

A MULTI-SENSOR AUTONOMOUS PLATFORM FOR FAST OCEAN OBSERVATION STUDIES

SANJEEV AFZULPURKAR^{1*}, GAJANAN NAVELKAR, ELGAR DESA,
R.MADHAN, NITIN DABHOLKAR, SHIVANAND PRABHUDESAI,
ANTONIO MASCARENHAS, PRAMOD MAURYA

Abstract

Variations in dissolved oxygen (DO), chlorophyll-a, temperature and salinity play an important role in the outcome of Primary Productivity [PP] levels in the oceans. The vertical structure and spatial distribution of these variables in time can help in providing insights on the role of PP as an indicator of ecosystem health. The DO values in Arabian sea where the studies have been undertaken, generally vary from 220 $\mu\text{M/L}$ at surface to near zero as depth exceeds 150 M. Oceanic waters that have less than 0.2 $\mu\text{mole/L}$ DO are known as Oxygen Minimum Zones (OMZ) or dead zones. The spatial and seasonal variations of the OMZ need to be tracked for better understanding of the cause of this phenomenon. It is well known that conventional technique of lowering instrumented packages and water sampling devices from a research vessel is a slow process resulting under sampling of spatial and temporal resolution of processes, and therefore limiting the scope of sampling oxygen deficient waters.

A new platform Autonomous Vertical Profiler (AVP) has been developed at CSIR - National Institute of Oceanography in Goa, India that can rapidly and autonomously collect repetitive data to 200m water depth. It is equipped with sensors to measure conductivity- temperature-depth (CTD), dissolved oxygen (DO), PAR, chlorophyll-a, turbidity and backscatter. A typical profile is obtained within ten minutes. The ability to collect profiles and transmit data to remote places over a radio or satellite link makes the AVP an appropriate tool for ocean observations related to climate, water quality studies etc. The AVP can be deployed for 12 days with four profiles per day to a depth of 100m and it is being enhanced to 30 days endurance. This enables several dives to be executed in a short duration to determine the movement of OMZ with respect to depth. Compared to the AVP, ARGO floats are designed for deep water operations with cm/sec descent rates and limited sensor payloads, although this situation is now improving with the advent BIO ARGO floats equipped with sensors for DO, and chlorophyll-a.

The AVP's initial tests were carried out in fresh water bodies at Amthane Dam, Goa and at Tillari dam, Maharashtra. AVP's subsequent deployments were at locations off Goa, off Ratnagiri, in Maharashtra and in Coral Islands of Lakshadweep Archipelago from depths of 30 m to 200 meters. It was generally observed that DO values declined rapidly beyond 30 meters to 100 meters depth and by 150m were practically zero indicating anoxic waters. During a cruise onboard RV Sindhu Sankalp the AVP was deployed off Kavaratti Island, Lakshadweep, India to a depth of 200 m. The data indicates presence of very low DO values, possibly the presence of an OMZ signature. Similarly, during a mid December 2010 cruise on RV Sindhu Sankalp, an OMZ was detected at 200m close to shelf waters off Goa (West coast of India). This again points to the possible intrusion of the OMZ waters from the Central Arabian Sea to coastal waters of the West coast of India.

*Corresponding author, CSIR - National Institute of Oceanography, Dona Paula, Goa 403004. ¹sanjeev@nio.org

The detection of anoxic waters found by many AVP profiles proves conclusively its use in the detection of low oxygen waters in rapid ocean observation studies. Currently, the AVP is also being used in satellite sensor validation experiments for the OceanSat 2 satellite launched by India, and in other wide ranging observations of anoxia in freshwater dams and in coastal waters off Goa, Vizag, and Kochi.

INTRODUCTION

The life cycles on the earth are dependent on oxygen, be it in air, or dissolved in water and needs monitoring. The DO content of seawater depends on different factors namely temperature, depth and the effects of living organisms in the water column. This varies from approximately 220 $\mu\text{M/L}$ at the surface to near zero as depth exceeds 150 M generally (1). This particular volume of water wherein the DO content is close to zero is called Oxygen Minimum Zone or simply OMZ. A very prominent OMZ exists in the Arabian sea and has been expanding over a period of time (2). To further understand this, it needs to be mapped with regularity and during all seasons/months. During the monsoons season there is a considerable gap in data collection due to the rough sea condition as research vessels can't operate freely. A very genuine requirement of filling this gap in data availability exists across multiple disciplines. Several tools/methods are employed to collect this data. The primary technique is to collect water samples using Niskeen samplers from research vessel stationed at desired locations and analyze for DO. Due to non availability of research vessels when required, this method has disadvantage in terms of spatial and temporal spread of the data collection. CTD probes with rosette water samplers have allowed oceanographers to obtain multiple parameter data including the DO during a single cast. A more recent advance is the use of autonomous underwater vehicles (3) which enables scientist to collect data spatially. However they are not very amenable for temporal data collection.

CSIR - National Institute of Oceanography, Goa, India has developed an autonomous vertical profiler (AVP) (4) which has the capability to collect multi-parameter profiles rapidly and is described below.

AUTONOMOUS VERTICAL PROFILER (AVP)

AVP is a robotic instrument that profiles water columns repetitively as programmed by the user. The vehicle has a designed large meta-centric difference between the center of gravity (CG) and center of buoyancy (CB) ensuring that the profiler body is always vertical in water. This has been achieved by placing the heavy batteries and other subsystems in the lower half while the lighter electronics and system sensors are placed in the top half. A net buoyancy is built in the design that makes AVP to float up when no power is applied. Typically this is adjusted to about 400 gm and is sufficient for all operations for current configuration . Any changes need to be reflected in the adjustment of buoyancy. The AVP layout is shown in Figure 1, with internal subsystems and external sensor suite (5) (6). The profiler has an endurance of

about 30 days at the rate of two dives per day to depths of 100 M. AVP has a brushless thruster that propels it against the positive buoyancy and the rate of ascent is controlled by the application of control voltage by the electronics module. It has a nominal speed of 0.6 m/s during powered descent and ascends under the influence of buoyancy at about 0.4 m/s. Currently there are two AVP models available, one with a RF data connectivity for short time (RF AVP), line of sight operation and the other with a satellite data connectivity for long term deployments (SAT AVP). The details of AVP specifications and current configurations are shown in **Table I and II**.

A graphical user interface (GUI), Fig. 2., developed at the institute enables a user to program his operational requirements. The GUI allows settings related to dive depth, number of dives, time of dives during the day while displaying the status related to all the subsystems. Once a mission is loaded, AVP acquires the profile at the programmed time collecting data during the ascent and descent. GUI automatically acquires the connectivity to the profiler, in case of RF AVP, enabling the user to download profile data immediately on resurfacing. For SAT AVP the GUI needs to connect to the satellite service provider to download the data. Data is stored internally for downloading after recovery of both types of AVP's.

As shown in Table II., currently the sensors installed are conductivity - temperature - depth (CTD), chlorophyll-a with backscatter, dissolved oxygen (DO), PAR. These are interfaced and controlled by an ARM microcontroller that switches the sensors on/off, acquires data, logs data in the internal memory storage. Figure 3., shows the electronics in a block diagram form. All the sensors are interfaced in serial format which is a standard, conventional method.

A Controller Area Network (CAN) connects three controllers, namely Communication Navigation and Mission controller (CNMC), Science Data Acquisition Node (SDAN) and a Silicon Laboratory C8051F041 Vehicle Parameter Acquisition Node (VPAN) on a distributed architecture. CNMC controller communicates with the modems to get the programmed missions and executes the same. The VPAN acquires the position on surface and depth data continuously in the water column. During the profile the SDAN acquires data from the science sensors and the data is logged. On reaching the desired depth CNMC terminated the dive by stopping the thruster through VPAN. The logged data is stored in a raw format which is transmitted same on RF modem and in a condensed format through SAT modem. During successive dives all electronics and sensors are powered down into sleep mode to conserve power. When the next dive time is attained, the AVP repeats the sequence which is continued till the battery lasts.

The dissolved oxygen (DO) sensor used on the profiler is RINKO from ALEC, Japan (7). The sensor is a fast optical sensor that gives output at 1 Hz. This enables the AVP to collect DO data at an interval of 1 M. This capability allows the AVP to built a profile during the descent and ascent.

METHODOLOGY

The initial testing of the AVP was carried out at Amthane dam, Goa which has a depth of about 20M when full. The AVP is programmed, for all tests and data collection using a Graphical User interface (GUI) executed on a notebook or laptop PC as shown in figure 2. The GUI allows settings related to maximum dive depth, number of profiles, time of profile etc. Once these parameters are selected, a mission load button sends the mission script through the RF

modem to the CNMC controller. During all data excursions the AVP was tied with a thin rope as a safety line though this absolutely not required. The AVP is lowered into the water and the profiles are collected. Once the AVP resurfaces, the GUI automatically communicates with onboard RF modem to get connectivity which is indicated on the GUI. The GUI also indicates latest surface position from GPS and the last data from all the sensors onboard AVP. The user has a choice to download the data, however the data is retained on the AVP's internal data storage card. Data has been collected using this technique and different locations. Now there is confidence that AVP will be able to collect data without any safety line.

FAST OCEAN OBSERVATION STUDIES USING AVP

Typically the AVP is able to undertake a profile very quickly compared to the existing profilers. These are Air Sea Interaction Profiler (8), the Wirewalker(9), the moored profiler MMP (10) and the ARGOS deep sea profiler (11).

Under typical operating conditions, the AVP has a powered decent rate of 0.45 m/sec and an ascent rate of about 0.3 ~0.4 m/sec with the built in buoyancy of ~400 gm. Assuming these as average velocities a profile to 100m depth is collected in a time of 8.5 minutes and to 200m in 17 minutes. Data is collected during the ascent and descent. The data is downloaded and the user can immediately view the profiles related to all variables. This allows users to further refine the strategy to collect future profiles.

ASIP, powered by a single thruster, obtains profiles only during ascent at ~ 25cm/sec. It has a sensor suite very similar to the AVP. The wirewalker is a tethered system where in the instrumented is attached to a surface floating buoy. The vertical motion of the buoy due to wave action is translated to the instrument package which slides down the wire rope. At the preset depth a cam reverses the motion of the package and it freely ascends to the surface. The Wirewalker has typically speeds of 0.05 to 0.25 m/s which depends on the wave action.

MacLane moored profiler was originally developed by WHOI, USA and refined later on by MacLane Research Lab. It is profiler that slides on wire which is anchored with the ship. It's operation is complex due to handling of the vessel at location for long times. It profiles at an optimum speed of ~ 20cm/sec.

ARGO profilers are deep sea profilers that drift underwater at a depth of about 2000M and can't be directly compared with an AVP. They take about 6 hours to rise to the surface while collecting data and transmits data when on surface through satellite connectivity. On average they collect T-S profiles at a speed of 0.1M/sec. Newer ARGO floats are carrying DO and other sensors for data related to biogeosciences.

DISCUSSION

The data collected represents three different regions, namely Lakshadweep, off Goa coast and off Ratnagiri coast. The profiles are taken in open ocean and coastal locations. Figure 4 shows that the AVP can collect DO profiles through the column till depth of 200m or generally beyond the OMZ depths. The profiles in coastal areas off Goa and Ratnagiri, India, figures 4a.,

and 4b, to depths of 21M and 28M show DO values progressively decreasing with depth from an initial values of ~ 180 $\mu\text{M/L}$. In the open ocean profile at Lakshadweep to a depth of 100M, figure 4c, the DO values vary from ~190 $\mu\text{M/L}$ at surface to ~ 15 $\mu\text{M/L}$. Figure 4d shows a DO profile to depth of 200M off Ratnagiri. Typically the surface values is similar to the other profiles while at depth of about 160 M the DO values almost are close 0 $\mu\text{M/L}$ and stay till 200M. This shows that the AVP is capable of collecting DO profiles to depths of 200m and detect DO values which are clear indicators of oxygen minimum zone. However to establish clearly the OMZ it will be essential to collect profiles at a specified location and depth regularly.

CONCLUSION

The profiles collected during the period establish the capability of AVP as a fast profiler to acquire DO data along with different parameters. It also establishes its technical capability, as per design, to undertake profiles to depth of 200m. The DO data profiles at the location show a clear presence of an oxygen minimum zone (OMZ). The persistence of OMZ in ocean space and time thus is within the capabilities of this fast profiling tool.

REFERENCES

- 1. Naqvi S.W.A, Naik H., Narvekar P.V.**
The Arabian Sea. Chapter 6. Biogeochemistry of marine systems. eds. by: Black, K.; Shimmiel, G.B. Blackwell; Oxford; UK; 2003; 157-207.
- 2. Naqvi S.W.A, H. Naik, D. Jayakumar, M.S. Shailaja, P.V. Narvekar.**
Seasonal oxygen deficiency over the western continental shelf of India. Past and Present Water Column Anoxia., Edited by Lev N Neretin. Springer 2006. Pp: 195 - 224.
- 3. Edgar An, Manhar R. Dhanak, Lynn Shay, S. Smith, John V. Leer.**
Coastal Oceanography using a small AUV. Journal of Atmospheric and Oceanic Technology. February 2001, Vol. 18, Pp: 215-234.
- 4. Desa ES, Pascoal AMDS, Mehra P, Naik GP, Desa BAE, Madhan Rajachandran .**
A Controlled Thruster-Driven Profiler For Coastal Waters . US Patent #6,786,087.
- 5. Elgar Desa (Member IEEE), R. Madhan, N. Dabholkar, S. Prabhudesai, G. Navelkar, A. Mascarenhas, S. Afzulpurkar, M. Phaldesai, P. Maurya.**
In-situ profiling of Eastern Arabian Sea Coastal waters using a new Autonomous Vertical Profiler. IEEE, Journal of Ocean Engineering. In press.
- 6. R. Madhan, N. Dabholkar, G. Navelkar, Elgar Desa, S. Afzulpurkar, A. Mascarenhas and S. Prabhudesai.** Autonomous profiling device to monitor remote water bodies. CURRENT SCIENCE, VOL. 102, NO. 2, 25 JANUARY 2012. Pp: 169-176.
- 7. RINKO. Fastest - optical oxygen sensor. www.alecvictoria.com, ocean.jfe-aadvantec.co.jp**
- 8. Brian Ward, Tim Fristedt.** Air-Sea Interaction Profiler: Autonomous Upper Ocean Measurements. US/EU Baltic International Symposium IEEE, 2008, pp. 1-8.
- 9. R. Pinkel, M. A. Goldin, J. A. Smith, O. M. Sun, A. A. Aja, M. N. Bui, And T. Hughen.**

The Wirewalker: A Vertically Profiling Instrument Carrier Powered by Ocean Waves.
Journal Of Atmospheric and Oceanic Technology, Volume 28. Pp: 426-435.

10. Archie T. Morrison III, John D. Billings, Kenneth W. Doherty, and John M. Toole.

The McLane Moored Profiler: A Platform for Physical, Biological, and Chemical
Oceanographic Measurements Proceedings of the Oceanology International 2000
Conference. March 7-10, 2000 • Brighton, UK. Pp: 1-18.

11. ARGOS deep sea profiler.

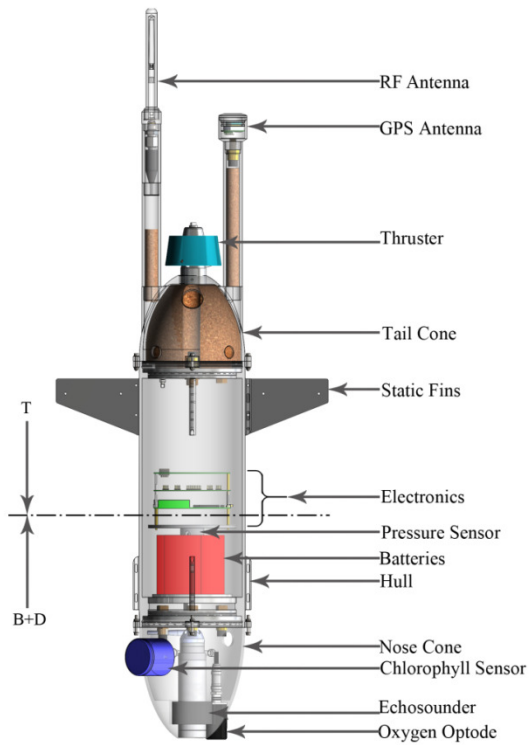


Figure 1.: Autonomous Vertical profiler - layout.

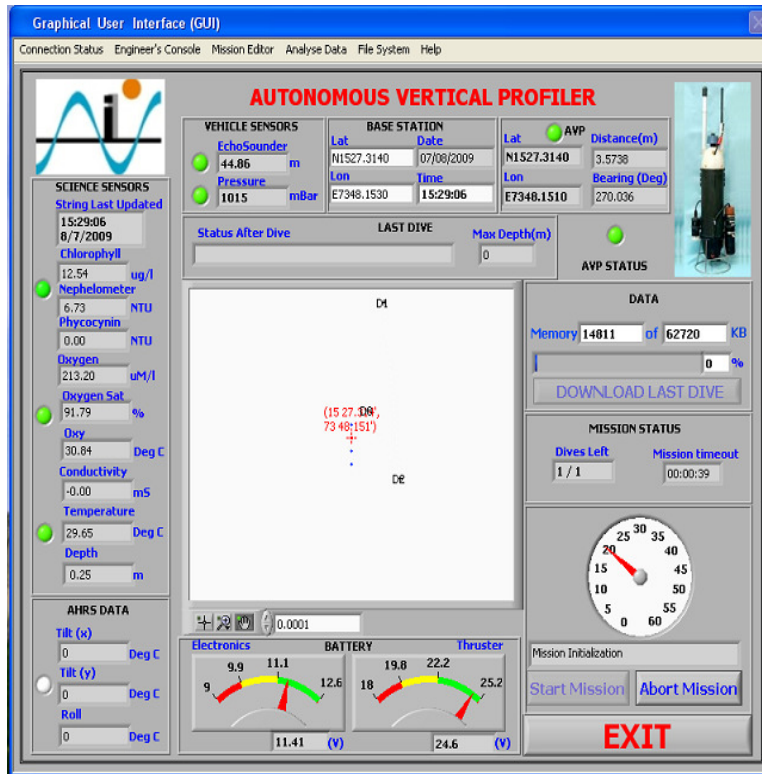


Figure 2. Autonomous Vertical Profiler - Graphical User Interface (GUI)

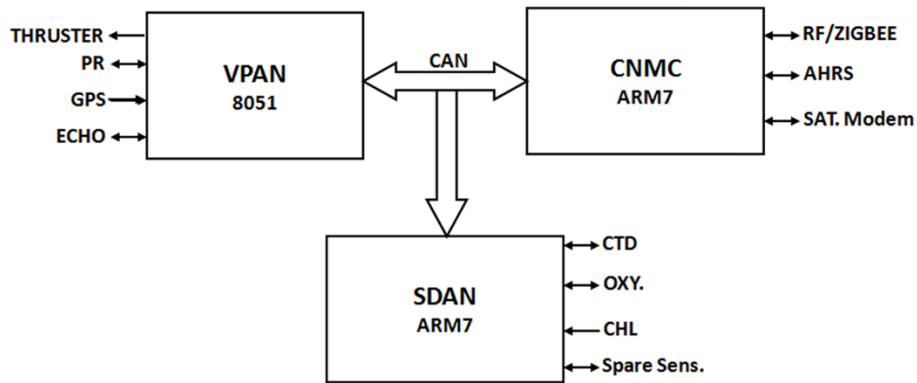
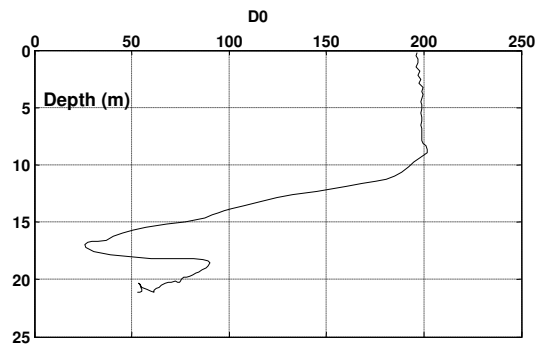
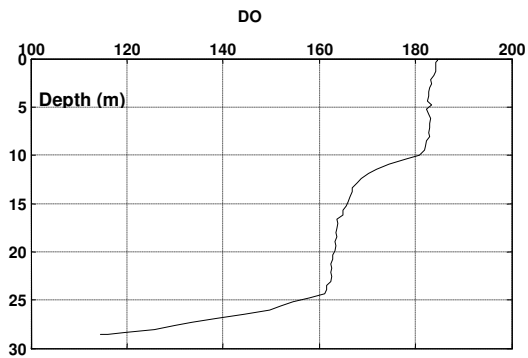


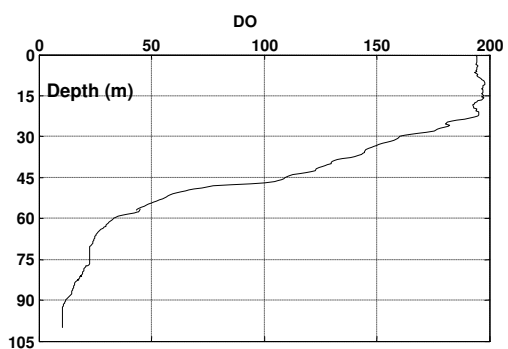
Figure 3.: Distributed electronic architecture of AVP



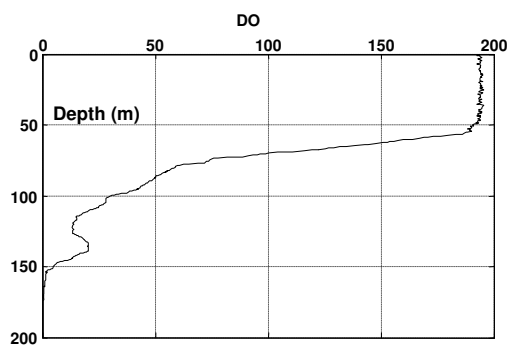
4a. SACII, Goa
(N15°29'59.88",E73°33'59.5)



4b. SAC I, Goa



4c. Lakshadweep, India (N10°37'5.88",E72°16'8.52")



4d. Ratnagiri, India
(N15°09'35.82",E72°57'6.42")

Figure 4. DO profile collected by AVP at different depth and locations.

Table I.: Autonomous Vertical Profiler specifications

Autonomous Vertical Profiler Specifications	
Alloy Hull Dimensions Length & Diameter	L = 1.17m ; Diameter = 0.184m
Weight in air	~ 13 kg (depending on sensors weight)
Nose and Rear Cones	Removable Acetal (Science sensors on Nose Cone)
Tested Depth	200 m
Propulsion	Model 260 Tecnydyne 24VDC Brushless motor, max - 5 kgf forward thrust, max depth 750m
Nominal speed	0.4 m/s. (Max speed 1 m/s)
Endurance (estimated)	7 days with 4 dives/day to 100 m
Power source	Lithium Ion Polymer cells (324 Wh)
Total average power	60W max (includes thruster & payloads)
Electronics	Microcontrollers – 8051 and two ARM7 as CAN nodes
GUI	Labview (National Instruments)
Communications	2.4 GHz, 115kbaud / Satellite Iridium modem (optional)
Vehicle Payloads:	Pressure sensor, GPS , Echo-sounder
Science sensors :	Chlorophyll, Turbidity, CTD (Conductivity-Temperature-Depth), Dissolved Oxygen

Table II. : Current AVP configurations

Parameter	Configuration I AVP with RF modem	Configuration II AVP with SAT modem
Operational time	1-2 days	~ 30 days
Number of profiles	20 - 30	~ 60
Communication	RF modem; line of sight	Iridium Satellite modem; world wide
Science sensors	CTD, DO, Chl-a with backscatter/ turbidity, PAR	DO, Chl-a with backscatter/ turbidity, PAR