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Metrics for the assessment of quantity and quality of the data by Argo floats

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Observing system or research initiative's foundation lies on reliable *in situ* data from sensors, which accurately tell about various key parameters that are being measured. Argo floats had brought huge amount of ocean observational *in-situ* data which is widely used from analysis to modelling. Present work describes a metrics for analyzing performance of sensors on Argo floats which can be used to assess the performance of float or set of floats as a whole. A set of new metrics like Total Data Return, Quality Data Returned and Quality Data Expected are proposed including the well-known Half-Life Period utilizing all of the Argo profile data. From the analysis, temperature and sensors performance is found to be more than 80 % and average Half-Life is found to be 1065 days. These metrics provide the overall performance of the floats, and can also be applied to other similar floats deployed by other countries as well as sensors fitted on other oceanic platforms.

[**Keywords**: Argo floats, Indian Ocean, Metrics, Quality assessment, Sensors]

Introduction

Argo is a global array of 3,000 free-drifting profiling floats that measures temperature and salinity (T/S) of upper 2000 m water column of the ocean. This allows continuous monitoring of the climatic state of the ocean, with all data being relayed and made publicly available within hours after collection. Conceptually, Argo builds on the existing upper-ocean thermal networks, extending their spatial and temporal coverage, depth range and accuracy, and enhancing them through addition of salinity and velocity measurements[1]. Argo is an international project in operation, with the cooperation with meteorological and oceanographic organizations of many nations, World Meteorological Organization (WMO) and International Oceanographic Commission (IOC). Argo reached its target of building up a global ocean monitoring system consisting of 3,000 Argo floats by Nov 2007. With the completion of Argo float network in 2007, one lakh T/S profiles in the global ocean are being reported every year. The number of floats deployed by 26 nations and European Union together in the world ocean is more than 3500.

Indian National Centre for Ocean Information Services (INCOIS) is responsible for the floats deployed by India under this programme, and as of July 2019 contributed 484 floats to the global Argo float network. All the Argo float data is disseminated to meteorological organizations around the world via the Global Telecommunication System (GTS) within 24 hrs after reception and served to observe the oceanic state and can be utilized in studies on climate changes. In addition, INCOIS performs additional high quality control known as delayed mode quality process. This is done once the data acquired from the float crosses 6 months, following a well-established scientific approach and the data is released within 6 months via internet with no additional charges to the user community. Further to these, the data are checked for visual quality control using GUI tools[2] and convex hulls methods[3] which are developed in house at INCOIS. The quality controlled data thus obtained is used in studies related to enhancing the existing Indian Ocean climatologies[4], inter-annual to intra-seasonal variability of salinity[5], variability of mixed and sonic layer[6,7], oxygen minimum zones[8,9], ocean state during pre and post cyclones[10] and many more with greater reliability.

INCOIS began its deployment of floats from 2002 onwards and have acquired different type of floats from various manufacturers. The data obtained from these floats are routinely passed through Real Time Quality Control (RTQC) and also Delayed Mode Quality Control (DMQC) once the float crosses 6 months of deployment. The data sets from these floats are flagged based on the outcome of the quality control procedures. The Argo Data Management Team (ADMT) endorsed quality flag associated with a predefined quality assessment. For instance a quality flag of '1' imply that the data returned is good and quality flag of '4' imply that the data returned is bad. Also in delayed mode assessment, some of these flags might be changed based on the comparison with best quality CTD data and best available climatologies. Through this process, each record of the Argo profile data is assessed for its quality.

There are many methods of assessing the quality of the data returned by the floats[11,12]. However there is no method of assessing the data returned by float or set of floats deployed by any country/group for their performance based on any single metric. It is for this, a set of new metrics are defined and are presented in this paper, to assess the overall performance of a float based on the data returned and the quality of data returned. These metrics are based on the quality flags assigned by RTQC and DMQC during the life time of the float.

Each Argo float's data acquisition is associated with a depth table based on which the profile length and number of records it returns is decided. For all the APEX floats which communicates via ARGOS constellation of satellites, this depth table is predefined and the same is maintained by the float during it life time. However for APEX float that communicates *via* Iridium satellites, this might change if the mission configuration is changed during the life time of the float. The only hindrance to the data return as per the number given in the depth table is that, the float would have moved to a shallow water region or hit a bottom which is not deep enough than the profiling depth (say 2000 or 1000 m) set for the float. But, for Provor/Arvor floats a concept of slicing is followed and the number of records of temperature and salinity returned varies with each profile (for more information see Provor manual[13]). It is based on these numbers of records of T/S and the quality flags assigned to them after the quality control process, the defined metrics assess the overall performance of a float or a set of floats. Materials and Methods describe the data and the methodology followed for obtaining the new metrics and Results and discussions describes the overall performance based on these metrics.

Materials and Methods

Data and methodology

All the 484 floats deployed between October 2002 - July 2019 are considered for the analysis in this work. Out of the 484 floats deployed by India, 143 are actively reporting the data (at the time of compiling this report) and other floats have either finished their life cycle and stopped reporting due to battery drainage, beaching, grounding or other unknown reasons. The floats chosen for defining the metrics comprise of APEX-8C, MetOcean-Provor, APEX-9A which were deployed and survived during the period 2002 - 2019. The details of the metrics defined are given below.

New metrics

New metrics were defined to assess the quantity and quality of data returned by the floats. New metrics like Total Data Expected (TDE), Total Data Returned (TDR), Quality Data Expected (QDE) and Quality Data Returned (QDR) are defined as follows:

Total Data Expected (TDE) is the amount of data expected to be given by the Argo float, according to the number of profiles achieved by the float as per the depth table assigned to it. For example if ‘m’ is the number of profiles measured by the float and ‘n’ is number of records as per the depth table assigned to the float, then TDE is given by the formula as:

$$TDE = \sum_{i=1}^{m} n_i \quad \text{... (1)}$$

Total Data Returned (TDR) is the sum of amount of data returned in each profile of the Argo float throughout its life, from its first cycle to the last cycle *i.e.* last time it communicated. For instance if ‘m’ is number of profiles observed by the float and p_i is the number of observation records for each i^{th} profile then TDR is given by the formula as:

$$TDR = \sum_{i=1}^{m} p_i \quad \text{... (2)}$$

Where, p_i is the number of records returned in each profile measured by the float, which might be less than or equal to n_i, the number recorded as per the depth table assigned to the float owing to issues like beaching, grounding etc.

After each profile is decoded, it is passed through a set of quality checks based on which each of the record is assigned a flag (1 - 4). Details on the quality control and flag assignment is discussed in Udaya Bhaskar *et al.*[14]. Based on these data flags, a metric called Quality Data Return (QDR) which is the sum of quality data returned (*i.e.* with quality flags assigned as 1) for each profile of the Argo float, throughout its life time is given by the formula shown below:

$$QDR = \sum_{i=1}^{m} Q_i \quad \ldots (3)$$

Where, Q_i is the number of records with quality flag assigned as 1. From these individual metrics TDE, TDR, QDR new metrics were defined which will give the true measure of the performance of the float as given below:

$$\text{Percentage of Total Data Returned (PTDR)} = \frac{Total\ Data\ Returned}{Total\ Data\ Expected} * 100 \quad \ldots (4)$$

$$\text{Percentage of Quality Data Returned (PQDR)} = \frac{Quality\ Data\ Returned}{Total\ Data\ Returned} * 100 \quad \ldots (5)$$

$$\text{Percentage of Quality Data Expected (PQDE)} = \frac{Quality\ Data\ Returned}{Total\ Data\ Expected} * 100 \quad \ldots (6)$$

$$\text{QDE\%} = \frac{TDR\% * QDR\%}{100} \quad \ldots (7)$$

These metrics are graphically represented to give a meaningful information about the overall performance of the individual floats and the program altogether. Following Kimber[15], the metrics are represented graphically by plotting PTDR against PQDR on a scatter plot and augmenting the plot by adding hyperbolic contours representing PQDE (Fig. 1). R, an open source environment and language for statistical computing and graphics[16] is used to create the figures in this work. The values of PTDR, PQDR, and OQDE should be high for a float to be considered as best and hence they should appear towards upper right hand corner of the graph indicated as BEST in Figure 1.

It is also important to show longevity of a float, which is represented by the number of profiles each float could measure; otherwise the metrics can be misleading. For instance if a float had given just one profile before it stopped communicating and given exactly as many number of records as indicated in the depth table and if all of them are quality flagged as 1, then all the metrics PTDR, PQDR and PQDE would be 100 %. This kind of metric can mislead a user about the performance of the floats deployed. Hence, the plots are augmented by adding circles to the plot with radii relative to the number of profiles. This feature of adding circles was not a part of Kimbers plot[16] but was improvised here for displaying the performance of the floats. For the radii (representing the profile numbers) to be of reasonable size, it is normalized by dividing them with 200 (arbitrarily chosen for the circle to be of reasonable radius based on average number of cycles given by all the chosen floats). The resultant number was used as diameter of circle that represents each Argo float.

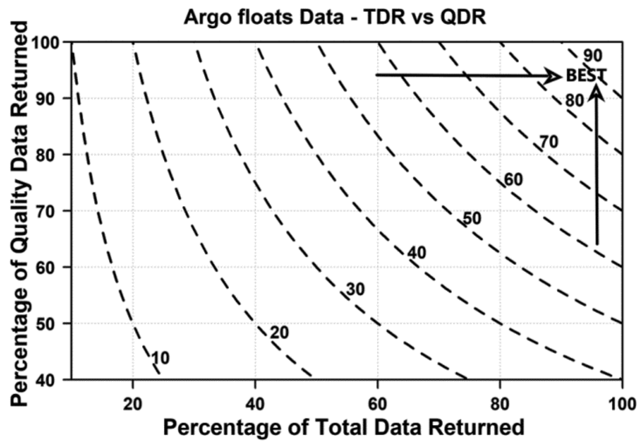

Fig. 1 — Template for the comparison of sensor performances of Argo floats

$$\text{diameter of circle} = \frac{No\ of\ Profiles}{100}$$

$$\text{radius of circle} = \frac{No\ of\ Profiles}{200}$$

Half-Life Period

The Half-Life (HL) is the time required for a quantity to reduce to half of its initial value. In this work, HL is defined as time required for half of the floats deployed in a year to die or stop reporting the data. Half-life in exponential decay can be described by:

$$N(t) = N_0 \left(\frac{1}{2}\right)^{\frac{t}{t_{1/2}}} \quad \ldots (8)$$

Where, N_0 is the initial quantity of the floats deployed, $N(t)$ is the number of floats that are still active at the end of the year and $t_{1/2}$ is the HL of the floats. A simple example of HL for Argo floats is described below:

Let's assume that 10 floats were deployed as a part of Indian Argo program in the year 2002. By the end of preset period (say one year), assume 5 of them have died and 5 are still alive and actively giving profile data. For the floats which stopped communicating, total number of alive days are computed as (end t - start t), with ‘t’ being the date. For all other floats which are active, a number which rarely occurs say 99999 is assigned and the series is sorted in ascending order. The HL for this set/batch of floats is the value that occurs in the middle of the series. One should note that HL will not change owing to how long the rest of alive floats survive and HL cannot be computed if more than half of the floats deployed in a batch or year are still alive and actively providing data.

Results and Discussion

Evaluation of individual sensor performance

Once the metrics are obtained based on the formula defined in methodology section, the performances of individual sensors are evaluated and are presented below.

Evaluation of temperature data

In general temperature sensor is less susceptible to fouling than salinity. Hence the data return and quality of the data return will be high for temperature compared to salinity. This is also reflected in the metrics shown in the Figure 2. Figure 2(a) shows the comparison of temperature sensor performance for the chosen floats. From the figure it is clearly evident that majority of the floats have a metrics between 90 – 100 % in terms of number of profiles observed, percentage of data returned, and percentage of quality data returned. This is clearly evident from many floats being cluttered towards the top right corner. The width of the circle for some of the floats, shows that number of cycles returned by these floats is poor even though their performance is better in all the metrics. This can be overcome by enhancing the battery life and following good deployment practices.

Evaluation of salinity data

In general, salinity sensor is prone to bio-fouling as these are unmanned instruments[17]. Bio-fouling causes choking of the pipe through which the sea water enters the float resulting in degradation of salinity sensor. Hence the quality of the data return will be less for salinity compared to temperature. This is also reflected in the statistics as shown in Figure 2. Figure 2(b) shows the comparison of salinity sensor performance for the chosen floats. As observed from the Figure 2(b) it is clearly evident again that the statistics for these floats follow the same trend as that of temperature (Fig. 2a). The number of floats falling in the range of 60 – 80 % is observed to be slightly high for salinity compared to temperature as the temperature sensor is less prone to fouling. Apart from this, Figure 2(b) resembles same as that of Figure 2(a) in all other aspects.

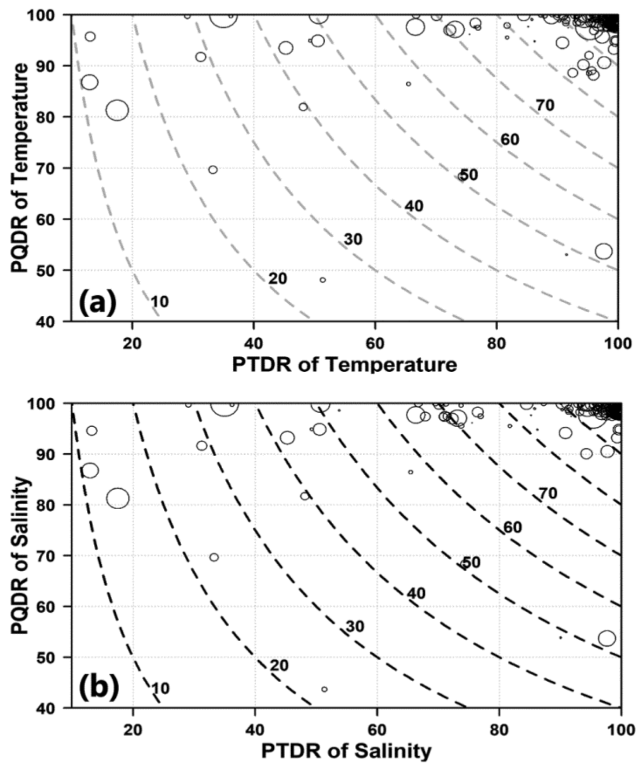

Fig. 2 — Comparison of sensor performances of floats: (a) temperature, and (b) salinity sensor

Inter comparison between types of floats

To evaluate the metrics further, two sets of floats deployed by India were inter-compared. India has deployed APEX-8C and Metocean Provors during the year 2002 - 2003. The metrics obtained from these two types of floats were inter-compared to see the application of defined metrics for different types of platforms. These metrics are show in Figure 3. The APEX-8C floats are represented by blue circles and Metocean Provor are represented by red circles. Over all it is observed that both APEX-8C and Metocean

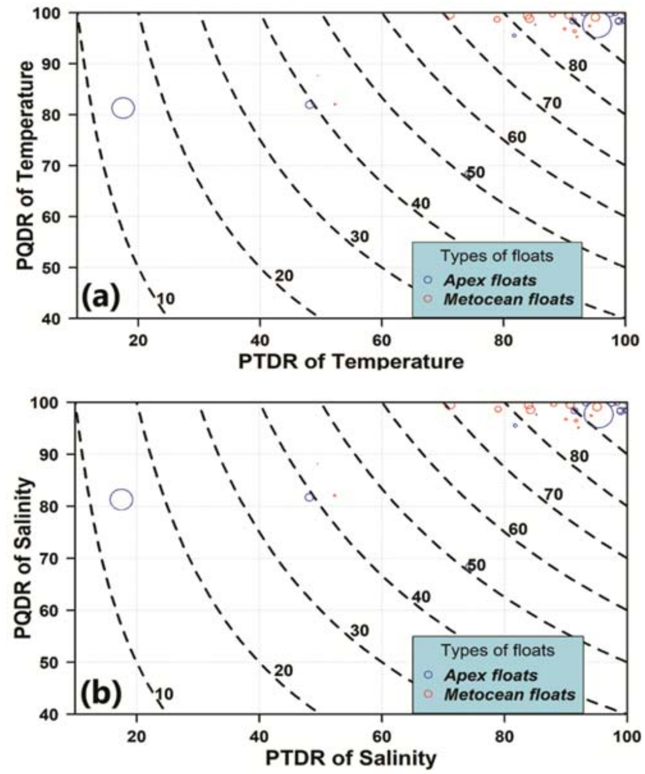

Fig. 3 — Comparison of temperature and salinity sensor performances of APEX-8C and Metocean Provor floats: (a) temperature, and (b) salinity deployed simultaneously by India

Table 1 — Number of floats deployed per year. * represents that it is considered as of the date of analysis

Year	#Floats
2002	11
2003	21
2004	30
2005	46
2006	15
2007	31
2008	15
2009	7
2010	23
2011	46
2012	34
2013	27
2014	45
2015	27
2016	29
2017	28
2018	15
2019	22*

Provor floats have similar metrics though the number of floats closer to 100 % are slightly higher for APEX-8C floats (Figs. 3a, b). This proves that the proposed metric is independent of the types of platforms and is purely dependent on the data returned by the instruments and can be applied to any sensors on most of the oceanic instruments whose data return and quality of data return needs to be quantified, for evaluating their performance.

Evaluating the Half Life estimates of floats

Based on the method described in methodology section, the HL of all the floats is computed based on deployments done every year. The number of floats deployed per year is listed in Table 1. HL corresponding to each of these floats deployed per

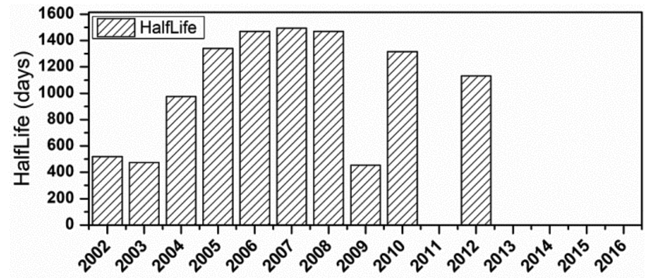

Fig. 4 — Half-Life period for all the floats deployed by INCOIS from 2002 to till date

year is given in Figure 4. From the figure, one can clearly observe that the HL of the floats increased starting from years 2002 - 2008. This increase in HL can be attributed to improvement in the float technologies, improvement in batteries and fixing of abrupt battery drainage. The low HL during the year 2009 is due to the fact that the number of floats deployed is low and many of the floats are found to be effected by micro leakage problem which were subsequently recalled by the manufacturer.

Starting from the year 2010 the floats acquired by INCOIS are from NKE, France which were found to abruptly stop reporting the data without any specific reason. This is reflected in slight reduction of HL for the years starting from 2010. HL for the years 2011, 2013 - 2018 is not computed as more than half the floats are still actively giving data. The HL corresponding to these years will be updated once more than half floats stops reporting data.

Conclusions

Ever since the inception of the Argo program in 2000, huge amount of oceanographic *in situ* data was generated. However, a good measure for assessing the sensor performances over time as part of the overall performance of the program is lacking. In this work, some new metrics like Total Data Returned (TDR), Quality Data Returned (QDR) and Quality Data Expected (QDE) were coined and estimated along with half life estimates. Novel graphical display for comparing the performances of temperature and salinity sensors based on these new metric was considered. The metrics give a holistic picture of the Argo floats and the program as a whole based on individual sensors performance. All those floats which stopped communicating were chosen from the list of 484 floats deployed by India and the metrics pertaining to these floats were obtained. The graphs depict the performance of the floats and thus give an indication of the overall performance of the Indian Argo program. From the analysis it is observed that the Indian Argo program's metrics stands more than 80 %. Even though these newly coined metrics were applied to a set of floats deployed by India, the same can be extended to all the floats deployed by India or any other country. HL period for all the floats deployed since 2002 is found to be increasing with the advancement of the float technology with the exception of one year (2009) which is due to micro leakage problems.

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Conflict of Interest

The authors declare no competing or conflict of interest.

Author Contributions

TVSUB conceived the metrics and prepared the manuscript and RUVNS performed data analysis and prepared the figures.

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