ADVENT OF DEEP ARGO DATA & AN ATTEMPT AT ANALYZING THE DEEPER SOUND SPEED PROFILES FOR EXTRAPOLATION CORRECTIONS

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Abstract: *Both R. Davis & D. Webb were able to develop Argo float technology during early 1990s. A profiling array comprising of 3300 such floats was proposed to cover the oceans globally in 1998 by the Argo's Science Team. The first Argo profiling float came into existence in the year 1999. By the year 2007, Argo had achieved its target of 3000 active floats covering the desired global ocean. The conventional depth for obtaining Argo data has been 0 - 2000 meters. As a giant leap forward, by the middle of 2014, a workshop named, "Deep Argo Implementation Workshop", was held in Hobart. In this conference, Johnson et al. proposed an array of 1228 floats providing coverage of 5° × 5° × 15-day cycles. Deployment of pilot arrays for covering particular regions has already been executed. Deep Ninja and Deep Arvor from Japan and France simultaneously cover depths of 0 - 4000, while Apex & Solo of Unites States are developed to cover 0 - 6000 meters. This study is focused on obtaining in-situ data from a couple of deep Argo buoys and then, compares their salinity, temperature, and sound speed's in-situ values with the extrapolated ones. Prior to availability of deep Argo, the data in depth was usually extrapolated for various parameter calculations. The literature presents numerous methods and examples for extrapolation of vertical profiles for salinity, temperature, and sound speed profiles. The measured temperature and salinity parameters with the pressure were converted to sound speed profile. The extrapolation was carried out using MATLAB's polyfit and polyval functions. The comparative analysis among in-situ data and the extrapolated one illustrates deviation in deeper vertical profiles especially after 2500 meters. The analysis results are presented in the form of graphs and marked accordingly for both in-situ and extrapolated curves. In addition, the study focuses on varying factors responsible for the typical anomalies especially in deeper oceans. The anomalies suggest that for deeper depth calculations, the real measured values present more accurate results instead of mere extrapolations.*

Keywords: *Argo profiling floats, temperature, salinity, sound speed profile, anomalies*

1. INTRODUCTION

Since 1999, Argo float's idea of measuring upper surface of ocean flourished, and by 2007, a targeted array of 3000 floats was accomplished & started covering the subsurface ocean. In the beginning, Argo floats were designed to collect ocean's salinity, temperature, and pressure data around the globe. Later on, various other sensors were included to measure the biogeochemical values around the ocean. To this day, over 1.6 million temperature/salinity profiles and trajectories have been acquired by this Argo program. Roughly, 90% of the profiles are available within a day of their collection. This in-situ Argo data is available online without cost and is capable of being used in research programs. On 11th of August 2014, New York Times famously quoted that, "That system, known as Argo, is one of the scientific triumphs of the age". Initially, the Argo floats were designed to dive deep to 2000 meters depth, but since mid-2014, a program for deploying deep Argo buoys was initiated. These deep Argo floats include Deep Ninja (Japan), Deep Arvor (France), Deep Solo (United States), and Deep Apex (United States) [1, 2, 3, 4]. Prior to availability of deep Argo, the data in depth was usually extrapolated for various parametric calculations [5, 6]. This study focuses on analyzing deep Argo data for salinity, temperature and sound speed profiles against the pressure. The analysis includes the measure values compared to the extrapolated ones for salinity, temperature, and sound speed profiles. Various deep Argo floats reaching the depths of 0 - 4000 meters with the help of deep sensors like SBE - 41 CTD, are selected for this particular analysis. These floats are detailed for their Argo number, cycle number, longitude, latitude, and dates accordingly. The study finally discusses the deviated results along with the reasons [4].

2. DEEP ARGO & ITS DATA UTILIZATION

As mentioned earlier, the conventional depth for obtaining Argo data has been 0 - 2000 meters. As a giant leap forward, by the middle of 2014, a workshop named, "Deep Argo Implementation Workshop", was held in Hobart. In this conference, Johnson et al. proposed an array of 1228 floats providing coverage of 5° × 5° × 15-day cycles. Deployments of pilot arrays for covering particular regions have already been executed. Deep Ninja and Deep Arvor from Japan and France simultaneously cover depths of 0 - 4000, while Apex & Solo of Unites States are developed to cover 0 - 6000 meters [7, 8]. This study is primarily focused on obtaining in-situ data from both NINJA D i.e. Float ID: WMO2902510 (Inactive) and Arvor D i.e. Float ID: WMO 3902132, and then compare its salinity, temperature, and sound speed profile's in-situ values with the vertically extrapolated profiles [9]. It is pertinent to mention here that extrapolation is carried out using MATLAB's polyfit and polyval functions after the conventional depth of 2000 meters [10]. In the following section, the study proceeds with the discussion of salinity, temperature and sound speed profile results for the above-mentioned deep Argo buoys.

3. COMPARATIVE STUDY FOR THE NINJA D (ID: WMO 2902510)

The NINJA D with ID: WMO2902510 (inactive), chosen for this study is currently inactive. The cycle of the float used for this study is 24th which commenced on 2014/03/02. The location of this particular float is illustrated in Fig. 1. This map is generated using the googleearth software [11]. This float covers the depth of ocean from 0 - 4000 meters. Similarly, Fig. 2 and Fig. 3 represent the salinity (degree celsius) and temperature (psu) profiles respectively for both in-situ and extrapolated values. The extrapolation is executed below the depth of 2000 meters for the entire comparative analysis. The sound speed profile is calculated by employing Mackenzie's equation has been employed. This equation is stated as [12]:

$$C = 1448.96 + 4.591T - 5.304 \times 10^{-2}T^2 + 2.374 \times 10^{-4}T^3 + 1.340 \times (S - 35) + 1.630 \times 10^{-2}D + 1.675 \times 10^{-7}D^2 - 1.025 \times 10^{-2}T(S - 35) - 7.139 \times 10^{-13}TD^3$$

where T = temperature in degrees Celsius, S = salinity in parts per thousand, and D = depth in meters.

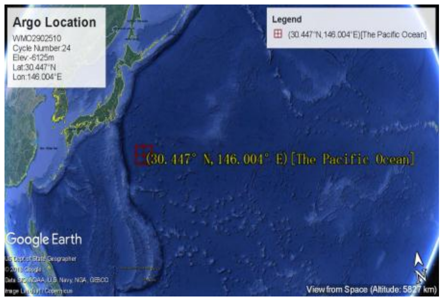

Fig.1: Location of the Argo float (Source: googleearth.com)

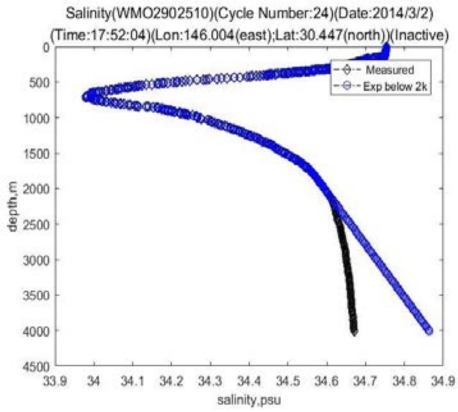

Fig.2: Salinity profile for both in-situ and extrapolated values

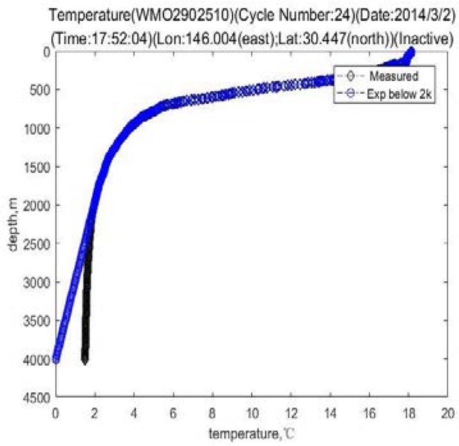

Fig.3: Temperature profile for both in-situ and extrapolated values

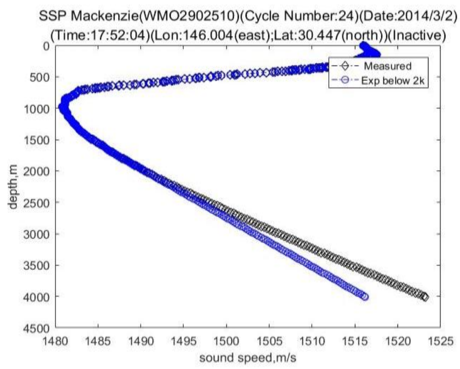

Fig.4: Sound speed profile for both in-situ and extrapolated values

The results shown in Figs. 2-4 are self-explanatory and detailed in the section 5. The extrapolated values for both the salinity and temperature profiles exhibit deviation from the measured i.e. in-situ values. The deviation of these values contributes to the deviation of sound speed profile as well just below the 2000 meters.

4. FURTHER ANALYSIS WITH AN ARVOR D (FLOAT DEEP) (ID: WMO 3902132)

The Arvor D with ID: WMO 3902132 (operational) is chosen for further analysis of the CTD in the deeper oceans. This float is chosen to exhibit the similar results like NINJA D for salinity, temperature, and sound speed profile. The cycle chosen for this particular activity is 84. The data was recorded on 2019/03/08. In this case, the vertical extrapolation for salinity, temperature, and sound speed profiles is taken after the depth of 2000 meters. Fig. 5 displays the location of this particular float with the help of googleearth software. Salinity, temperature, and sound speed profiles are shown in Fig. 6, Fig. 7, and Fig. 8 respectively. As mentioned earlier, the sound speed profile is generated by using the Mackenzie equation.

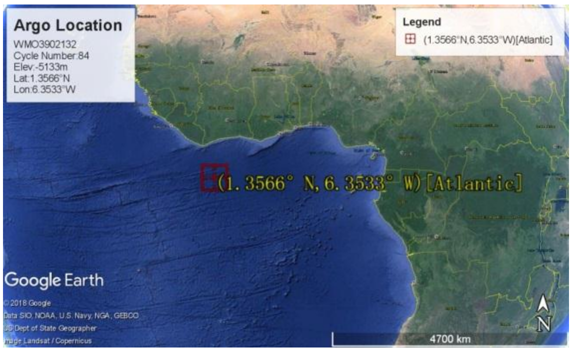

Fig.5: Location of the Argo float (Source: googleearth.com)

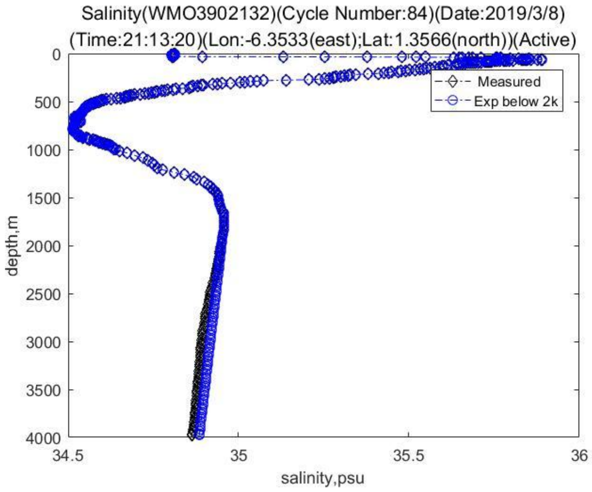

Fig.6: Salinity profile for both in-situ and extrapolated values

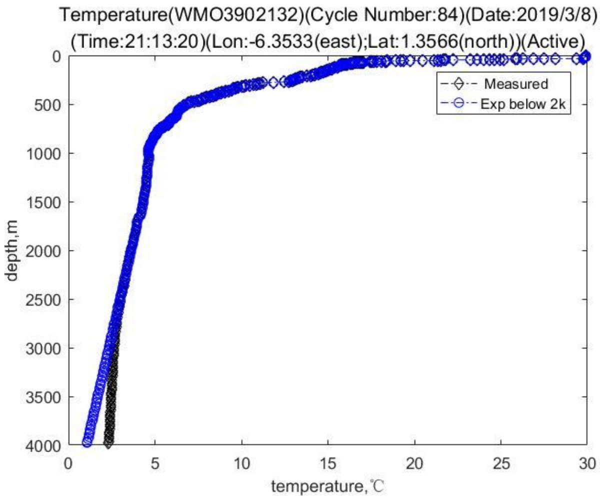

Fig.7: Temperature profile for both in-situ and extrapolated values

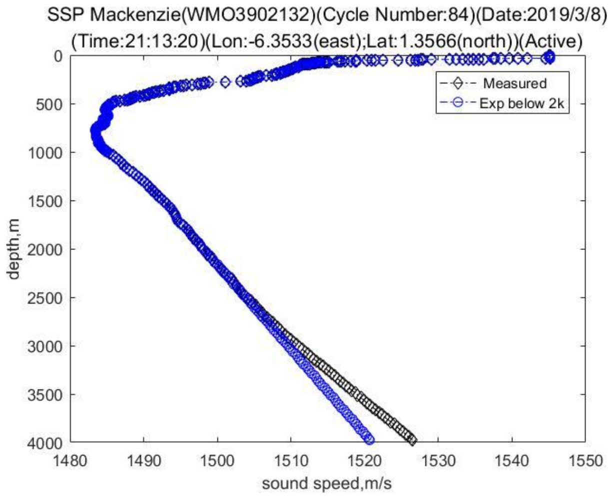

Fig.8: Sound speed profile for both in-situ and extrapolated values

5. DISCUSSION

The aforementioned discussion illustrates that the extrapolated value of the Core Argo Program below the depth of 2000 meters come out to be erroneous if compared with the in-situ values of the Deep Argo Program. In this regard, results from a Deep Ninja Argo float with ID: 2902510 are employed for observations and the float is in its 24^{th} cycle. The outcomes illustrated in figures from 2 - 4 exhibit the obvious deviations from the measured in-situ values to the extrapolated ones especially below the depth of just below 2000 meters. This deviation for salinity in Fig. 2 is evident just below 2000 meters and becomes widely apart at the depth of 4000 meters with measured value lagging by 0.2 psu from the extrapolated value. Similarly, the temperature of the measured in-situ value exceeds roughly by 1.8 °C. This temperature difference has ultimately altered the in-situ value of sound speed profile to exceed by nearly 8 m/s than the extrapolated one as can be observed in Fig. 4. In the fourth section, the figures from 6 - 8 display the results for salinity, temperature, and sound speed profiles for both measured and extrapolated values in case of an Arvor D float with ID: 3902132. In Fig. 6, the measured value of salinity lags negligibly from the extrapolated value. The measured value of temperature starts deviating from the extrapolated value just below 2500 meters depth and ends by exceeding by roughly 1 °C at 4000 meters depth. The resulting sound speed profile for the measured value exceeds the extrapolated one by nearly 6 m/s. These obvious variations for the salinity, temperature, and the sound speed profile for both measured in-situ and extrapolated values suggest the alarming situation in case the real values are absent. Thus, the study strongly suggests the employment of measured data in case of precise calculations for the deeper oceans. The measured values have displayed obvious variations from the extrapolated values.

6. ACKNOWLEDGEMENTS

The author is especially thankful to Prof. Piao Shengchun & Mingzhang Hui for their valuable supervision and suggestions. In addition, the entire group has been thoroughly supportive for this particular study.

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