Analysis of drift characteristic in conductivity and temperature sensors used in Moored buoy system

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ABSTRACT

Conductivity and Temperature (CT) sensors are attached in the Ocean Moored buoy network in Northern Indian Ocean (OMNI) at different depths up to 500 m below the sea surface. Drift in these sensors were analyzed based on the result of calibration. For detailed investigation, the sensor’s drift is categorized based on the position of sensors in the mooring as surface layer (above 50 m), thermocline layer (50–200 m) and deep layer (200–500 m) and analysis was carried out at both Arabian Sea (AS) and Bay of Bengal (BoB). The drift analysis revealed that over the time of deployment the drift in temperature sensor was very minimal and well within the accuracy limit. However, the drift in the conductivity sensors was more significant. Drift in the conductivity sensor decreases as the deployment depth of the sensor increases and also drift in the sensors which were deployed in AS is high as compared to the sensors deployed in BoB. Biofouling of the sensor is measured spatially in AS and BoB and it indicates that biofouling and Abrasive scouring of cells are due to the flow of high concentrations of plankton in the euphotic zone (top layer), which may cause the drift in the conductivity sensor.

1. Introduction

Temperature and salinity are the most important physical parameters in oceanography to determine the accurate dynamic height variability (Maes, 1998) and to understand the dynamic nature of the global climate and marine ecosystem (Feistel et al., 2015), wherein differences in these physical parameters drive the ocean circulation, called the thermohaline circulation (Toggweiler and Key, 2003; Tsuchiya, 1968). These physical parameters differ in BoB and AS. BoB is low saline and forms strong vertical density stratification due to the large inputs of freshwater through precipitation and river discharge (Shenoi et al., 2002; Venkatesan et al., 2013 b). However, AS is highly salty as a result of the influences of the three major water masses in the northern side, namely, the Arabian Sea High Salinity Water (ASHSW), which is generally present in the upper layer of 100 m, Persian Gulf Water mass (PGW) between 200 and 250 m and Red Sea Water (RSW) between 600 and 900 m (Prasanna Kumar and Prasad, 1999). For better understanding of the physical characteristic of these Oceans, temperature is measured in ITS-90 °C (°C). ITS-90 is an instrument calibration standard agreed to by a number of Scientists in 1990, which provides for comparison and compatibility of temperature measurements internationally. For the ocean, temperatures typically range from −2 to 35 °C (28.4–95.0 °F).

Salinity can be derived from the measurement of conductivity. Conductivity is a measure of a material’s ability to conduct electrical current. Water with a large amount of dissolved salts has high conductivity, while fresh water has low conductivity. Temperature also affects conductivity: warm water has high conductivity, while cold water has low conductivity. The units for conductivity are Siemens/meter (S/m). For water ranging from freshwater to seawater, conductivity typically ranges from 0 to 7.5 S/m.

Under the Ocean Observation Network of India (I-OON), the Ocean Moored Buoy Network for the Northern Indian Ocean (OMNI) with seven buoys in the Bay of Bengal and five in the Arabian Sea (Fig. 1) are attached with sensors to collect meteorological, surface and subsurface oceanographic parameters on a real-time basis through INMARSAT satellite (Venkatesan et al., 2013 a) for the past 7 years. This network of OMNI buoy systems has been providing data which are of great relevance to the climate research community to constantly monitor the seasonal, intra-seasonal, annual and inter-annual variations in the northern Indian Ocean.

These buoy systems have a time-series of vertical profiles of temperature and conductivity (SBE37 IM CT sensor Make Seabird USA) up to 500 m water column from the surface at ten discrete depths in the
Bay (Fig. 2). Accuracy and range of the sensor used in OMNI Buoys are given in the Table 1.

The OMNI buoy programme addresses a long-standing need to understand the observed variability of upper ocean thermohaline and current structures on several timescales that has an important bearing on the evolution of seasonal monsoons and cyclones (Venkatesan et al., 2013 b). However, there is no study results regarding the time drift of the temperature and conductivity sensors. Ando et al., 2004 studied the drift in CT sensor using Triangle Trans Ocean Buoy Network (TRITON) and revealed that drift in temperature sensor were 0.1 mK and conductivity drifted higher in the sensor moored in the upper ocean than the sensor moored in the deep ocean. Freitag et al., 2005 studied the drift in temperature sensor in TAO/TRITON moored buoy Array in the tropical Pacific and the PIRATA Array in the tropical Atlantic, which revealed that drift in temperature sensor was −0.0095 °C.

This article describes the use of a different kind of technology to measure conductivity and temperature, conductivity and temperature calibration system, time drift of sensor using post deployment calibration, bio fouling in moored instrument, and data correction.

2. Technology to measure conductivity

In the last century, two methods were employed to measure salinity, one is by drying a sample and weighing the residue (Forch et al., 1902) and the other method is by carrying out a complete chemical analysis of the sample's composition and adding up the constituent masses. These two methods show results with different values for the same seawater (Millero et al., 2008). Efforts are being taken for obtaining consistency in the measurement of salinity. However, the link has not been established between any of the salinity definitions and the international system of units (SI) (Maes, 1998). At present, conductivity defines salinity using suitable correction equations. As a result of recent advancements, many techniques were used to measure conductivity (Nelson et al., 2003; Diaz-Herrera et al., 2006; Tengesdal, 2014). However, due to practical implications in the field, inductive and conductivity cells are mostly used by many of the ocean observations.

Conductive type sensors used in the OMNI buoys are SBE37, manufactured by the company viz., Sea Bird Electronics, USA (Sea Bird). It is a conductivity cell type sensor. The conductivity measured by the sensor using a scale factor or cell constant reflects the ratio of length and cross-sectional area of the sampled water volume in which the electrical current actually flows.

The conductivity derives from the relationship:

\[ R = \frac{\rho}{L/A} \]

where: \( R = \) resistance = \( \frac{1}{\text{conductance}} \), \( \rho = \) resistivity = \( \frac{1}{\text{conductivity}} \), \( L = \) length of sampled water volume, \( A = \) cross-sectional area of sampled water volume.

The conductivity cell is made up of borosilicate glass with three internal platinum electrodes; it has zero external fields by connecting its outer electrodes together and no voltage difference exists to create an external electrical current (Fig. 3). Thus, it is immune to proximity errors and readily protected from fouling by anti-biology (toxic) gatekeepers placed at the ends of the cell.

Stable cell geometry is important for an accurate conductivity measurement. Cell contaminated with oil, bio fouling or other foreign materials will reduce cell geometry. Through formula 1, contamination of the cell increases the apparent resistance because of the reduction of cell diameter, hence, the conductivity measurement becomes lower than the actual value. Abrasive scouring of cell due to flow of high concentrations of plankton into the cell may increase the cell diameter and conductivity measurement becomes higher than the actual value. Generally, it is called positive drift of sensor (Freitag et al., 1999).
characteristics of sensor, therefore, have a natural tendency to drift during the contamination. Sea-Bird moored CTDs use EPA approved anti-fouling devices to keep the insides of the sensors clean, so that fouling will not affect the measurements. The Anti-Fouling Device is an expendable device that is installed on each end of the conductivity cell, so that any water that enters the cell is treated (Seabird, 2016b). Anti-Fouling Devices have no effect on the calibration because they do not affect the geometry of the conductivity cell in any way (Marc le men, 2012; Seabird, 2009). In OMNI buoy system, the SBE 37 CT sensor with pump (Fig. 4) is fixed at particular depth, the pump flushes the conductivity cell at a faster rate than the changes in the environment, so the T and C measurements stay closely synchronized with the environment (i.e., even slow or varying response times are not significant factors in the salinity calculation).

3. Technology to measure temperature

The Platinum Resistance Thermometer (PRT) provides accurate temperature measurement and is used as the laboratory standard. Generally, platinum-resistance thermometer is used as interpolation device, for the temperatures commonly found in the ocean. It has a loosely wound, strain-free, pure platinum wire whose resistance is a function of temperature.

Thermistors are mostly used because of the lower cost involved compared to other temperature sensors. The sensing element of the SBE 37 sensors is glass-coated thermistor bead, pressure-protected in a thin-walled stainless steel tube. Thermistors differ from Resistance Temperature Detectors (RTDs) based on the material used. A thermistor is generally made up of ceramic or polymer, whereas RTDs use pure metals. So, a thermistor can be interchanged without applying any calibration on it thereby saving the cost of calibration.

4. Calibration system

Calibration of sensors is performed in computer-controlled temperature baths for temperature and conductivity by M/s Seabird Electronics USA. Calibrations in pre and post deployment are important for the data correction. SBE3 temperature sensor is used as secondary reference to calibrate the temperature sensor used in the mooring (SBE 37). SBE3 sensor is calibrated by using Standard Platinum Resistance Thermometer (SPRT), which is calibrated using physical standards as triple-point-of-water cells and gallium melt cells that are certified by NIST USA. Temperature calibrations are done at 7 points over the oceanographic range of 1–32.5 deg C.

IAPSO Standard Seawater is used as a primary standard for conductivity calibration (Seitz et al., 2011). The practical salinity of IAPSO is obtained by a series of conductance measurements at OSIL relative to KCL standard solutions, prepared using precise weights of KCL crystals (Bacon et al., 2007). Salinometer with IAPSO water is used to calibrate the SBE4 conductivity sensor, which is the secondary standard to calibrate the conductivity sensor used in mooring (Ando et al., 2004; Venkatesan et al., 2012; Bihana et al., 2014). Conductivity calibrations are done at 8 points over the range of 0–6 S/m. Post-deployment calibration is done without cleaning conductivity cell. Based on the result of post-deployment, the pre deployment calibration is performed either by re-platinizing the cell or after cleaning the internal part of the cell.

5. Drift of the sensor estimated using laboratory calibration

Sensors retrieved from the OMNI buoy systems are sent back to M/s Seabird Electronics USA, for pre and post deployment calibration. From these calibrations the drift of the sensor is calculated as described in the document appnote31 released by M/s Seabird Electronics USA, (Seabird Electronics, 2016a). Totally 80 sensors were calibrated and its deployed mean time at sea was 580 days and the distribution of the sensor at sea reflects that around 50% of the sensors were calibrated after 450–600 days of operation at sea (Fig. 5). The regular service period of the OMNI buoys at sea is scheduled for one year. However, in few cases the early replacement happened due to vandalism or drifting of buoy system. The longer service periods were due to the non-availability of ship time for the regular maintenance or due to redeployment of same sensors at sea.

The drift in temperature sensors is very minimum and it is well within the accuracy limit of the sensor even if it was redeployed continuously for three years of the moored period. It also indicates that the drift does not depend on the time in function and depth at which the sensor is moored (Fig. 6). The post deployment calibration indicates that about 93% of the sensors drifted in negative side (Fig. 7) and the average drift was −0.00012 °C and −0.00027 °C per year and standard deviation were 0.00012 °C and 0.00015 °C in A5 and BoB, respectively. The post deployment calibration clearly indicates that the temperature sensor is very stable over time and drift is not dependent on depth (Fig. 8) and time.

However, the conductivity sensor used in mooring drifted more significantly (Fig. 9). The post deployment calibration indicates that about 87% of the sensors are drifted in the positive side and 13% drifted in the negative side because of the abrasive scouring and contamination.

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Fig. 4. Left panel: Pumped flow through the sensor. Right panel: Anti-Foulant device.

Fig. 5. Distribution – Day in the measurement at sea.
of the cell, respectively. Calibration result of conductivity sensor indicates that the sensors moored in 200m and 500m depth are well within the sensor accuracy limit, whereas few sensors which were moored in the euphotic zone (above 200m depth) drifted more than the accuracy limit.

For detailed investigations, the drift in the sensor is categorized according to the places where the sensors are moored as surface layer above 50m which includes 10, 15, 20 and 30m moored sensors, thermocline layer from 50 to 200m depth, which includes 50, 75 and 100m moored sensors and Deep layer from 200 to 500m depth, which include 200 and 500m moored sensors. Further, it is categorized spatially as BoB and AS.

The drift of the conductivity is higher in surface layer and decreases in thermocline layer and it further decreases in deep layer (Fig. 10).

Drift in the conductivity sensors that were deployed in AS is high when compared to the sensors deployed in BoB. The Average drift of conductivity in the surface layer was very high i.e. 0.00335 and 0.00275 PSU/month for AS and BoB, respectively (Table 2). In the thermocline layer, the drift is 0.00318 and 0.00196 for AS and BoB, which is comparatively lesser than the surface layer.

Thus, the conductivity measurement over the period becomes higher than it should be measured. The standard deviation also increased in the surface and thermocline layers, indicating a large variance of drift for each sensor. On the other hand, the drift of the conductivity in the deep layer (below the euphotic zone) was very small 0.00014 and 0.00013 for AS and BoB, respectively which are not significant when compared to the accuracy limit of the sensor. This analysis revealed that the conductivity sensors are very stable. The drift in conductivity sensor in the surface and thermocline layer was not caused by the sensor itself but by its environment. Bio fouling on the conductivity sensor is a limiting factor to provide high quality data in the euphotic zone (surface and thermocline layer). To overcome these
issues, NIOT implements various methods of anti-fouling approach, which includes copper guard protection, polyester tape on sensor casing and anti-fouling paints on frames. These resulted in reduced biofouling on the surface layer.

6. Biofouling in the moored instrument

Euphotic is the zone where enough light for photosynthesis is available; in this zone many plants and other organisms live and food is also abundant. Biofouling on an underwater instrument is caused by the development of microscopic life forms (algae or bacteria) in the euphotic zone. After growth in stages, they become large organisms, such as shells and barnacles and get attached to the submerged objects in the ocean. Biofouling is one of the limiting factors in ocean monitoring and it disrupts the quality of the measurements (Marc le menn, 2012; Delauney et al., 2010; Venkatesan et al., 2017). Thus, the underwater sensors moored in the OMNI Buoy system are prone to biofouling.

Venkat et al., studied biofouling in OMNI Buoy mooring which revealed that biofouling is predominant only up to a depth of 50 m and Lepas anatifera (goose neck barnacle) is the common biofoulant irrespective of the location and water conductivity. For detailed investigation, the biofouling deposited over the sensor was measured upon retrieval of the OMNI buoy, which revealed that there were more bio fouling deposits in the surface layer and got reduced gradually in

Fig. 11. Bio Fouling in the CT sensors corresponds to the moored depth with the mooring diagram.

Fig. 12. Fouling trend in the AS and BoB.

Fig. 13. Comparison of uncorrected and corrected data with reference ship based CTD sensor.

Fig. 14. Picture of the field calibration setup (Left panel) a) Temperature reading b) conductivity reading from all sensors at 1000 m depth.
the deep layer (Fig. 11). This analysis shows that the sensor moored in AS is highly affected by biofouling when compared to the sensors in the buoy deployed in BoB (Fig. 12). This could be due to the high productivity in the Euphotic zone of AB when compared to the productivity in the BoB (Madhupratap et al., 1996).

7. Data correction

The abrasive scouring and contamination of cell is the limiting factor for accurate conductivity measurement. We could make the correction in the measured data using the post cruise calibration coefficient. Behavior of drift over the period of deployed duration is unknown. However, assuming the linear drift in the conductivity, the data was corrected. The corrected data from the moored buoy was compared using the in-situ ship based CTD data which was taken just before the retrieval of buoy system and it revealed that the error in the data is reduced as compared to the uncorrected data (Fig. 13). Large drift was observed in the surface and thermocline layer in the uncorrected data and the drift were reduced after the correction.

8. Field calibration

It is important to have post-cruise calibration in the same state of cell geometry as identical to that during the retrieval of the sensor to have a better understanding about the drift and data correction accurately. Allowing the cell to dry or keeping in salt water between the retrieval and post calibration could change the cell geometry. Field calibration provides an opportunity to have similar cell geometry to perform the calibration.

Ocean is the good source for getting variable temperature and conductivity, as we go deep the stability is also much better. By using this ocean characteristic, the authors made comparative calibration using a reference sensor (Ship CTD) and this system was lowered along with the retrieved CT sensor moored in the buoy as shown in Fig. 14. CTD was lowered along with the retrieved sensors to pre-defined fixed depths (200,400,600,800 and 1000 m) to get a range of temperature and salinity measurements in the ocean environment. During these fixed depths the CTD was held until the sensor gets stable readings. Field calibration also revealed that the same result as laboratory calibration, i.e. temperature sensors are very stable and drift does not depend on the depth at which sensors are moored (Fig. 14a). However, conductivity sensors moored in euphotic zone (above 200 m) drifted significantly (Fig. 14b).

9. Conclusion

Drift of conductivity and temperature sensors moored with OMNI buoy system in AS and BoB was investigated using pre and post deployment calibration. It is identified that the temperature sensor is very stable and its drift is very minimum, within the accuracy limit and also revealed that drift does not depend on the sensor moored depth and period in function. However, the drift in the conductivity sensor is significant and it depends on its moored position. Euphotic zone (Surface layer) of the ocean is highly prone to phytoplankton production and bio fouling due to availability of nutrient; hence, more drift in conductivity at surface layer and very less drift in the deep layer. Data correction based on post cruise calibration shows an improvement in conductivity measurement. Many techniques were evolved to prevent the biofouling on the instrument by researchers. However, only a few have been tested in-situ.

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