

# Technology demonstration of a novel seabed resident event-driven profiling system

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*The seabed resident event-driven profiling system (SREP) was deployed in the northeastern Arabian Sea for winter convention studies. SREP is an autonomous profiling system consisting of two parts: a stationary seabed unit and a positively buoyant tethered profiling unit (profiler). It offers a novel and optimized approach to profiling in coastal waters from close to seabed (14.63 m above seabed) to the sea surface. The seabed unit houses an underwater winch system, underwater acoustic modem, pressure sensor, low-power electronics, batteries and divinylcell hydraulic crush point foam for subsea applications. The profiler houses a suite of oceanographic sensors: conductivity–temperature–depth, DO, chlorophyll, PAR, underwater acoustic modem, low-power electronics, batteries and divinylcell hydraulic crush point foam for subsea applications. The underwater winch system on the seabed unit spools out and spools in the profiler throughout the water column. Data acquisition on the profiler is done during ascending. The profiler ascends gradually in the water column at an average velocity of 20 cm/s. The seabed unit and the profiling unit communicate using a pair of underwater acoustic modems operating at 18–34 kHz. SREP was developed to obtain time-series water column measurements of coastal waters during the summer monsoon season (June–September) when the sea wave and wind conditions are extreme, thus making it difficult to deploy profiling packages from the ship. A description of SREP and observations made during the field deployment are presented in this article.*

**Keywords:** Coastal waters, profiling system, seabed unit, technology demonstration, winter convention studies.

THE west coast of India experiences upwelling during monsoon season. Nutrient-rich upwelled water fertilizes the upper oxygenated coastal waters resulting in increased biological productivity. Long-term continuous profiling of the coastal waters is essential to unravel such monsoon-driven changes in the Arabian Sea. The seabed resident event driven profiling system (SREP) developed at the Marine Instrumentation Division of the National Institute of Oceanography, Goa, India is a water column profiling system that can be deployed in coastal waters using an oceanographic mooring. The underwater winch system on the seabed unit spools out the tethered buoyant profiler gradually through the water column until it

reaches the sea surface. Throughout the spool-out phase, the profiler acquires data and at fixed time intervals transmits the most recently acquired data packet (via the acoustic channel) to the sea-bed unit for safekeeping. After remaining on the surface for a short duration of 30 sec, the underwater winch system spools in the profiler. The unique features of SREP are: acoustic communication between the seabed and profiling units<sup>1</sup>, battery power saving using low-power electronics and sleep–wake-up modules, data redundancy on the seabed unit in the event of accidental loss of the profiling unit and time-triggered and forced (user command) profiling modes. There are other autonomous profilers which are capable of measuring upper-layer water column similar to the SREP, viz. HOMER (HOMing Environmental Recorder)<sup>2</sup>, CAPABLE (The Coastal Autonomous Profiler And Boundary Layer system)<sup>3</sup>, SeaCycler<sup>4</sup> and uprising microstructure profiler<sup>5</sup>. A different class of profilers like the wire walker, uses the ocean wave energy to move a buoyant profiler down a wire suspended from a surface

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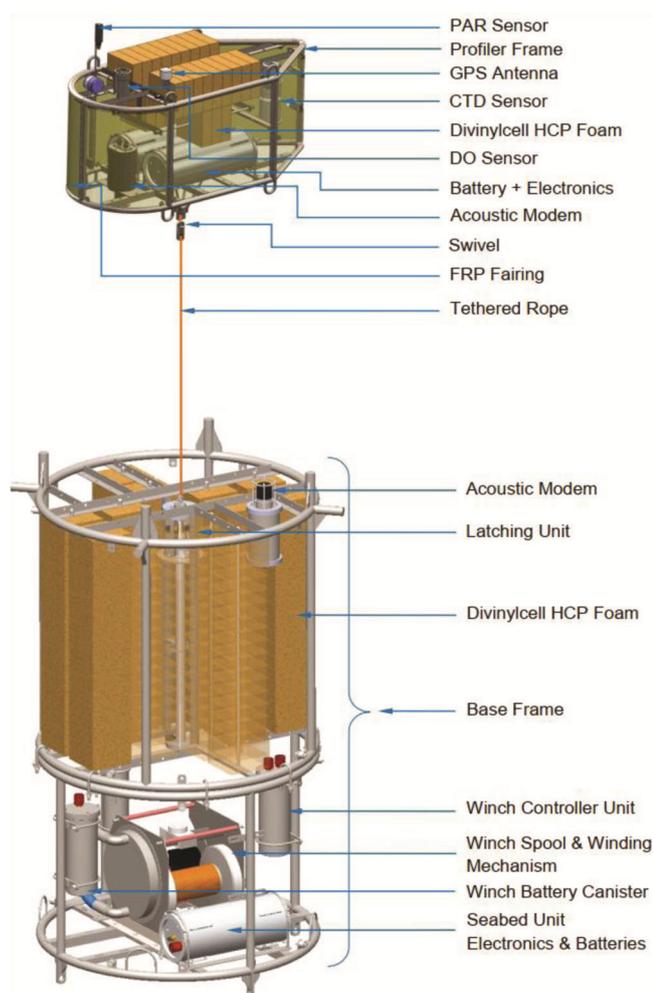
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float and uses only buoyancy to surface up<sup>6</sup>. Here we describe the SREP and present the field deployment results.

### The seabed resident event-driven profiling system

Figure 1 shows the SREP configuration. The function of the winch system on the seabed unit is to spool out and spool in the positively buoyant profiler. During the spool-out phase, the profiler ascends the water column by virtue of its buoyancy (~10 kgf). This buoyancy is provided by divinylcell hydraulic crush point (HCP 50) floats for sub-sea applications. These floats are rated for 300 m water depth and 50 bar crushing pressure limit. They have a density of 250 kg/m<sup>3</sup> and can be easily machined. The profiler is tethered to the seabed unit using a non-conductive 3 mm diameter mono filament kevlar rope with maximum breaking strength of 300 kg. Table 1 provides the main specifications of SREP. The conductivity

temperature depth (CTD) sensor is non-pumped, model CTD-NV (Citadel); sampled at 4 Hz. The dissolved oxygen (DO) sensor is RINKO2 (JFE ALEC) sampled at 1 Hz. Chlorophyll and turbidity sensor is FLNTUS (Wetlabs); sampled at ~4 Hz. Photosynthetically active radiation (PAR) sensor is PAR-SER (Satlantic); sampled at 4 Hz. At a pre-designated profiling time (timed profile), the SREP wakes up, powers on the sensors, unlatches the tethered profiler and initiates a profile. The winch spools out the profiler gradually in the water column at an average speed of 20 cm/s. At every 4 sec interval the profiler transmits a most recent acquired data packet to the seabed unit using the underwater acoustic modem for data redundancy. The profiler rises to the water surface due to its positive buoyancy, with the tether remaining taut throughout, until the profiler breaks the sea surface. When the profiler is on the surface, the slackness in the tether is detected by the tensioner and the winch stops spooling out. Additionally, the profiler commands the seabed unit to stop spooling out when it is on the surface. These are the safety measures to avoid creeping of the tether. After a brief stay of 30 sec on surface the winch starts spooling in the profiler which is switched to a low-power mode with no data acquisition while descending, until it is latched to the seabed unit waiting for the next time profile to commence. Power saving is achieved using ultra-low power consumption electronics (PIC 18F97J94). Apart from the timed profiles, SREP can be commanded to execute a forced profile using a compatible ship-based ultra short base line-cum-acoustic modem (USBL). The USBL when configured in the promiscuous mode is able to capture the instant message communication between the seabed unit and the profiler acoustic modems during profiling, which is useful for monitoring the performance of SREP.



**Figure 1.** Three-dimensional drawing of the SREP showing the profiler latched to the seabed unit and oriented upwards as would be the case before the start of profile.

### Sea deployment

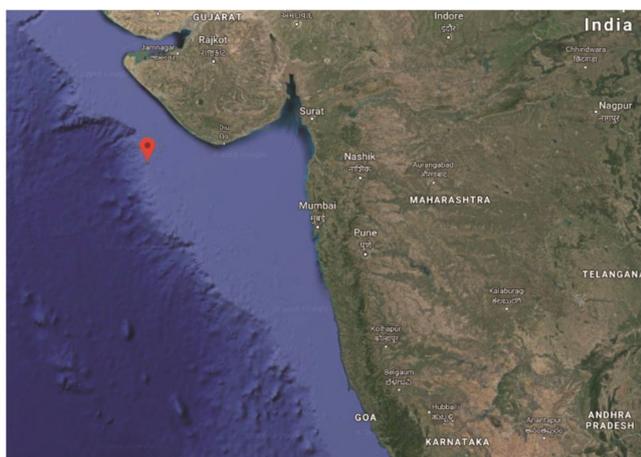
During the period 5 February to 4 March 2018, SREP was deployed at a location (latitude: 20°18.183 N, longitude: 69°25.161 E) in the northeastern Arabian Sea (Figure 2) off the Indian coast of Gujarat for winter convention studies using National Institute of Oceanography (NIO)'s research vessel *R V Sindhu Sankalp* (cruise SSK-115). The deployment location was selected in the region close to the 200 m depth contour line with a gradual change in depth up to 205 m, i.e. 0.5 nautical miles west of the 200 m depth contour. A standard mooring configuration consisting of anchor weight, acoustic release, hard ball floats and the necessary mechanical hardware (chains, shackles and swivel) was used for deployment.

On 5 February 2018, the mooring components were assembled and pre-checks were carried out on SREP (seabed unit and profiler). A gantry test for the seabed unit was performed using the A-frame pulley of the ship

**Table 1.** SREP specifications

<b>Seabed unit</b>	
SS304 frame dimensions height and diameter	Height = 1.6 m; diameter = 1.0 m
Weight in air	~228 kg
Net buoyancy in water	~80 kgf
Tested depth	200 m
Endurance (estimated)	100 days; with 2 profiles/day up to 200 m
Power source (winch motor assembly)	Lithium sulfuryl chloride primary cells (2880 Wh/2 × 24 V/60 Ah)*
Power source (winch controller)	Lithium bromine chloride primary cells (240 Wh)
Power source (acoustic modem, sensors, electronics)	Lithium ion polymer cells (864 Wh/24 V)
Total average power	3.5 Whr/day during profile; 3.9 Whr/day during sleep mode
Communication	18–34 kHz, 1 kbaud (acoustic modem)
Electronics (microcontroller)	PIC18F97J94
Sensors	Pressure sensor Keller 36XW
<b>Profiling unit</b>	
SS304 frame dimensions: height, length and width	Height = 0.5 m; length = 1.1 m; width = 0.4 m hydrofoil shape
Weight in air	~66 kg
Net buoyancy in water	~10 kgf
Tested depth	200 m
Endurance (estimated)	100 days with 2 profiles/day up to 200 m
Power source (acoustic modem, sensors, electronics)	Lithium ion polymer cells (1296 Wh/24 V)
Total average power	7.8 Wh/day during profile; 3.89 Wh/day during sleep mode
Communication	18–34 kHz, 1 kbaud acoustic modem
Electronics (microcontroller)	PIC18F97J94
Sensors	Chlorophyll, turbidity, conductivity–temperature–depth, dissolved oxygen, photosynthetically active radiation
Minimum distance of sensors from seabed	14.63 m

\*Standard battery set consists of two banks of 24 V/60 Ah connected in parallel. Additional battery bank can be installed to achieve the estimated endurance.



**Figure 2.** SREP deployment location (latitude: 20°18.183 N, longitude: 69°25.161 E).

with a 10 kg weight simulating the buoyancy of the profiler. SREP was deployed at 15:27 h.

The deployment operation was completed in about 15 min. After a gap of 1 h, a forced profile command was issued to SREP using the ship-based USBL and acknowledgement of profile initiation was received. Another forced profile command was issued later in the evening. Per-programmed timed profiles designated at 02:00 h and 14:00 h were initiated by SREP from 6 February 2018.

After a month of deployment, a cruise (no. SSK117) was undertaken from 2 to 7 March 2018 to observe the performance and retrieve the SREP system. On the morning of 5 March 2018, the ship was positioned at the SREP drop point location and ship echo sounders were switched-off to eliminate possible interference with the 12.0 kHz acoustic release deck unit transducer. A ranging command was executed using the acoustic release deck unit and the measured slant range of the SREP acoustic release was 284 m. Post-verification, a release command was issued at 08:15 h. SREP surfaced in the estimated time of 2 min 33 sec.

The ship was manoeuvred to position the SREP off the starboard bow with the wind on the starboard side. The SREP was grabbed from the ship's bow using a grapnel hook. The profiler was manually lifted on the front deck and disconnected. The seabed unit was lifted using a 0.6 tonne crane followed by the mooring components (hard-ball floats and acoustic release). The retrieval operation was complete at 09:00 h.

In all, 54 timed profiles were executed. One timed profile (02:00 h, 11 February 2018) failed to execute. During the period from 18 (02:00 h) to 22 February 2018 (14:00 h), the profiler continuously surfaced up. Figure 3 shows the velocity of the profiler while ascending. The velocity varied from 10 to 30 cm/s and the average velocity of the profiler was 20 cm/s. We used a second-order lowpass butterworths filter, with cut-off frequency at 0.1 rad/s. The filter was implemented with zero phase

distortion. All the profiles did not sample up to the surface because of the drag force on the profiler and the presence of underwater currents, due to which the profiler encountered profile termination condition (mission time-out: 980 sec or maximum payout length: 250 m).

## Observations

It is known that during winter (November to February), the northern Arabian Sea cools due to radiative heat loss as well as heat loss due to enhanced evaporation under the dry continental trade winds that blow from the Asian land mass towards the ocean<sup>7</sup>. Evaporation not only lowers the surface temperature, but also increases the salinity of the surface waters. Thus, the resultant cooling combined with the increased salinity enhances the density of the surface waters. This densification of surface waters

kick-starts the convective mixing, thereby deepening the oceanic mixed layer. In this process of deepening of mixed layer, the subsurface waters from the upper nutricline/thermocline are brought into the upper water column thus fertilizing the euphotic zone. This process initiates the rapid photosynthesis by phytoplankton, which eventually leads to the phytoplankton bloom. Though the mechanism of winter bloom is somewhat understood in detail, what is not known is the time evolution of convection and the intra-seasonal variability of the phytoplankton bloom. In this context, SREP was deployed in the northern Arabian Sea during February to March 2018 to capture the signatures of winter cooling and convection, and associated winter phytoplankton bloom.

The vertical distribution of temperature during February and March 2018 in the northern Arabian Sea showed warm temperatures of 26°C in the upper 50 m of the water column during the first week of February (Figure 4). The upper water column temperature was further reduced to 25°C till the end of February 2018. This indicates that winter cooling was more intensified during 9 to 28 February 2018. In the first week of March 2018, a warming in the upper ocean was noticed with increase in temperature by 1°C. In the subsurface levels, colder waters with temperature of 17°–18°C were seen entraining towards shallower depths during the active spell of winter cooling. This indicates that there was strong convective mixing during 10–24 February 2018. Isothermal layer showed a shoaling trend from 100 to 20 m during 5–28 February 2018.

The mixed layer depth (MLD) was calculated based on the temperature criteria, i.e. 1°C drop from sea surface temperature. The MLD showed 100 m variability during the observation period from 5 February to 5 March 2018. During 5 to 22 February, mixed layer was deep and was on an average about 90 m. The maximum value of MLD was 120 m during 6 and 15 February 2018, which clearly indicates that winter cooling and convection were active till 22 February 2018 in the study region. After 22 February 2018, a sudden shoaling in MLD was observed and it shoaled to 30 m (Figure 5). Again during the first week of March 2018, MLD showed a gradual deepening trend. A total of 54 profiles were used to understand the upper water column structure, out of which 50 profiles sampled the water column from 195 to 25 m. Since MLD during the period of observation varied from 30 to 120 m, the four profiles which did not sample from the surface to 25 m would not impact the determination of mixed layer. A total of 33 profiles were sampled from near surface to 195 m. These data were used to understand the time evolution of winter cooling in the northern Arabian Sea. The present data can be used for the above studies, as MLD which is the indicator of winter convection is greater than 30 m.

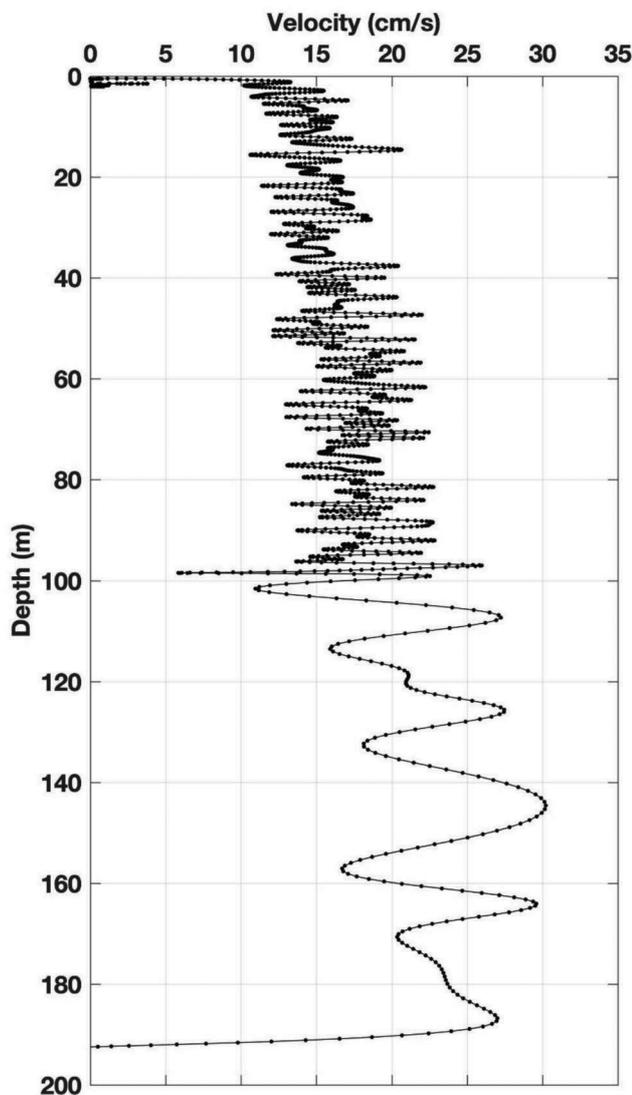


Figure 3. Profiler velocity (date: 12 February 2018, time: 14:00 h).

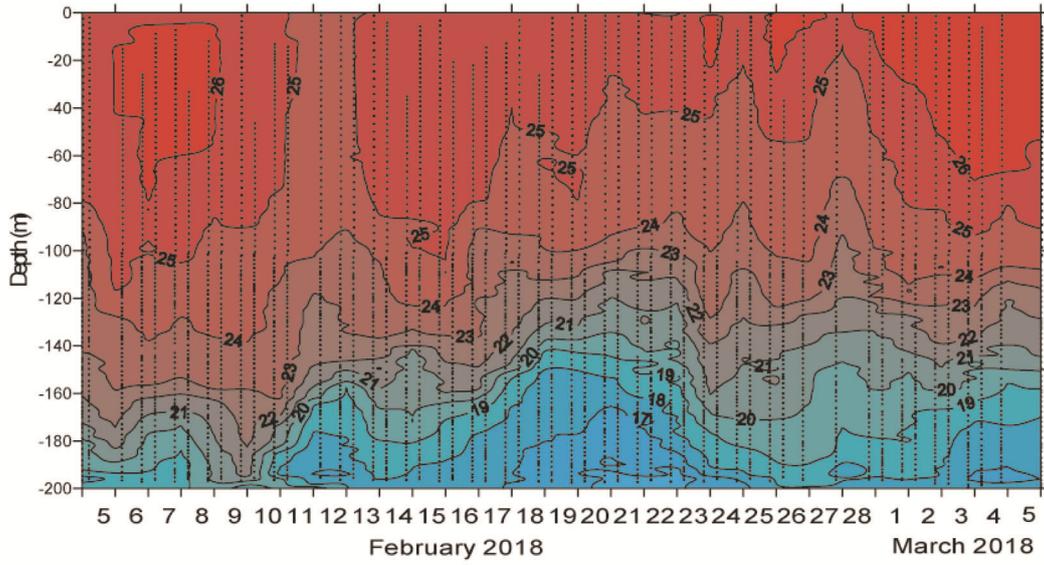


Figure 4. Time evolution of temperature captured by SREP.

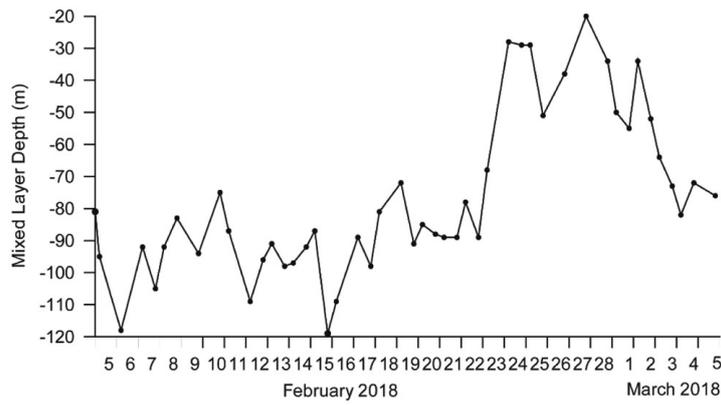


Figure 5. Mixed layer depth (MLD) variability during 5 February to 5 March 2018 in the northern Arabian Sea based on SREP data.

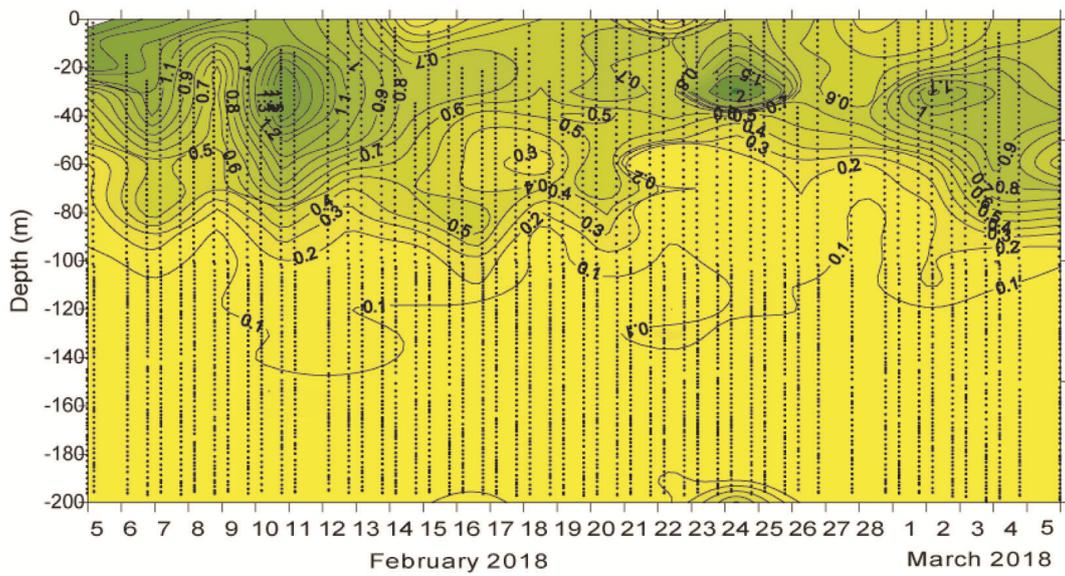
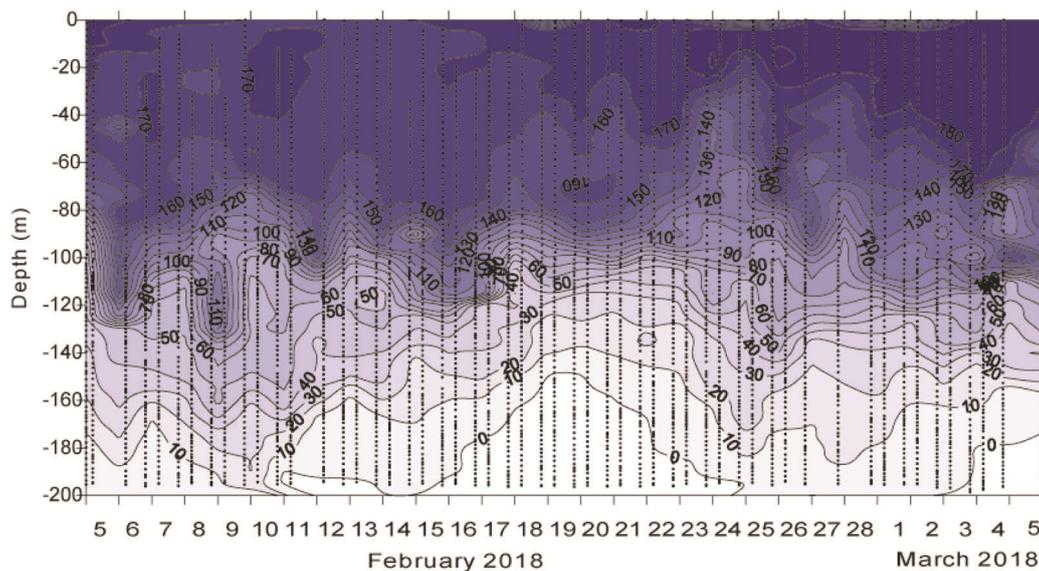


Figure 6. Time evolution of chlorophyll captured by SREP.



**Figure 7.** Time evolution of dissolved oxygen captured by SREP.

The chlorophyll variability in the upper 200 m clearly shows that the phytoplankton productivity occurs in the upper 100 m in the northern Arabian Sea during winter. The upper 80 m of water column showed high levels of chlorophyll concentration throughout February. The maximum chlorophyll of  $2 \text{ mg/m}^3$  was observed during 24 and 25 February 2018 (Figure 6). The turbidity values of the water column throughout the deployment varied between 1 and 3 NTU, and would not affect the chlorophyll measurements.

The vertical distribution of DO showed a well-oxygenated upper 40 m of water column, with values exceeding  $170 \text{ } \mu\text{mol/kg}$  from 5 to 24 February 2018. Thereafter, the surface waters showed an increasing DO concentration up to  $180 \text{ } \mu\text{mol/kg}$  (Figure 7). The evolution of DO showed a progressive shoaling of oxycline with time, for example, the  $140 \text{ } \mu\text{mol/kg}$  isopleth shoaled from 110 m in the first week to 40 m towards the last week of February. The most striking feature of the distribution is the presence of suboxic waters below 160 m during the entire measuring period. However, from 11 to 25 February 2018, anoxic waters were seen below 180 m. A second episode of anoxic waters was noticed towards the end of the measurement period below 180 m. These suboxic and anoxic waters are important in the context of denitrification and also the ecosystem response. Thus SREP was able to precisely capture the episodic occurrences of anoxic conditions.

## Conclusion

The SREP was successfully deployed and retrieved using research vessel *R. V. Sindhu Sankalp*. The month long deployment proved the sea worthiness of SREP system.

The SREP captured the signatures of winter cooling and convection and the associated winter phytoplankton bloom.

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