higher hardness, strength, and lower resilience, abrasion, heat, and oil and fuel resistance, along with lower temperature flexibility. An air pump inflates the air bladder compartment of the external bladder and increases the profiler’s freeboard on the sea surface for data transmission. A solenoid valve controls the air flow of air pump from hull to external bladder and vice versa.

2.1.2.1 Achieving neutral buoyancy at parking depth: In order for the float to reach neutral buoyancy at the parking depth, the downward force acting on the float must be equal to the forces acting upward on the float, which is given by equation (1)

$$Mg = \rho Vg.$$  \hspace{1cm} (1)

Here $M$ is the mass of AUPD, $g$ is the gravitational force, $\rho$ the density of the fluid in which AUPD is submerged and $V$ is the volume of the displaced body of fluid. Kenji et al. (2001) explain about the weight adjustment of the float to make it neutral buoyant at parking depth.

The float volume $V(t, p)$ at the parking depth is calculated using equation (2)

$$V(t, p) = V_0[(1 - \gamma P) + \alpha[(T(p) - T(0))]].$$  \hspace{1cm} (2)

Here, $\alpha$ is the coefficient of thermal expansion of the float volume, and $\gamma$ is the compressibility of the float. $V_0$ is the float volume at room temperature (an appropriate standard temperature is selected) and 1 atm. $V_0$ is given by equation (3)

$$V_0 = V_s + \delta V,$$  \hspace{1cm} (3)

where $V_s$ is float volume at surface and $\delta V$ is the displacement provided by the buoyancy engine. As
the float mass remains constant at sea surface and at parking depth, from \( M = \rho V \), equation (4) equates the mass at sea surface and at parking depth. Equation (5) is derived from equations (2–4).

\[
\rho(0) V_0 = \rho(p) V(t, p),
\]

\[
\rho(0)(V_s + \delta V) = \rho(p) V_0[(1 - \gamma P) + \xi(T(p) - T(0))].
\]

Here \( \rho(0) \) is the density of seawater at surface and \( \rho(p) \) is the in-situ seawater density at parking pressure \( p \). \( T(p) \) and \( T(0) \) in-situ temperature at parking depth and sea surface, respectively. At parking depth, the expansion of the bladder is nil, as it retrieves the full oil from external bladder to internal reservoir to attain neutral buoyancy, so \( V_s \) becomes \( V_0 \) as given in equation (6)

\[
\rho(0) V_0 = \rho(p) V_0[(1 - \gamma P) + \xi(T_p - T_0)].
\]

Equation (7) gives the following volume displacement required for AUPD float to ascend to sea surface from parking depth

\[
\frac{\delta V}{V_0} = \frac{\rho(p)}{\rho(0)} \{1 - \gamma P + \xi(T_p - T_0)\} - 1.
\]

### 2.1.3 Control electronics and software

The main processor of the control electronics is 32 bit Atmel microcontroller which performs buoyancy control, sensor data acquisition, data logging and data transmission. The control electronics consists of analog to digital converter (ADC), two serial communication ports, buoyancy engine motor drive circuit, pneumatic circuit control, EEPROM for profile data storage, and satellite transmitter interface as shown in figure 3.

The ADC measures battery voltage, oil level in internal reservoir, and internal hull pressure. The ADC channels are configured and monitored through customized software. Once the system is deployed, these channels are sampled as per mission requirements and stored in memory to be transmitted via satellite. The Argos transmitter receives the data from the controller of the float over serial link. The transmitter is programmed to check the incoming character periodically over RS232 link. This check is only interrupted at the time of transmission, and it resumes once the transmission is over. The AUPD ascends to sea surface at the end of each mission cycle and transmits the data to the shore station through Argos communication satellite at uplink frequency of 401.65 MHz. For each cycle, 512 bytes of profile data is collected, which is transmitted in 16 packets (each packet consists 32 bytes of data). The first byte of every packet is a checksum byte to detect if any error is introduced during transmission and data transfer.

The onboard processor is programmed to execute the scheduled mission, perform profiler’s dive to the parking depth, active ballast, profile data logging, data transmission and time sequencing of the complete mission. The application software is programmed in embedded C language, which simplifies maintenance of the system software.

### 2.1.4 Sensors and measuring scheme

There are three sensors used in the system: (i) conductivity temperature and depth (CTD) sensor which is from Seabird Scientific and provides highly stable and accurate temperature and salinity on profiling floats. This CTD is widely used over standard floats of Argo International Program. The SBE 41 CTD uses the proven MicroCAT temperature, conductivity, and pressure sensors and has engineered anti-foul protection (model 41 pumped MicroCAT with accuracies of 0.002°C, 0.0035 PSU and 2 dbar for temperature, salinity and pressure, respectively. Complete specification of the CTD is provided in table 2. CTD samples are collected in discrete mode and sampled every 10 dbar from the surface up to depth of 400 m and from there on every 50 dbar up to the target depth 2000 m. A typical cycle of 2 days for profiling to the depth of 2000 m, a total of 73 levels are programmed to collect the CTD samples. (ii) Onboard vacuum sensor is integrated to check for any leak from the seals of the hull. The onboard vacuum sensor monitors the hull’s internal pressure and this data is stored in memory and transmitted to satellite as system health parameter. The analog voltage read from the vacuum sensor is conditioned using an instrumentation amplifier which is then read by an analog channel of the microcontroller. (iii) Linear variable differential transformer (LVDT) sensor to observe the oil level as it is desired to know the quantity of oil in the bladder. This is achieved by measuring the piston level with respect to the cylinder. Except CTD, other sensor data is stored in memory and transmitted as health or engineering parameter of the system.
3. Mission

The profiler follows a typical cycle of 2 days for 2000 m parking depth having predefined levels for sampling the water column while ascending. The float uses one-way Argos data telemetry, which does not allow any modification of the mission once the float is deployed in the sea and the same mission cycle runs during the entire life cycle of the float. So a well-planned mission cycle is programmed into the float, which suites oceanographers’ interest. The complete mission cycle is shown in figure 4. AUPD dives from sea surface to target depth, drifts freely at target depth, and then periodically ascends to the sea surface. The float can also be programmed to have an intermediate depth for, where it will drift for pre-programmed duration and then again descend to parking depth. During the ascend cycle, it collects CTD samples at pre-programmed depths and transmits over satellite once it reaches to sea surface. At sea surface, it transmits the profile data for 10 hours as ARGOS using the polar-orbiting satellite, passes of the satellite to a particular location are less, and transmission for 10 hours ensures the reception of complete dataset. A satellite pass is for <15 minutes, so a number of orbits are required to transmit the complete dataset collected and stored for one profile. After completing data transmission, the profiler descends back to the parking depth for the next cycle, a typical cycle of 2 days for 2000 m of depth with 73 levels, programmed for these floats. The observations at 2000 m are used for sensor drift corrections as the salinity variations at depths are very minimal (Johnson et al. 2007).

AUPD mission parameters, including parking depth, cycle time and CTD sampling, are adjustable on deck via serial communication prior to deployment. After the deployment, the profiler first checks for the oil level in the external bladder and pumps the entire oil into the bladder from internal reservoir if it is not full. This feature of the profiler helps anyone, such as ship crew, to deploy the float in the sea. The float weight is trimmed in a way that once the entire oil is transferred from the external bladder to the internal reservoir, it will reach the profile depth with a speed of 0.08 m/s.

### Table 2. CTD sensor features.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
<th>Accuracy</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salinity</td>
<td>0 to 42 PSU</td>
<td>± 0.0035 PSU</td>
<td>–</td>
</tr>
<tr>
<td>Temperature</td>
<td>−5 to 45°C</td>
<td>± 0.002°C, 0.0001°C</td>
<td>0.04 dbar</td>
</tr>
<tr>
<td>Depth</td>
<td>0 to 2000 m</td>
<td>± 2 dbar</td>
<td>0.04 dbar</td>
</tr>
</tbody>
</table>

![Figure 3. Control electronics.](image1)

![Figure 4. Mission cycle.](image2)
m/sec. During ascend, the float ascends to the sea surface by successive pumping of the hydraulic oil from internal reservoir to the external bladder in fixed intervals. Time taken by the float to reach the surface is maximum 7 hours. To obtain an uninterrupted full depth profile, the profile is collected during the ascent phase.

The final transmission time that the float spends on sea surface to transmit the data may vary if different satellite communication is used. There are a number of floats which use Iridium communication (higher bandwidth compared to Argos system) in which the transmission time is very less as compared to the one which uses Argos communication, so they remain on the surface for very less time (hardly one hour). In this case, the surface drift will be lesser comparatively. Such difference does not impact the measurement methodology and quality of the datasets as the measurements are taken while ascending. The standard velocity of ascend in standard Argo float is 0.08 m/sec and the same is maintained in AUPD float.

4. Energy

The energy source for the AUPD float is a primary lithium battery. As the AUPD works with battery power and power demand for prolonged operation of AUPD depends on the power package density. Also the battery pack has space and weight constraints, so the selection of battery had been a primary aspect while designing the AUPD. Considering the required power, and the merits and demerits of lithium battery, lithium thionyl chloride batteries were chosen for the float. However, certain kinds of mistreatment may cause lithium primary batteries to explode; necessary safety measures were taken while handling the same. They are one of the most popular types of battery for portable electronics, with high energy-to-weight ratios, no memory effect, and a slow loss of charge when not in use. The electrochemical system of Li-SOCl₂ cell offers the highest energy density of any available primary battery, up to ~650 Wh/kg.

The battery bank of the float contains Li-SOCl₂ primary lithium D-cells which offer high current capability and low voltage drop over time. The life span of the AUPD depends on how far the batteries can be discharged before failing to supply the required voltage. AUPD battery bank has a capacity of 9072 kJ, which allows the float to survive minimum of 150 cycles taking account of self-discharge and efficiency of each cell.

The float consumes a total energy of 43 kJ for each profile. Buoyancy engine is the most energy-expensive device of the AUPD float, and consumes 30 kJ in one profile to descend to target depth and ascend back to sea surface. Energy consumed by Argos transmitter is 7.8 kJ to transmit the complete dataset of one profile. CTD consumes 0.648 kJ in every single profile. Figure 5 shows the energy consumption chart of the float.

5. Testing and evaluation

The AUPD floats, once deployed, work autonomously for their entire life. The float is tested in various test facilities to qualify its ability to perform at operational depth. Hyperbaric test facility, buoyancy engine test rig, float volume test facility, ballasting test setup and post-ballasting test facility were designed and established in NIOT and qualification tests were conducted. Following qualification tests were performed to operationally qualify the system for deployment at sea.

5.1 Hyperbaric test

The float is rated for 2000 m and the hyperbaric test is conducted for 220 bars pressure. NIOT has 3 m long and 1 m diameter hyperbaric test facility to test the systems up to 900 bars pressure. The pressure enclosure of the float was tested for the pressure of 220 bars at NIOT pressure chamber.

Energy consumption for each profile

![Energy consumption chart](image)

- **Buoyancy engine**
- **Data telemetry**
- **CTD sampling**
- **other peripheral and embedded system**

Figure 5. Energy consumption of AUPD.
facility. During the pressure test, pressure was gradually increased and decreased from 1 bar to 220 bars and vice versa. Once the hull was qualified for high pressure, the integrated AUPD system with all the subcomponents was tested for 200 bar pressure.

5.2 Buoyancy engine test

Buoyancy engine is tested by pumping hydraulic fluid at high pressure into the bladder and retrieving back to simulate ascending and descending of the float in the water column. It was tested for the simulated pressure variation for minimum 150 cycles for 200 bar pressure.

The buoyancy engine is used to vary the volume of the AUPD without altering the mass by pumping the hydraulic fluid from internal reservoir to external bladder and vice versa to ascent and descent in the ocean up to the depth of 2000 m. While ascending and descending the AUPD, the piston and cylinder will experience ambient pressure via the rubber bladder assembly. The pressure experienced on the piston and cylinder varies from atmosphere pressure to 200 bar and vice versa during descent and ascent sequence, respectively. The same sequence was simulated to test the buoyancy engine with rubber bladder assembly by using small pressure chamber rated for 200 bar pressure.

5.3 Ballasting

As the float descends to target depth by retrieving certain volume of hydraulic oil, it should be made sure that the float does not go beyond the target depth and this can be achieved by precisely trimming the weight of the float. The float is made neutrally buoyant, when the float volume is at minimum at the target density layer by adjusting its weights.

After system integration and high-pressure test of the float, ballasting of the float was performed in a pressure chamber facility. The objective was to make the float neutrally buoyant at 2000 m depth and trim the float weight accordingly. Ballasting test setup was prepared as discussed in Boebel et al. (1995), a metal chain was attached at the bottom of the float and the height of the float is monitored from a camera placed inside the pressure tank. Authors have referred the steps of ballasting procedure discussed in Swift and Riser (1994).

First the float was made neutral buoyant in the pressure tank filled with fresh water (tank salinity 0.0784 PSU, temperature 26.82°C) at target pressure of 2000 dbar and trim mass was determined by the height of the chain lifted and was calculated 87.1 gram (wet weight). This weight was added inside the float. Second, the compensation mass was calculated to account for the difference between salinity and temperature of tank water and target seawater. Finally, the float mass was adjusted, taking into account trim mass and compensation mass.

Sea water density at the parking depth was estimated from previous in-situ observations made in the recent past, nearest to the deployment location and the weights were adjusted to make the float neutrally buoyant at the desired density layer. The weight needs to be adjusted very precisely as the change of 1 gm will change the parking depth by 8–12 m. Figure 6 shows the float at hyperbaric test facility, which is seen in the background.

5.4 Post ballasting test

The post-ballasting test was carried out in a vertical test setup to test descend, parking with active
ballast control and ascend operations of the AUPD float. The vertical test setup was made with PVC pipe of 16 m length and 0.32 m diameter with view ports at the intermediate length for watching the vertical movement of the AUPD float. Salinity of the water was adjusted approximately to the deployment location and was measured at 34 PSU in the test setup. The temperature observed in the setup on surface was 30.19°C, and minimum at the bottom of the test setup was 28.18°C. The float was activated in the mission mode operation and was deployed in vertical test setup. The extensive test was carried out to record the in-situ temperature and salinity profile of AUPD float during ascent cycle and qualify the float for the sea trail.

5.5 Sea trial

The float was deployed in Arabian Sea (off Cochin) beyond Exclusive Economic Zone of India, using Ocean Research Vessel Sagar Manjusha on 16th May 2013. The ocean column was profiled for temperature and salinity over a period of nine months.

6. Results and discussion

The results from the qualification tests show that the float has the ability to sustain and operate up to operational pressure of 200 bar. During hyperbaric test, hull of the float was qualified for high pressure in hyperbaric test facility for pressure up to 220 bar. The observed weight of the hull, before and after the pressure test, was the same with an accuracy of ±2 grams. No deformation in shape was observed after the pressure test. During buoyancy engine test, functionality of the sub-components was observed for the sequence of pumping the hydraulic oil from internal reservoir to the external rubber bladder and retrieving it back. The power consumption of buoyancy engine (PMDC motor power) at different pressure was monitored and is shown in figure 7. The plot in figure 7 shows the current consumption of the motor increased with the increase in external pressure, which was acting on the external rubber bladder. The motor was sourced from 14 VDC during the test and consumed 1.05 A at 200 bar pressure which was within the acceptance criteria. The VBE test concluded that the VBE of AUPD is capable to operate up to the pressure of 200 bar. The result from ballast test was obtained in the form of trim mass obtained, which was measured from the positional increment in the chain link added to float, shown in table 3. Trim mass weighed 87.1 grams in water. The final weight of the system was observed as 25.071 kg after

<table>
<thead>
<tr>
<th>Pressure (bar)</th>
<th>Position change in upward direction (inch)</th>
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<tr>
<td>0</td>
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<tr>
<td>25</td>
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<td>6.5</td>
</tr>
<tr>
<td>203</td>
<td>6.7</td>
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including the trim mass and compensation mass. During the post-ballast test, it was observed that the float was capable of diving and surfacing in the water, which had the property of target water in terms of salinity and temperature. The mission program was tested for five cycles and the performance of the float was observed satisfactory.

Functional and environmental tests were conducted in laboratories, on subcomponents of AUPD float initially and then on the integrated float. These tests allowed us to validate all the functionalities before deployment of AUPD float at sea. In particular, the assessment of the buoyancy engine concluded that the float was capable of profiling 150 cycles up to 2000 m.
Sea trial results

The AUPD float survived more than 270 days in sea and has provided 135 profiles, among which 101 profiles had achieved a parking depth of 1600 m and below. The plots of temperature and salinity profile are shown in figures 8 and 9, respectively. Data received from these floats were passed through quality check as per the Argo Quality control method and none of the profiles received a bad flag.

These plots in figures 8 and 9 include observation period from May 2013 to October 2013. Water near the surface is warmer and coldest at deeper levels.
In May, the observed sea surface temperature (SST) is 30.24°C and it falls to 28.4°C in June which is due to the seasonal rainfall of western India. May month observed the highest SST 30.46°C observed at 6.5 m depth. Trajectory followed by the AUPD float is shown in figure 10.

Saltier water is observed nearer the surface in salinity plot. May month shows the highest salinity observed in depth close to 100 m. Presence of a band of high salinity water sandwiches between salinity lower than 36.4 PSU is observed in the salinity data. This high salinity band reduces and then fades away in the months of September and October. Salinity at higher depths is seen higher in May and June as compared to July and afterwards. This is due to the summer monsoon, which adds freshwater to the Arabian Sea.

During the sea trial, the float could achieve its maximum parking depth around 1600 m in most of the profiles. Float weight needs to be trimmed very precisely to make it neutrally buoyant at parking depth. As mentioned 1 gm change in float weight will make a minimum 8 m difference in parking depth. Though the experiments were conducted in a way to keep the errors least, some of the measurement errors could not be avoided, such as, during ballasting experiment the observation of upward increment in the chain link and then deriving the dry weight and wet weight of the same. Other reason for error is, for final weight calculation, target water density and temperature are taken into account, and these values differ from in-situ values. Incorporating active ballast mechanism, which will allow pumping or retrieving oil as per requirement, will solve the problem and will be taken up for future work.

6.2 Comparison of AUPD and WMO datasets

AUPD subsurface temperature datasets are compared with WMO 2901621 for two different profiles where the time and space could get the best match. Temperature profile from the two floats is compared. Temperature profile collected by WMO on 25th November 2013 at 1.962°N, 92.197°E (X1) and by AUPD on 24th November 2013 at 3.792°N, 89.143°E (Y1) is compared. The distance between the two locations is 300 km. Figure 10 shows the trajectory of AUPD (blue track) and WMO float (red track). Datasets of temperature profile from WMO and AUPD is plotted, and a visual comparison is shown in figure 11. It is observed that the measurements are strongly correlated with the coefficient of determination $R^2$ value of 0.9906, as shown in figure 12.

Same way, another temperature profile which is collected by WMO 2901621 on 05th December 2013 at 2.287°N, 91.748°E (X2) and AUPD on 04th December 2013 at 3.259°N, 89.160°E (Y2) is compared. The distance between the two locations is 290 km. Datasets of temperature profile from WMO and AUPD is plotted, and a visual comparison is shown in figure 13. Here also, the measurements are strongly correlated with the coefficient of determination $R^2$ value of 0.9932, as shown in figure 14.
7. Conclusion

NIOT developed the AUPD float, which is capable of measuring salinity and temperature up to 2000 m depth. Sea trial results of AUPD showed that the float could achieve the maximum parking depth around 1600 m. Measurement errors during weight trimming experiments and the difference between reference values and in-situ value of physical parameter of target water are observed, the reason for the achieved parking depth as 1600 m. However, the qualification tests concluded that the AUPD float is capable to profile up to the upper 2000 m of ocean depth. Work to introduce active ballast to overcome this problem is taken up as future work. The profile data measurements are made during the ascent profile and are transmitted to shore in near–real time according to the International Argo program recommendations. Temperature profiles collected by AUPD and WMO 2901621 are compared at two different locations where time and space had the closest match. Strong correlation is found with the coefficient of determination $R^2$ value of 0.9906 and 0.9932 for two individual temperature profiles. Industrialization of the float is being carried out for production. Work to enhance the capacity of the buoyancy engine is also being carried out, which will allow the float to be equipped with additional sensors and also to dive deeper than 2000 m.

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Author statement

Muthuvel P is responsible for design, development, qualification tests and field data collection. Sarojani Maurya is responsible for qualification tests, field data collection, analysis and validation of the data and drafting the original manuscript. Tata Sudhakar is responsible for managing the project and overall support.

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