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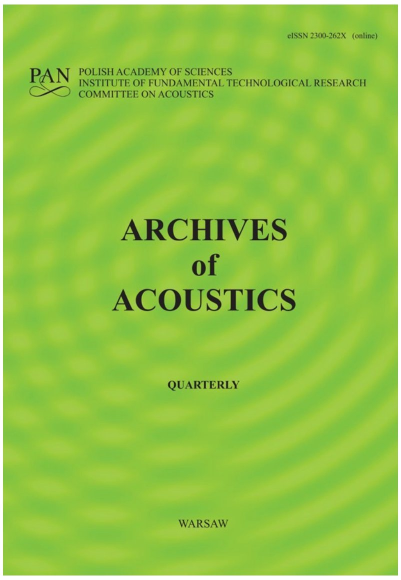

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An Empirical Approach to Investigate Environmental Effects on Acoustic Signal Speed in Oceanic Layers

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Abstract

This paper investigates and demonstrates the effects of three significant environmental contributors: temperature, depth and salinity impact on the acoustic signal propagation across distinctive ocean layers: Mixed, Thermocline and Deep Layers. In the field of underwater wireless sensor networks (UWSN), exact and precise determination of coordinates for sensor localization is very crucial for data validation. Temperature dominates the upper layers; depth becomes prime factors for deeper domain with minimal thermal variations. Salinity while having a diminished effect, facilitates to finer alterations in propagation and deviation of acoustic signal speed. In our work we have analyzed these interdependences by using different empirical models (e.g. Mckenzie, Medwin) customized to each layer, accounting to their incomparable environmental parameters. In Mixed layers sound speed variation are mainly thermal driven, where depth is minimal important and salinity effect is negligible but as we go deeper the temperature starts to fall and depth (pressure) started getting importance and also salinity and temperature variation almost become corresponding. By evaluating ocean layer specified empirical formulas, we have calculated average speed of sound and measure the respective contribution of all parameters. Our work has provided a sub structure which will help to optimize UWSN nodes identification or localization. The results of this work underscored the essential to have an adaptive sound speed modeling for enhanced and precise acoustic signal communication systems.

Keywords : acoustic signal speed; ocean layers; salinity; empirical formulas; sound speed modeling

1 Introduction

The underwater sensor network has been a pivotal field of research among researchers over decades. The vast expansion of ocean has brought both known and yet-to-be known exploration and monitoring challenges to us. At present marine monitoring is increasing promptly. As it is more difficult to establish and monitor underwater sensor network than terrestrial network because of its positing in the rough environments. It is important to gather marine precise information of underwater location as it helps to do underwater surveillance, ocean life exploration , natural disaster study and so on (Tan et al. 2011). The understanding of the accurate node location in the underwater network is very important for both tracking and validate collected data. Electromagnetic radio waves has very poor performance underwater due to sea water because it also faces a high attenuation which makes it expensive and also effect the propagation for long ranges (KukuChuku et al. 2018). As radio signal has a low propagation range, we generally use acoustic signal as a substitute (Anirban et al. 2020). So, in underwater communication and other necessities like distance measurements we usually use acoustic signals. The history of underwater velocity determination was started in the early 1800, where scientist used a tube for listing underwater which was suggested by the famous artist Da Vinci and scientists recorded the speed of the submerged bell proceeding across Lake Geneva (Discovery of Sound in the Sea 2015). Another invention in the field of underwater communication was the invention of 'Gertude' or we can say marine telephone it uses analog modulation and its carrier frequency was between 2 kHz to 15 kHz (Stojanovic 2007). So, numerous researches have scrutinized diverse perspective of UWSN, furthering in the understanding and utilization of under communication with an array of different rang and field for AUV (autonomous underwater vehicles) and indifferent of the positioning type (submerged, indoor, outdoor, underneath. Many studies have proclaimed that environmental factors can bring variation to the acoustic signal speed. According to Chen C.T., Millero and F.J. (Chen et al. 1977), the speed of sound has been affected by temperature depth and salinity. The scope of this article is to understand and analysis environmental variable relationship with acoustic signal as it is the core of underwater communication. This paper highlighted the process of sound speed calculation and how in ocean for each layer a dominating ecological parameter is responsible. This work shows an empirical calculation using the values of different indicator available or introduced by many prominent researchers. Our work can be useful in fields of UWSN localization, ocean engineering and also for understanding underwater signal processing. In the article also sound profile of different empirical formulas are implemented. The major contributions of this article are arranged as follows:

1. This paper demonstrates that how average speed of sound is calculated underwater using divergent empirical formulas.

2. The analysis of the effect of temperature, depth and salinity for different oceanic layers is exhibited to observe ecological variable impact domination for different covering.

3. Finally, the evaluation of empirical formulas' behaviors on the environmental parameter for different oceanic layers is also performed in this research.

The remaining of the paper has been organized in different section structurally. Section 2 which is divided into two parts: problem field and review of the previous research work.In problem field we have evaluate the issues arise in measureing the acoustic speed velocity for UWSN and included a network architecture for visualization purpose and also the way to examine the effects of environmental parameters on the speed of sound for marine communication using empirical formulas. Section 3 has shown a method of the work, and also including mathematical equation along with additional acronym and indicators. In Section 4 all the simulation work are shown with detail information. Section 5 offers a rivaling discussion and finally, in Section 6, the article concluded.

2 Background

2.1 Problem Domain

In our proposed UWSN structure in Fig.1, we consider single beacon on the top of the water surface column and four submerged sensors are deployed underwater that required distance measurement. The sensor nodes can be considered in any layers as extend as the components meet the empirical formulas constrains. For accurate measurement of acoustic speed or speed of sound we required the values of temperature, depth and salinity from both beacon and sensors region. Determining these variables for beacon is uncomplicated as temperature and salinity of the surface water traditionally determine at depth nil. However, if we do not integrate specific sensors (for example, temperature, depth and brininess sensors) for deployed sensors it becomes very much difficult to grasp those variables accurately. In this paper, our focus is to investigate the effect of these three environmental variables on the acoustic velocity for three different ocean layers such as mixed layer, thermocline layer and deep layer using different empirical equations. For ease of comprehension, we think that all the deployed sensor are stationary at the moment of implementation time calculation. We have neglected the motility of the sensor nodes because our main concern here is to measure the average acoustic velocity and analyze the effect of environmental variables using various empirical equations. Our work uses the value of three underwater layer (Mixed, Thermocline and Deep layer) ranges to make our desired simulation.

2.2 Literature Review

Numerous researches have scrutinized diverse perspective of UWSN, furthering in the understanding and utilization of empirical equations throughout an array of different rang and field. Multitudinous empirical formula exists that are established throughout the years to determine the acoustic velocity on the base of oceanographic variable like temperature, depth and salinity. Rahman and his team (Rahman, Muthukkumarasamy, et al. 2013a) has analyzed the

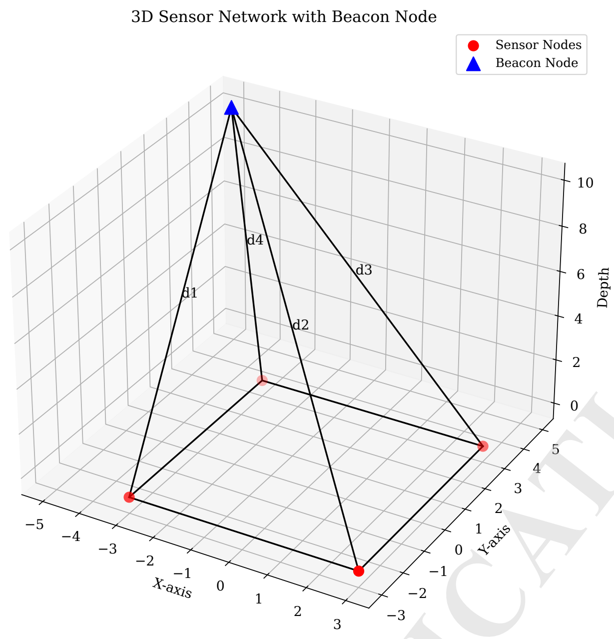


Figure 1: Underwater network deployment considering one beacon and multiple submerged sensors.

ecological variables to see which parameters has high influence on acoustic signal velocity for a vertical water column for a specific problem field, they considered one beacon on the top of the water surface and few submerged sensors which were deployed and needed to measure their distance. They used Mackenzie equation and triple integral method to measure the average speed of sound to analyze which environmental parameter among temperature depth and salinity has most significant impact on the speed of sound for the considered configuration of UWSN with a single beacon and few submerged sensors. This work visited only one formula with a specific range to examine the influenced of environmental elements. Another pivot research of Rahman (Rahman 2014) has proposed an innovative manner to resolve sensor localization using the measurement of in-situ acoustic velocity using Mackenzie formula and utilizing as minimal as a single beacon. The coordinates of the mathematical system were solved using Cayley Menger Determinant followed by linearization and solving nonlinear equations, as it is considered that no node has information of the other node position after that for distance measurement, he considered both radio and acoustic signal but as we all know radio signal has minimal propagation range underwater and he used this to only synchronize the clock between beacon and deployed sensors. He has considered the surface plane as parallel but also shown a non-parallel state of subsets for both configurations, he has considered minimal single beacon which is on the top of the water surface and submerged sensors that are installed underwater. Correspondingly, Talib and his team (Talib et al. 2011) has determine the value of speed of sound using different empirical equation such as Del-grosso, Mackenzie and Medwin as the efficacy of speed of sound is highly sensitive to temperature, density and salinity. They talk about the on-site monitoring of speed of sound for various types of water categories such as sea water, fresh water and inlet. There work can be very helpful for hydrographer which will save time while electing appropriate speed of sound in adjusting echo sound equipment and this observation will be valid for moderate atmosphere change countries. Huang with his team (Huang et al. 2024) in their work they have investigated the field of underwater sound speed profile or in short SSP as synchronous and precise establishment of zonal SSP plays a significant role in marine positioning, navigation and timing (PNT) systems as it appreciably influenced the signal propagation manner for instance trajectory. There are generally two methods for construction of SSP, one is direct SSP measurement another one is SSP inversion. For direct SSP measurement they have used some efficiently functional empirical formulas like Wilson, Leroy, Medwin, Del Grosso etc. These methods have helped promoting the rapid advancement in the field of underwater sensing apparatus.

3 Methodology

3.1 System Overview and Workflow

To deliver a coherent insights of the research procedure, Figure 2 demonstrated the general workflow applied in this study. Firstly, we have consider three oceanic layer name Mixed layer, Thermocline Layer and Deep layer. The first layer of ocean is Mixed layer or we can call it Surface layer, it has a direct connection with atmosphere and it also has almost homogeneous vertical qualities in terms of temperature, depth and salinity (Gill 2016). The second layer Thermocline layer is the middle layer between warmer seawater and deeper cold water in other words we can state that stratified, unstable water forms a Thermocline layer, which develops a frequent temperature drops (Lana et al. 2017). The relates to the worldwide ocean that is extend deeper than 200 m and also it is noted that the large area of the marine habitat can have their own general understanding, either negatively or positively depending on the circumstances (Jamieson et al. 2025). For each layer we have considered a range for the main three environmental parameters temperature, depth and salinity. Now, for the calculation of velocity of sound underwater we need to use formulas which are incorporated with these parameters and calculate the velocity of a vertical water column, and for that we have consider empirical formulas like Mackenzie, Medwin, Wilson, Leroy etc. After calculating the speed value of vertical column we use triple integral method to find the value of the average sound of the speed. Now we have analyze the effect of temperature, depth and salinity effect and for that we have consider some fixed values of these indicators and examine the change of the average speed for each layer for different empirical formulas. For temperature change we have consider fixed range surface temperature, for depth we consider a specific range of depth across three oceanic layer and for salinity for three layers we consider a range where we calculate the average speed for a slight variation of salinity

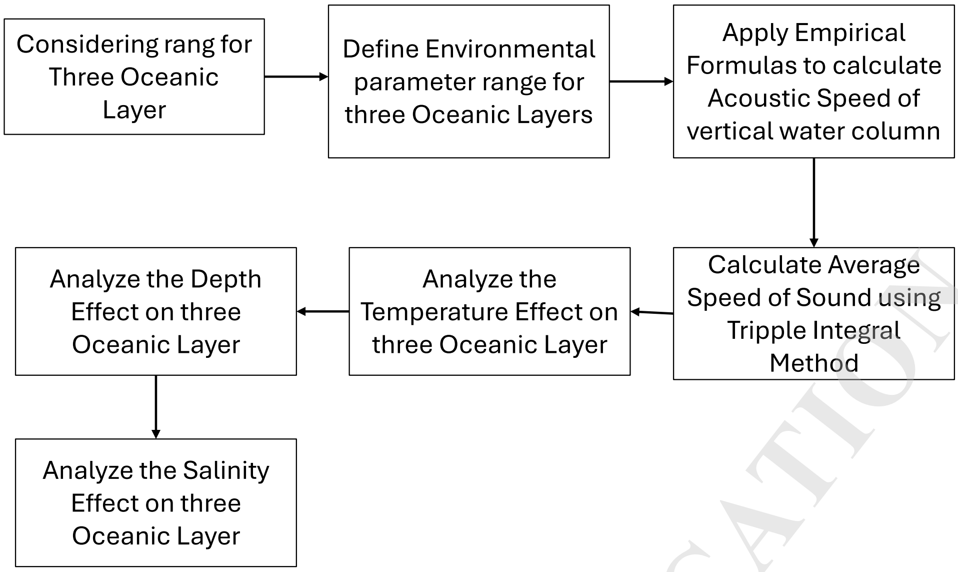


Figure 2: Overview of the research workflow.

3.2 Analytical Framework

In order to determine the distance from, beacon to sensor position traditionally we consider speed of sound and travel time and the equation becomes(Talib et al. 2011),

$$Distance(d) = \frac{1}{2} \times \text{Speed of Sound(v)} \times \text{Travel Time(t)} \tag{1}$$

In general, acoustic signal is used instead of radio signal as it has lowest propagation range than acoustic signal (Rahman, Muthukkumarasamy, et al. 2013b) the speed of sound or in this case acoustic wave near the sea plane is considered about 1500 m/s which is four times faster than in air (Rahman 2014). Nevertheless, the effect of environmental variable on the acoustic speed cannot be ignored. To calculate the sound speed velocity underwater we need to inspect the accurate value of temperature, depth and salinity and for that we cannot use traditional formulas.So, to calculate acoustic velocity we can use empirical formulas which take these three environmental values in concern for calculation. The are given below,

1) Mackenzie empirical formula (Mackenzie 1981):

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

where, v_m is the speed of Mackenzie formula considered and T stands for temperature and

D is for depth.

2) Medwin empirical formula (Medwin 1975):

$$\begin{aligned} v_m d = {} & 1449.2 + 4.6T - 0.055T^2 + 0.00029T^3 \\ & + (1.34 - 0.010T)(S - 35) + 0.016D \end{aligned} \tag{3}$$

where, $v_m d$ is the speed of Medwin formula considered

3) Chen–Millero empirical formula (National Physical Laboratory (NPL) n.d.):

$$v_C = C_1(T,P) + C_2(T,P)\cdot S + C_3(T,P)\cdot S^{3/2} + C_4(T,P)\cdot S^2 \tag{4}$$

where:

$$\begin{aligned} C_1(T,P) = {} & 1402.388 + 5.03830T - 0.0581090T^2 + 0.00033432T^3 - 1.47797\times10^{-6}T^4 + 3.1419\times10^{-9}T^5 \\ & + (0.153563 + 0.00068999T - 8.1829\times10^{-6}T^2 + 1.3632\times10^{-7}T^3 - 6.1260\times10^{-10}T^4)P \\ & + (3.1260\times10^{-5} - 1.7111\times10^{-6}T + 2.5986\times10^{-8}T^2 - 2.5353\times10^{-10}T^3 + 1.0415\times10^{-12}T^4)P^2 \\ & + (-9.7729\times10^{-9} + 3.8513\times10^{-10}T - 2.3654\times10^{-12}T^2)P^3 \end{aligned}$$

$$\begin{aligned} C_2(T,P) = {} & 1.389 - 0.01262T + 7.166\times10^{-5}T^2 + 2.008\times10^{-6}T^3 - 3.21\times10^{-8}T^4 \\ & + (9.4742\times10^{-5} - 1.2583\times10^{-5}T - 6.4928\times10^{-8}T^2 + 1.0515\times10^{-8}T^3 - 2.0142\times10^{-10}T^4)P \\ & + (-3.9064\times10^{-7} + 9.1061\times10^{-9}T - 1.6009\times10^{-10}T^2 + 7.994\times10^{-12}T^3)P^2 \\ & + (1.100\times10^{-10} + 6.651\times10^{-12}T - 3.391\times10^{-13}T^2)P^3 \end{aligned}$$

$$C_3(T,P) = -0.01922 - 4.42\times10^{-5}T + (7.3637\times10^{-5} + 1.7950\times10^{-7}T)P$$

$$C_4(T,P) = 0.001727 - 7.9836\times10^{-6}P$$

where, v_c is the speed of Chen-Millero ,T for temperature, P is for pressure and S is for salinity. In the given formula considered and C_1 to C_4 is its coefficients.

4) Wilson empirical formula (Wilson 1977):

$$v_W = 1449.14 + v_1 + v_2 + v_3 + v_{tpS} \tag{5}$$

where:

$$v_1 = 4.5721T - 4.4532\times10^{-2}T^2 - 2.604\times10^{-4}T^3 + 7.9851\times10^{-6}T^4$$

$$v_2 = 1.60272\times10^{-1}P + 1.0268\times10^{-5}P^2 + 3.5216\times10^{-9}P^3 - 3.3603\times10^{-12}P^4$$

$$v_3 = 1.39799(S-35) + 1.69202\times10^{-3}(S-35)^2$$

$$
\begin{aligned}
v_{tpS} = &(S-35)\big(-1.1244\times10^{-2}T + 7.7711\times10^{-7}T^2 + 7.7016\times10^{-5}P - 1.2943\times10^{-7}P^2 \\
&+ 3.1580\times10^{-8}PT + 1.5790\times10^{-9}PT^2\big) \\
&+ P\big(-1.8607\times10^{-4}T + 7.4812\times10^{-6}T^2 + 4.5283\times10^{-8}T^3\big) \\
&+ P^2\big(-2.5294\times10^{-7}T + 1.8563\times10^{-9}T^2\big) + P^3(-1.9646\times10^{-10}T)
\end{aligned}
$$

where, v_w is the speed of Wilson ,T for temperature, P is for pressure and S is for salinity. In the given formula considered and v_1 , v_2 and v_tps is its coefficients.

5) Leroy empirical formula (Leroy 1969):

$$
\begin{aligned}
v_L = 1492.9 + 3(t-10) - 0.006(t-10)^2 - 0.04(t-18)^2 \\
+ 1.2(S-10) - 0.01(S-35)(T-18) + D/61
\end{aligned}
\tag{6}
$$

where, v_L is the speed of Leroy ,t for temperature, D is for deepth and S is for salinity.

6) Coppens empirical formula (Coppens 1981):

$$
v_{Co} = v_0 + (16.23 + 0.0253T)\cdot 0.001Z + (0.213 - 0.01T)\cdot 0.000001Z^2 \tag{7}
$$

$$
v_0 = 1449.05 + 4.57T - 0.0521T^2 + 0.00023T^3 + (1.333 - 0.0126T + 0.00009T^2)(S-35)
$$

7) Del Grosso empirical formula (National Physical Laboratory (NPL) n.d.):

$$
v_D = C_{000} + \Delta C_T + \Delta C_S + \Delta C_P + \Delta C_{STP} \tag{8}
$$

$$
\begin{aligned}
C_{000} &= 1402.392 \\
\Delta C_T &= 5.012285T - 0.0551184T^2 + 0.000221649T^3 \\
\Delta C_S &= 13.2953S + 0.0001288598S^2 \\
\Delta C_P &= 0.1560592P + 0.0002449993P^2 - 8.833959\times10^{-8}P^3 \\
\Delta C_{STP} &= 0.006353509TP - 4.383615\times10^{-7}T^3P - 0.00001593895TP^2 + 2.656174\times10^{-8}T^2P^2 \\
&+ 5.222483\times10^{-10}TP^3 - 0.01275936ST + 9.688441\times10^{-5}ST^2 - 0.0003406824STP \\
&+ 4.857614\times10^{-6}S^2TP - 1.616745\times10^{-8}S^2P^2
\end{aligned}
$$

where, v_D is the speed of Del Grosso formula, and C_000 to C_T , C_P , C_STP is its coefficients.

Each equation has different types of range for the three environmental parameters. In this work our desired environmental parameter unit is for temperature is Celsius, salinity it is p.s.u and for depth it is meter but as discussed in (Huang et al. 2024) for Equation 5 and Equation 7 the depth unit is in 1000 kg/cm^3 (kilograms per cubic centimeter) and Equation 3 the unit is in 1000 bar. To determine the velocity of vertical water column and also to measure the average speed of sound it is needed to convert them to our desired parameter. To convert the depth value into a meter we will use the following formula (National Physical Laboratory (NPL) n.d.), To convert pressure to depth in meters:

$$Z_s(P, \Phi) = \frac{9.72659 \times 10^2 P - 2.512 \times 10^{-1} P^2 + 2.279 \times 10^{-4} P^3 - 1.82 \times 10^{-7} P^4}{g(\Phi) + 1.092 \times 10^{-4} P} \quad (9)$$

Here,$g(\phi)$ (variation of gravity with latitude) is consider 1000 m/s^2 and P (Pressure) is around 9.81 $\times 10^6 n/m^2$ and as the equation with these values provided a yield value which do not align with expected physical depths, we have used a scaling factor of 0.08593 which gives the depth value as 8000 meters for 1000 kg/cm^3 and for 1000 bar the scaling factor is considered 0.008618 which give us a depth of same 8000 meters. In TABLE 1, we can see the comparison different empirical formulas range for temperature, depth and salinity.

Table 1: Comparison of different empirical formulas for speed of sound.

Equation	**Proposed Year**	**Applicable Range**		
		Temperature (°C)	**Depth (m)**	**Salinity (p.s.u)**
Mackenzie (Mackenzie 1981)	1981	[2–30]	[0–8000]	[25–40]
Medwin (Medwin 1975)	1975	[0–30]	[0–1000]	[0–40]
Chen–Millero (National Physical Laboratory (NPL) n.d.)	1980	[0–40]	[0–8000]	[5–40]
Wilson (Wilson 1977)	1960	[0–30]	[0–1000]	[0–37]
Leroy (Leroy 1969)	1969	[–2–40]	[0–1000]	[0–42]
Coppens (Coppens 1981)	1981	[0–35]	[0–4000]	[0–45]
Del Grosso (National Physical Laboratory (NPL) n.d.)	1974	[0–30]	[0–8000]	[30–40]

After determining and transferring the numeric values of temperature, depth and salinity with the top beacon which has all the information from top to the bottom region, we can calculate the average speed of acoustic signal by following work of Rahaman A. (Rahman, Muthukkumarasamy, et al. 2013a) using Equation 10.

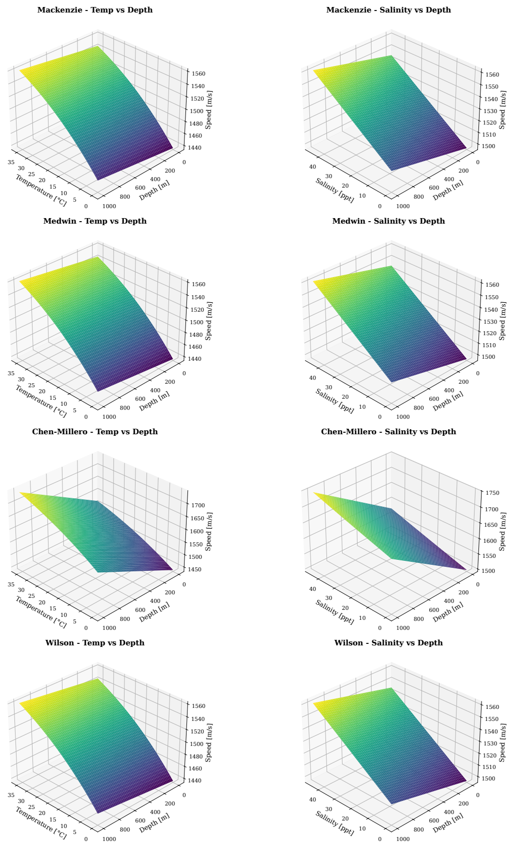


Figure 3: Acoustic profile for Mackenzie, Medwin, Chen–Millero, and Wilson.

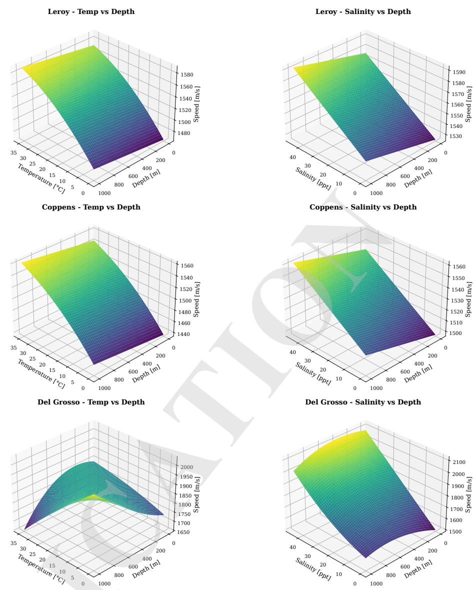


Figure 4: Acoustic profile for Leroy, Coppens and Del Grosso .

$$
\begin{aligned}
V\text{avg} &= f_{\text{avg}}(T, D, S) \\
&= \frac{1}{A} \int\int\int_{R} f(T, D, S) \\
&= \frac{1}{A} \int_{S_i}^{S_f}\int_{D_i}^{D_f}\int_{T_i}^{T_f} f_{\text{avg}}(T, D, S) dT dD dS
\end{aligned} \tag{10}
$$

Considering the ranges of all empirical formulas from TABLE 1, we can initialize the upper and lower ranges for all empirical formulas and plot there acoustic profile using python simulation environment and from Figure 3 and Figure 4 has demonstrate that.

In this work, ‘A’ is considering the area produced by the limits of T, D, S; f (T, D, S) which is for all empirical equation as in Equation 2 to Equation 8. In, Figure 3 and Figure 4, the right-side graph represents the acoustic profile for salinity and depth where temperature is constant and in the left side acoustic profile is for temperature and depth where salinity is constant. So, by the help of acoustic profile we can visualize the three environment parameter.

4 SIMULATION RESULTS

Environmental Constrains: In this work, there has been considered the whole underwater environment into three factor which are temperature , depth and salinity and these variables fluctuated based on different layers like Mixed layer, Thermocline layer and Deep layer. According, to Kudu S. work (Kundu 2016) each ocean layer has its own range for environmental parameters and it highly impact the ecological paramets which mentioned in the TABLE.2

Table 2: Environmental variable range for different layers.

Ocean Layers	**Depth range (m)**	**Temperature range (°C)**	**Salinity range (p.s.u)**
Mixed Layer	0-450	30-25.5	25-25.045
Thermocline Layers	450-1000	10-4	34-34.5
Deep Layers	1000-8000	4-2	34.8-35.1

To investigate the effect of environmental parameters on acoustic speed, we have simulated different empirical models which align with our ranges of sea layers given in TABLE.2 using Python enviroment.The simulation was conducted by applying Python 3.12 utilizing a cloud-based environment facilitated by Google Collab . Throughout the computation, a suite of python libraries was implemented; each of the library was selected based on specific computational conditions. The NumPy library was applied to perform efficient computational operations, specifically for optimizing numerical arrays for environmental variable range. SciPy library was implemented to perform mathematical integration for calculating average sound speed by utilizing quad function. Mathplotlib library was also applied for visualization purposes like, originating computational plots to differentiate environmental variables to observe their characteristics. Each empirical equations have been developed as a custom function in python that takes temperature, depth and salinity as input and return a comparable sound speed. The resulting simulation calculates the average sound speed for different empirical formulas, then visualizes the outcomes into labeled subplot to help with comparative analysis. In this work TABLE.2 shows the simulation environment parameter which later has been simulated using the python environment mentioned above. Average speed of sound was calculated for six empirical models for Mixed layers and Thermocline layers (Makenzie, Medwin, Leroy, Wilson, Coppens and Chen–Millero) and for Deep layers there is only five (Makenzie, Leroy, Wilson, Coppens, Chen-Millero) in accord with the simulation ranges and the Del-Grosso empirical formula was not included for the simulation or analysis and its range do not satisfied with our desired range of simulation.To calculate the average speed for Mixed, Thermocline, Deep layer, temperature range is considered from 25.5°C, 4°C and 2°C for bottom temperature and 30°C, 10°C and 2°C for surface temperature. Respectively, in Figure 5, Figure 6, and in Figure 7 for Mixed, Thermocline and Deep layers the variation of salinity are 0.045 p.s. u, 0.5 p.s. u and 0.3 p.s.u with added Gaussian noise, estimated to 1% of each empirical models mean acoustic speed, in order to replicate uncertainty in measurements, it has been directly added in the ‘average speed of sound. After 100 iterations the mean average speed, has been in the range, for Mixed Layers is 1526.71 m/s to 1560.14 m/s, for Thermocline Layers is 1527.09 m/s to 1564.39 m/s and lastly for Deep layers is 1524.19 m/s to 1597.12 m/s.

Figure 8 has portrayed the effect of temperature on the average speed of sound for Mixed Layers. The bottom temperature is considered from 10°C to 30°C under the surface temperature fixed to 25°C and 28°C. Additionally, in Figure 9, for Thermocline Layers the bottom temperature -8°C to 2°C and the surface temperature is fixed to 4°C as well as 6°C whereas, Figure 10 is for Deep layer where surface temperature is fixed at 2°C and 4°C where bottom is varying for -20°C to 0°C. In Mixed layers the average speed increases by 2.0 m/s to 2.25 m/s per 1°C increment in surface temperature for Leroy and Coppens formulas and on the other-hand, Mackenzie,Medwin, Wilson, and Chen-Millero showcase a moderate level sensitivity which is approximately 1.37 m/s for the set bottom temperature range. A 5°C rise in bottom temperature will increment the average sound speed by 0.46% to 0.66% depending on the formula while formula like Leroy and Coppens reacts most with a increase around 0.62% and 0.66%. The rest of the formulas has a overall increment around 0.46% Meanwhile for Thermocline Layers the increment in average sound speed has been increased because of 1°C is 1.5 m/s to 2 m/s, with again Mackenzie,Medwin, Wilson, and Chen-Millero increased is low which is 1.5 m/s but Leroy and Coppens has the high increase which is 2 m/s so, it is observed with most sensitivity. Again for a 5°C bottom temperature increases the speed around 0.29% to 0.41% for all the formula. It is 0.29% to 0.31% for Medwin, Wilson, Chen-Millero and for Leroy and Coppens it is around 0.37% and 0.41% Lastly, for Deep Layers the effect of temperature on average speed becomes weaker. The average sound speed hike only 1.0 m/s to 1.2 m/s while in 5°C bottom temperature rise the sound speed to 0.21% to 0.31% again Leroy and Coppens showing highest sensitivity.

In Figure 11, Figure 12, and Figure 13 the depth measurement accuracy on computed speed of sound was systematically for 450 m water column for Mixed layers, 1000 meter for Thermocline Layers and 8000 for Deep Layers. In Mixed layer the speed of sound increment is 0.08 m/s to 0.085 m/s for each 10 m increase in the depth and for Thermocline and Deep layer the increase of sound per 10 m increment is 0.16 m/s to 0.166 m/s and 0.12–0.13 m/s. In all layers Coppens has the high response and for Thermocline and Deep layers along with Coppens Mackenzie also shows a grate impact around 0.022% to 0.40% and 0.019% to 00.40%. Now if we consider 5% error for Mixed (22.2 m) Thermocline (50 m) and Deep layer the effect on average speed increment is 0.18–0.19 m/s (0.012%), 0.80 to 0.83 m/s (0.055%), and 4.8 m/s to 5.3 m/s (0.3–0.35%). The negligible depth can be for each layer are [$\leq$ 50 m], [$\leq$ 100 m]and finally [$\leq$ 200 m] So, finally we can say that the rate of change of sound is Mixd , Thermocline and Deep layers is accordingly to 0.0083 $\mathrm{m\,s^{-1}\,m^{-1}}$, 0.0165 $\mathrm{m\,s^{-1}\,m^{-1}}$ and 0.013 $\mathrm{m\,s^{-1}\,m^{-1}}$ which means the sound speed rises to 0.083 m/s , 0.0165 m/s and 0.013 m/s for each 1 m increment on the depth.

The effect of salinity has been portrayed on Figure 14, Figure 14, and Figure 16 respectively. To observe the salinity impact on the three oceanic layer we consider a fixed temperature for all the three layers which are 27°C, 5°C and 2°C respectively. Considering the salinity increases to 0.045 ppt for Mixed layer shown in Figure 14, for Thermocline in Figure 15, and Deep layer from the Figure 16 it is shown to be 0.5 ppt and 0.3 ppt. All formula shows a positive rise in the average speed of sound. In Mixed layer the rise in average speed is +0.049 m/s to +0.068 m/s were Mackenzie and Medwin shows a positive arise of +0.049 m/s (0.0033%) Leroy and Wilson shows a very high effect around +0.059 m/s (0.00398%) and +0.068 m/s (0.00441%) although this time Coppens has the lowest impact which is +0.049 m/s (0.00185%). The effect of salinity is still negligible. In Thermocline layer with a increase salinity variation the domination increases. The average speed rise for all formula is still positive and it is around 0.73 m/s to 0.90 m/s. Mackenzie shows +0.75 m/s (0.05%) , Medwin it is +0.73 m/s (0.048%) and for Leroy, Wilson , Coppens and Chen-Millero it is correspondingly +0.82 m/s (0.055%), +0.90 m/s (0.058%), +0.70 m/s (0.026%) and +0.78 m/s (0.053%). The salinity effect is still less then temperature cannot be ignored. Lastly, for Deep layer the variation is just 0.3 ppt but its influence is noticeable for increase of the speed of the sound. The all formula still shows a positive increase from +1.20 m/s to +1.35 m/s, where Mackenzie, Leroy, Wilson Coppens and Chen-Millero are respectively +1.20m/s (0.08%), +1.28 m/s (0.087%), +1.35 m/s (0.089%), +1.15 m/s (0.043%) +1.30 m/s (0.085%) so we can say Mackenzie has the least effect and Wilson has the highest effect. Comprehensively, the salinity effect increases layer by layer.

5 Discussion

In this study, we have systematically analyzed the effect of three environmental parameters which are temperature, depth, and salinity.The effects of these parameters on the acoustic signal for three ocean layers are demonstrated using different empirical formulas.Each formulas compute mean speed of sound considering the ranges of deep-ocean conditions. After considering the different empirical formulas and all the parameters the calculated the average speed for the empirical formulas which satisfied the simulation range and got the mean average sound speed around 1526.71 m/s to 1560.14 m/s for all three oceanic layers and for practicality we introduced Gaussian noise with a mean 0 and standard deviation for 100 iterations.For the computation of average sound speed triple integral method was considered. In TABLE.3 a detailed interpretation of this research work has been presented. The three prime oceanic layers-the 'Mixed Layer', 'Thermocline Layer', and 'Deep Layer'-have been observed to estimate the variation in mean sound speed and each layer has its own range of the environmental parameter which has been demonstrated in TABLE.2. Each layer displays a unique response to the major environmental variables: temperature , depth, and salinity.The effects of these parameters depend on difference between each layer range and also upon different empirical formulas including Mackenzie , Medwin, Leroy, Wilson, Coppens and Chen-Millero. The TABLE.3 highlights the amplititude of changes in average speed of sound due to gradual variation on the values of temperature, depth and salinity.

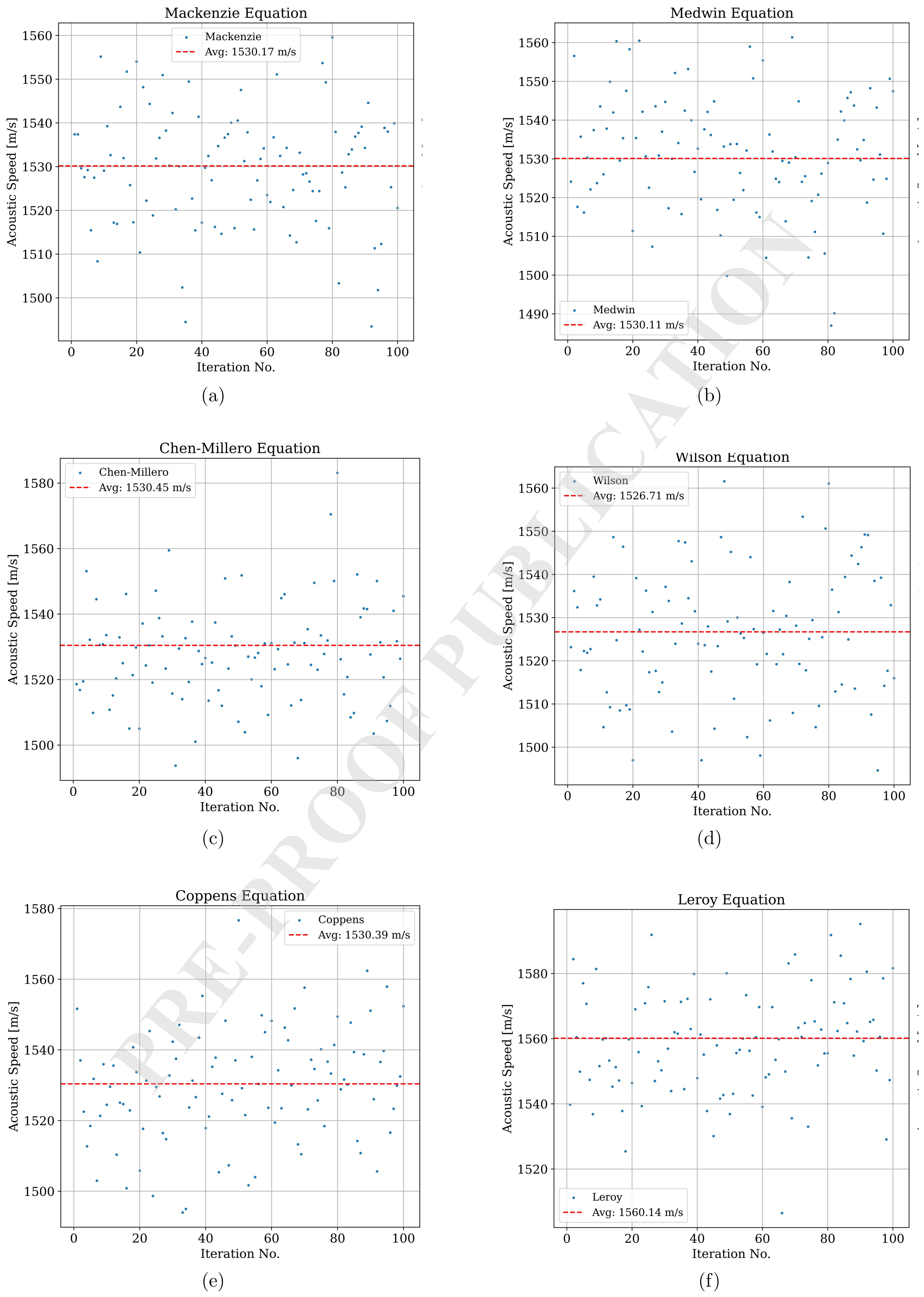


Figure 5: Average sound speed variation for Mixed layersc:a)Mackenzie , b) Medwin , c) Chen-Millereo , d) Wilson , e) Coppens f) Leroy

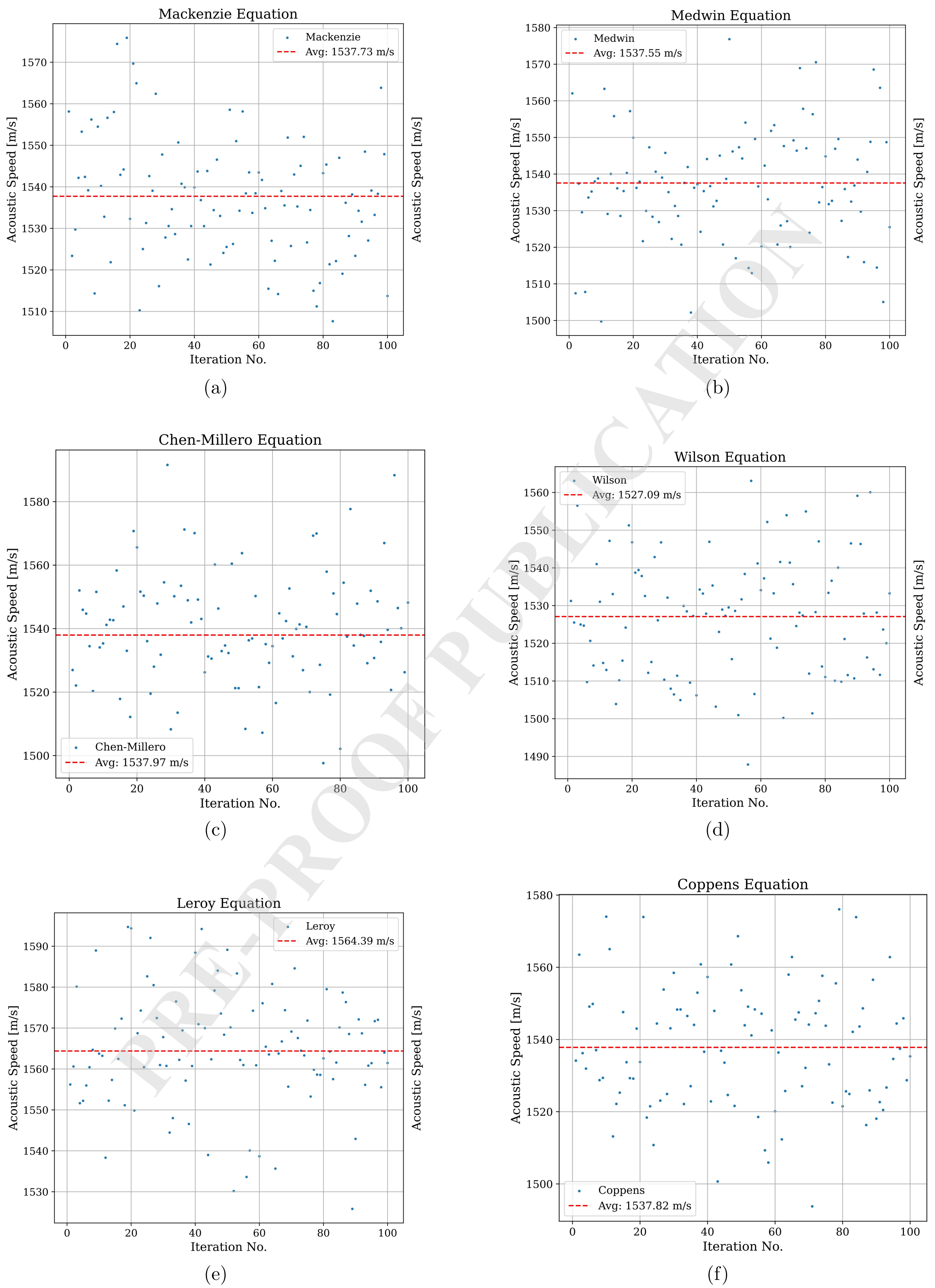


Figure 6: Average sound speed variation for Thermocline layersc:a)Mackenzie , b) Medwin , c) Chen-Millereo , d) Wilson , e) Leroy, f) Coppens

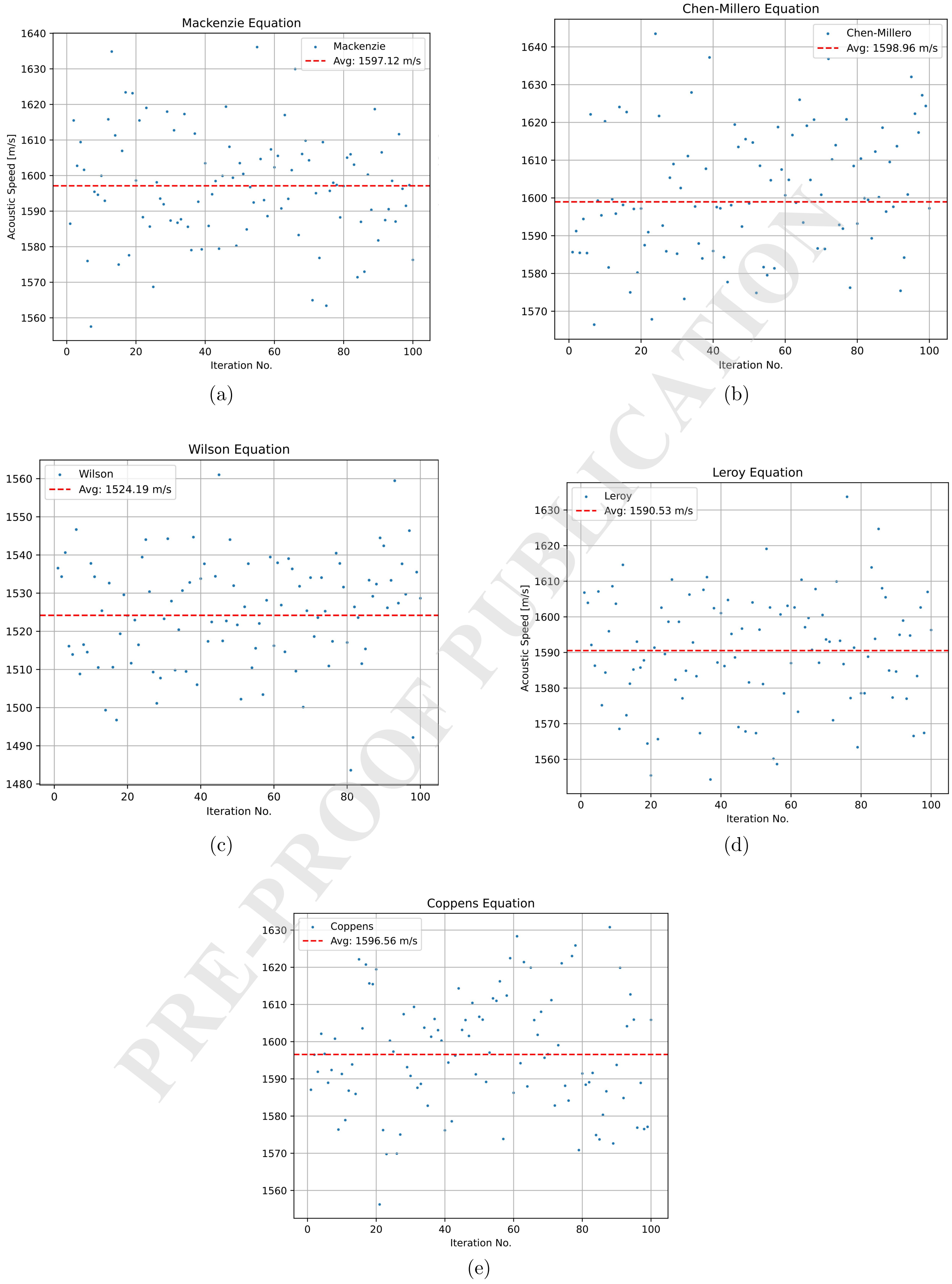


Figure 7: Average sound speed variation for Deep layersc:a)Mackenzie , b) Chen-Millereo , c) Wilson , d) Leroy, e) Coppens

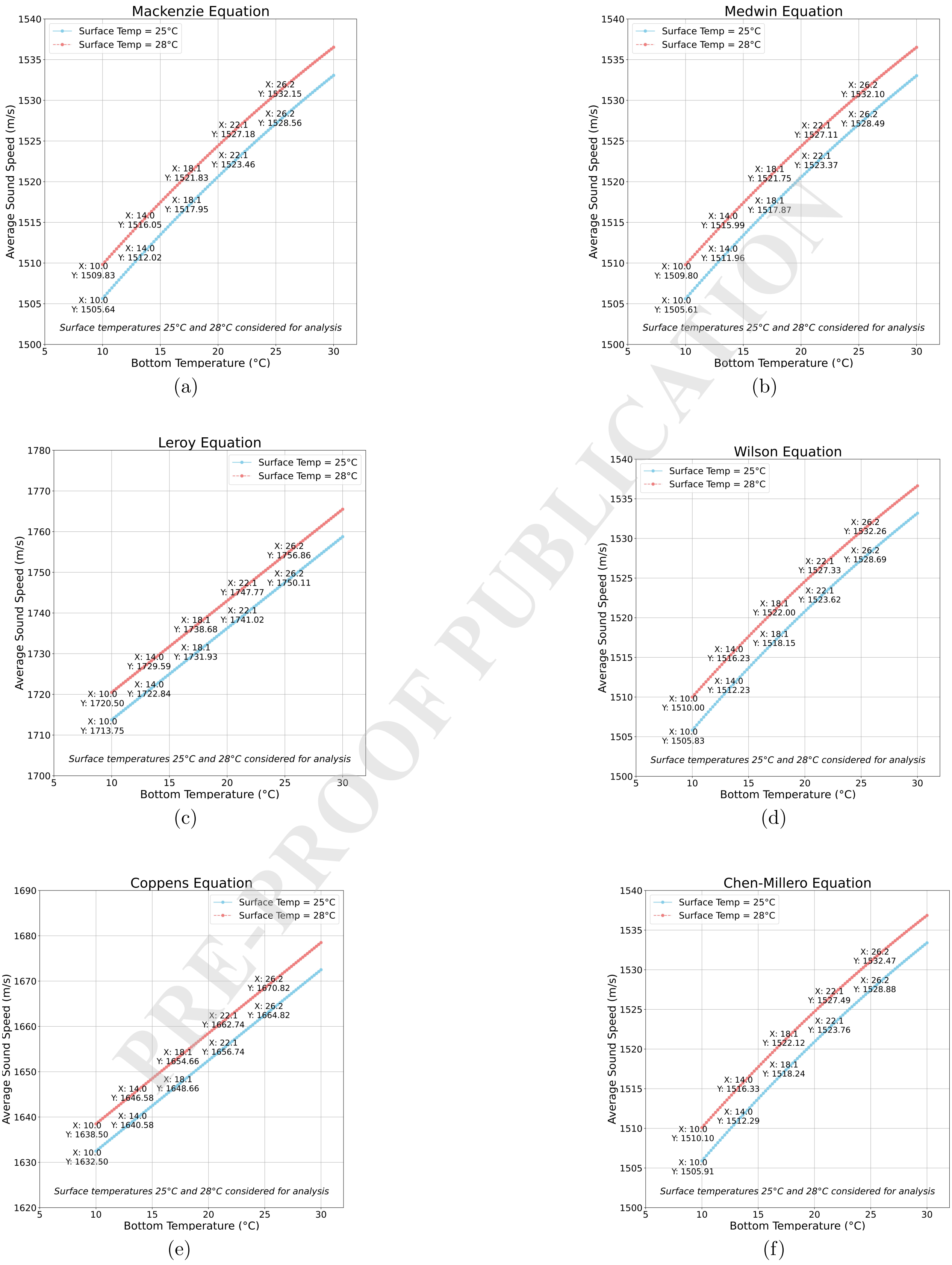


Figure 8: Average sound speed variation due to temperature changes for Mixed layers: (a) Mackenzie, (b) Medwin, (c) Leroy, (d) Wilson, (e)Coppens , (f) Chen-Millero .

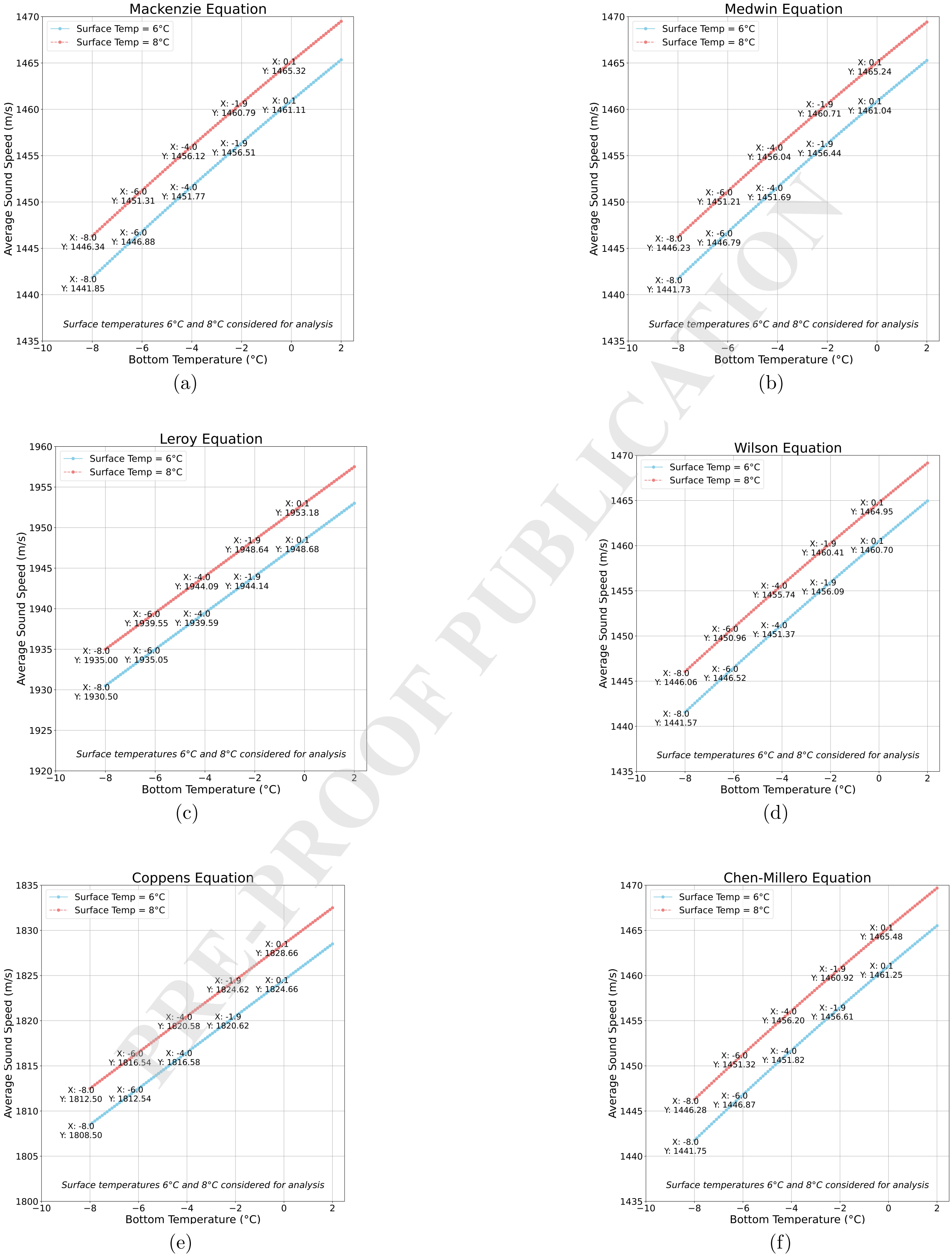
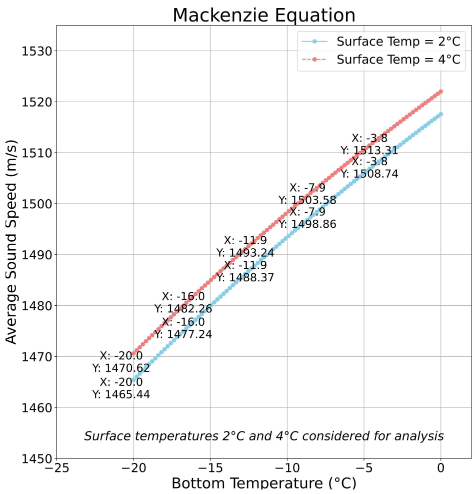
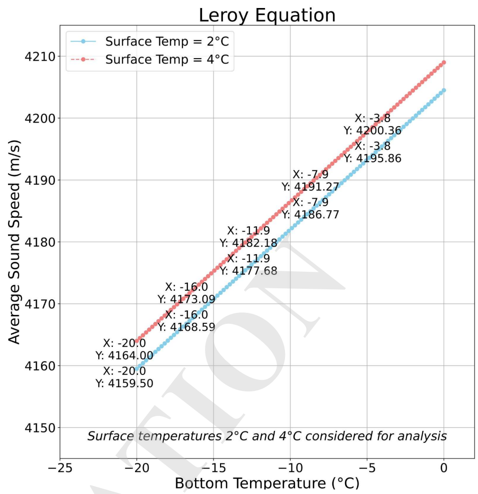


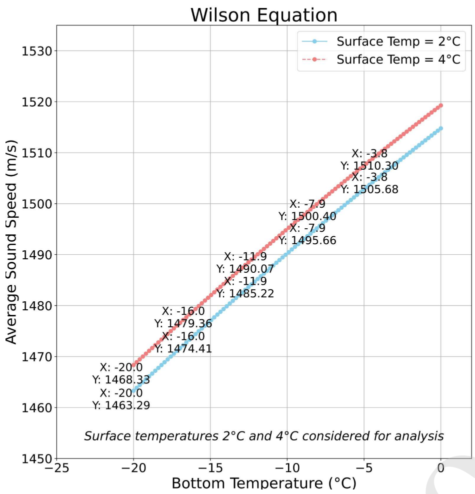
Figure 9: Average sound speed variation due to temperature changes for Thermocline layers: (a) Mackenzie, (b) Medwin, (c) Leroy, (d) Wilson, (e)Coppens , (f) Chen-Millero .



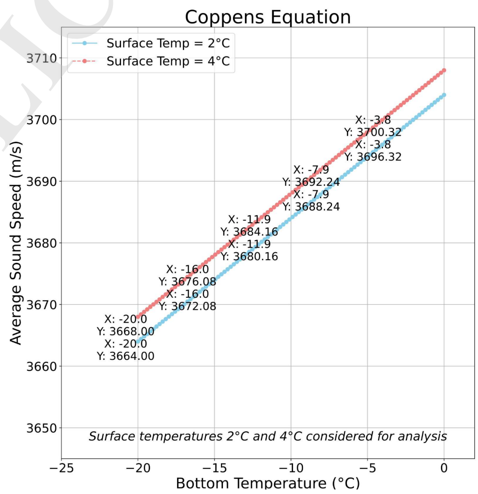
(a)



(b)



(c)



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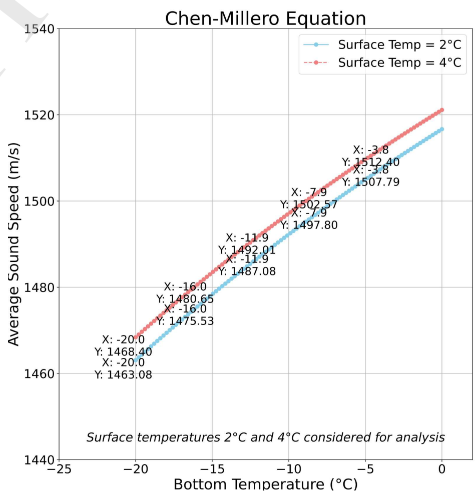


(e)

Figure 10: Average sound speed variation due to temperature changes for Deep layers: (a) Mackenzie, (b) Medwin, (c) Leroy, (d) Wilson, (e)Coppens , (f) Chen-Millero .

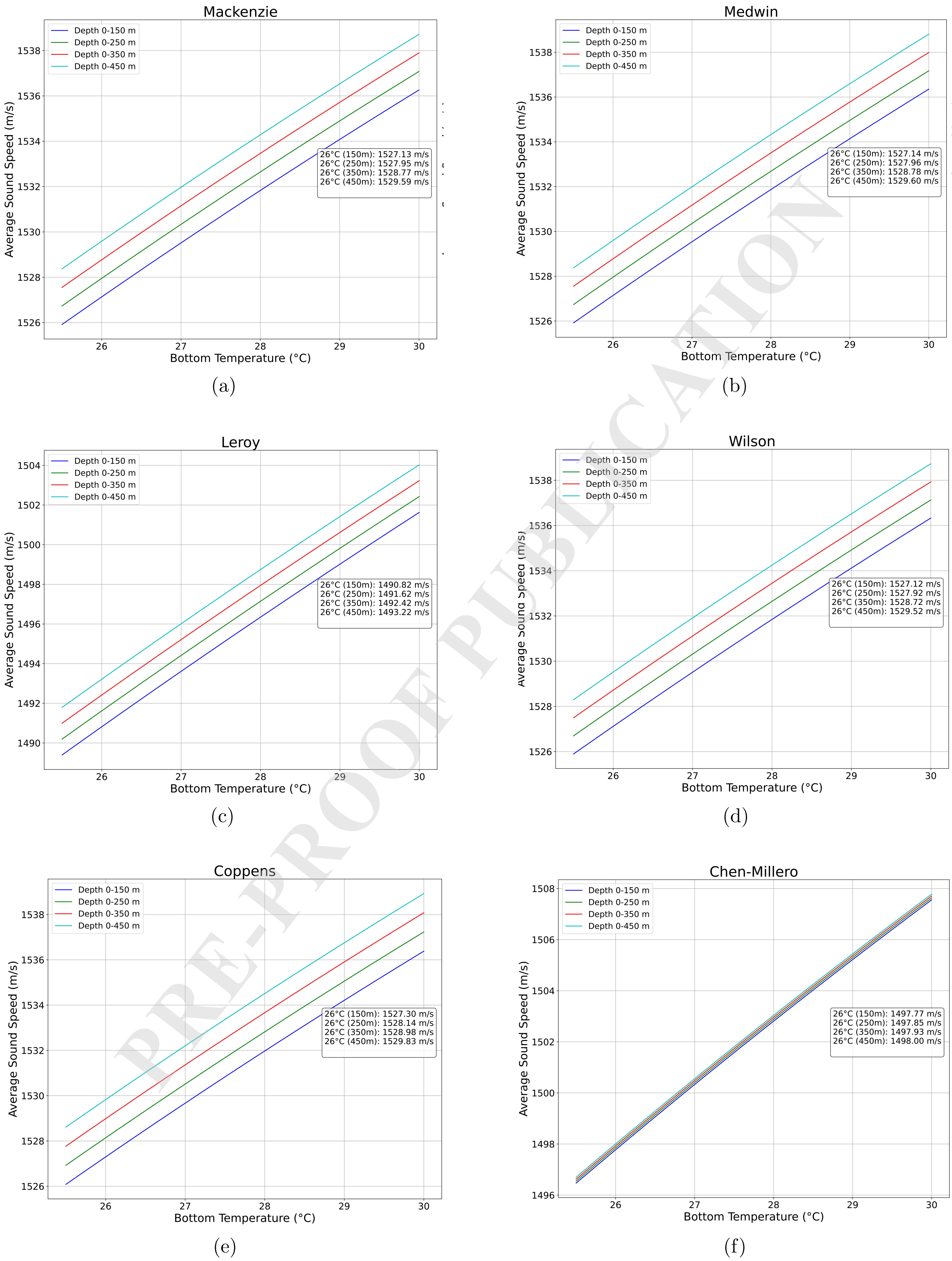
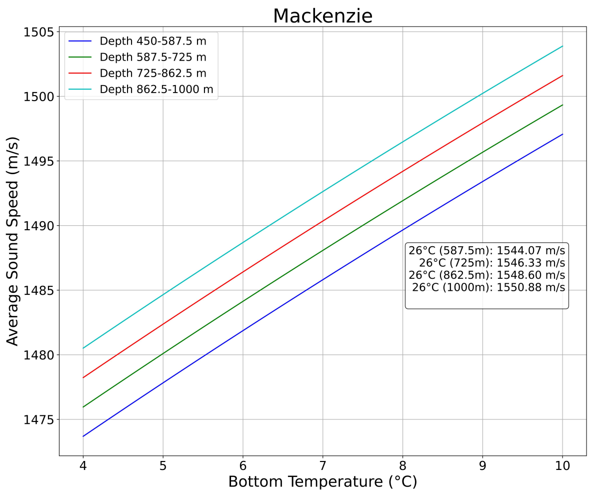
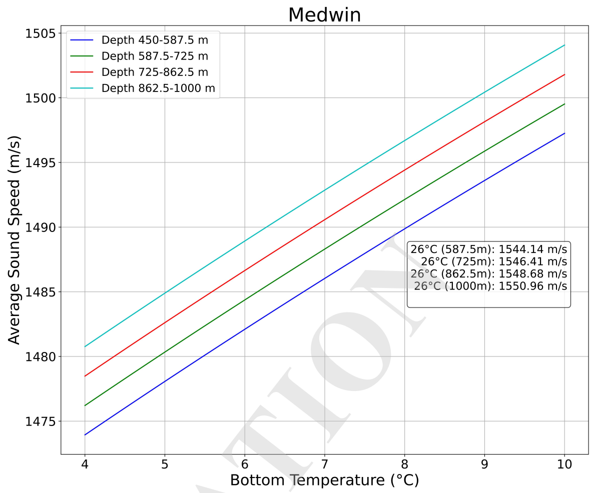


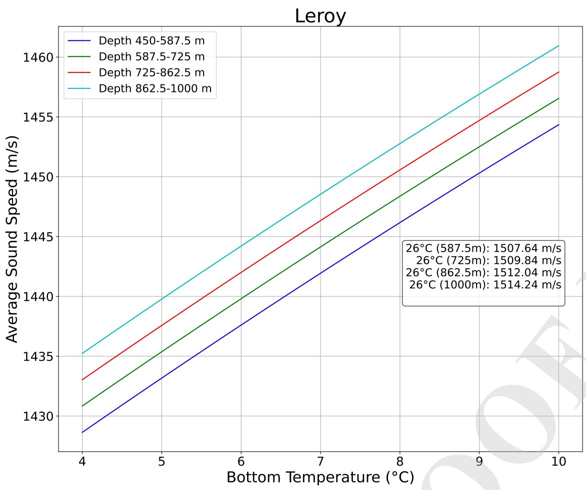
Figure 11: Average sound speed variation due to depth changes for Mixed layers: (a) Mackenzie, (b) Medwin, (c) Leroy, (d) Wilson, (e)Coppens , (f) Chen-Millero .



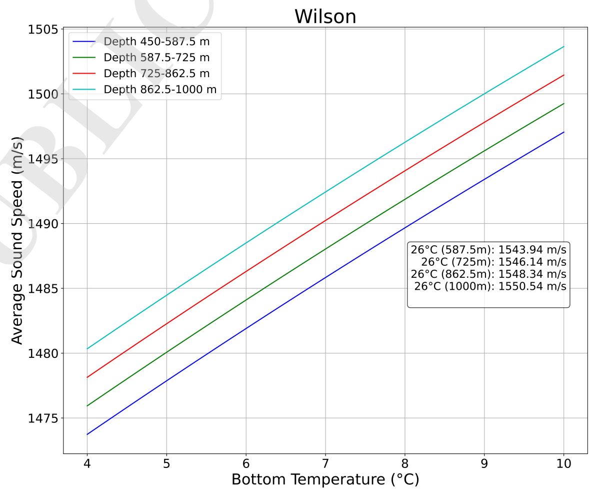
(a)



(b)



(c)



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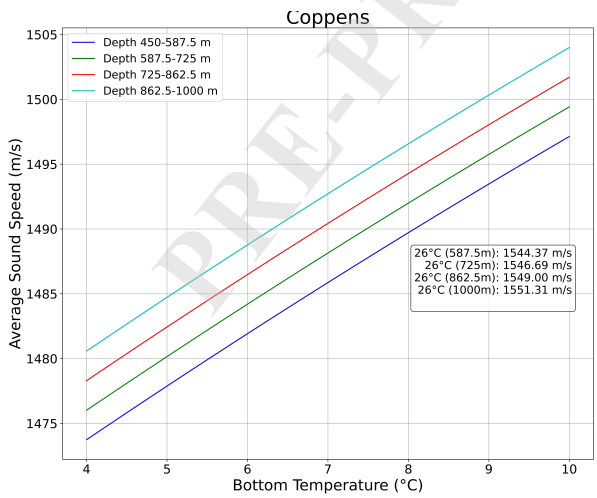
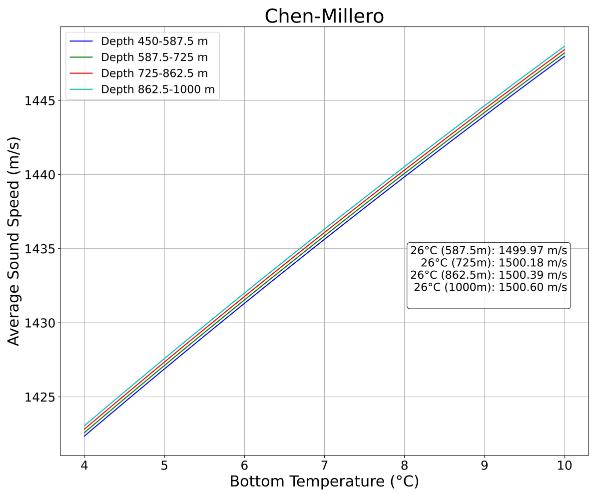


(e)



(f)

Figure 12: Average sound speed variation due to depth changes for Thermocline layers: (a) Mackenzie, (b) Medwin, (c) Leroy, (d) Wilson, (e)Coppens , (f) Chen-Millero .

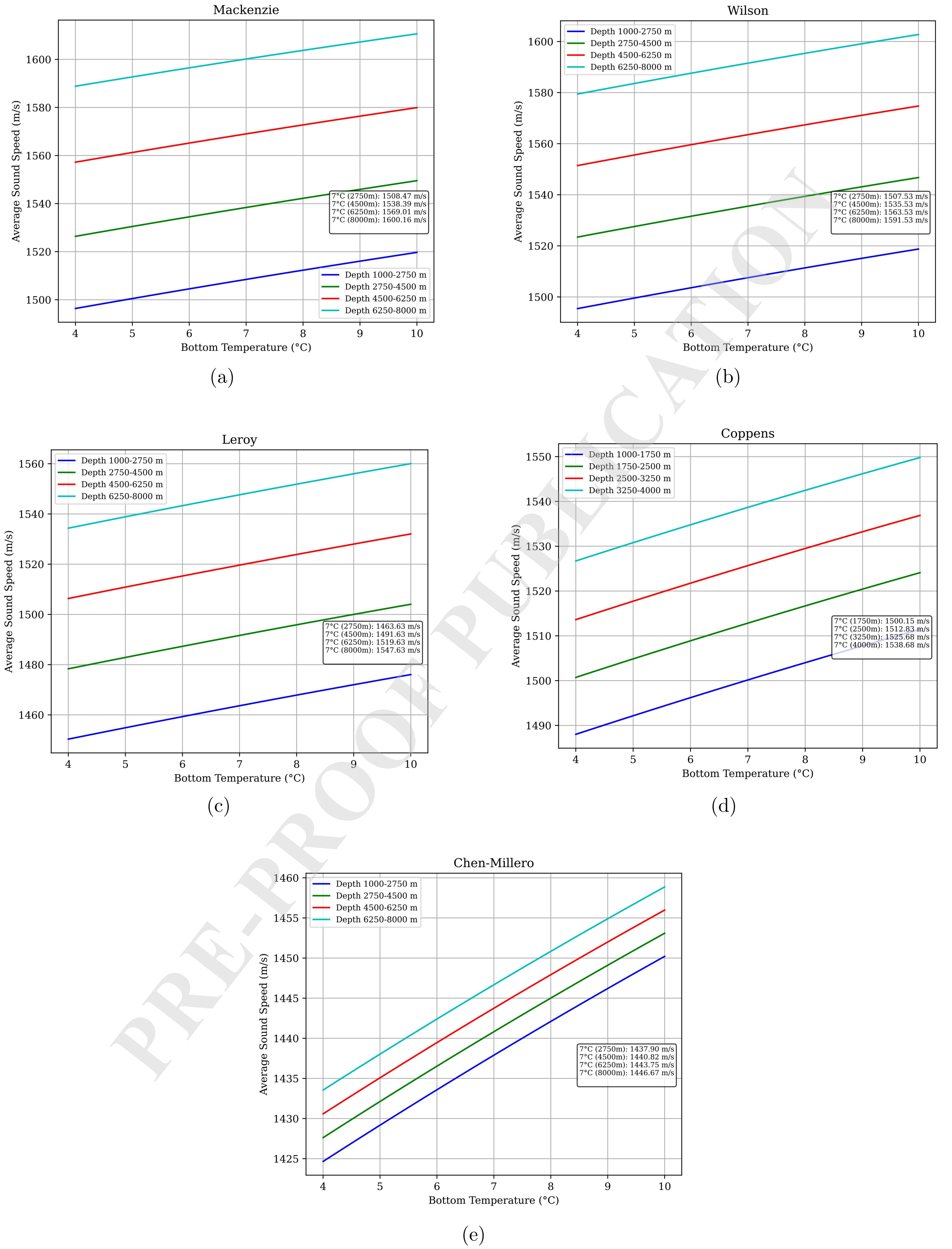


Figure 13: Average sound speed variation due to depth changes for Deep layers: (a) Mackenzie, (b) Medwin, (c) Leroy, (d) Wilson, (e)Coppens , (f) Chen-Millero .

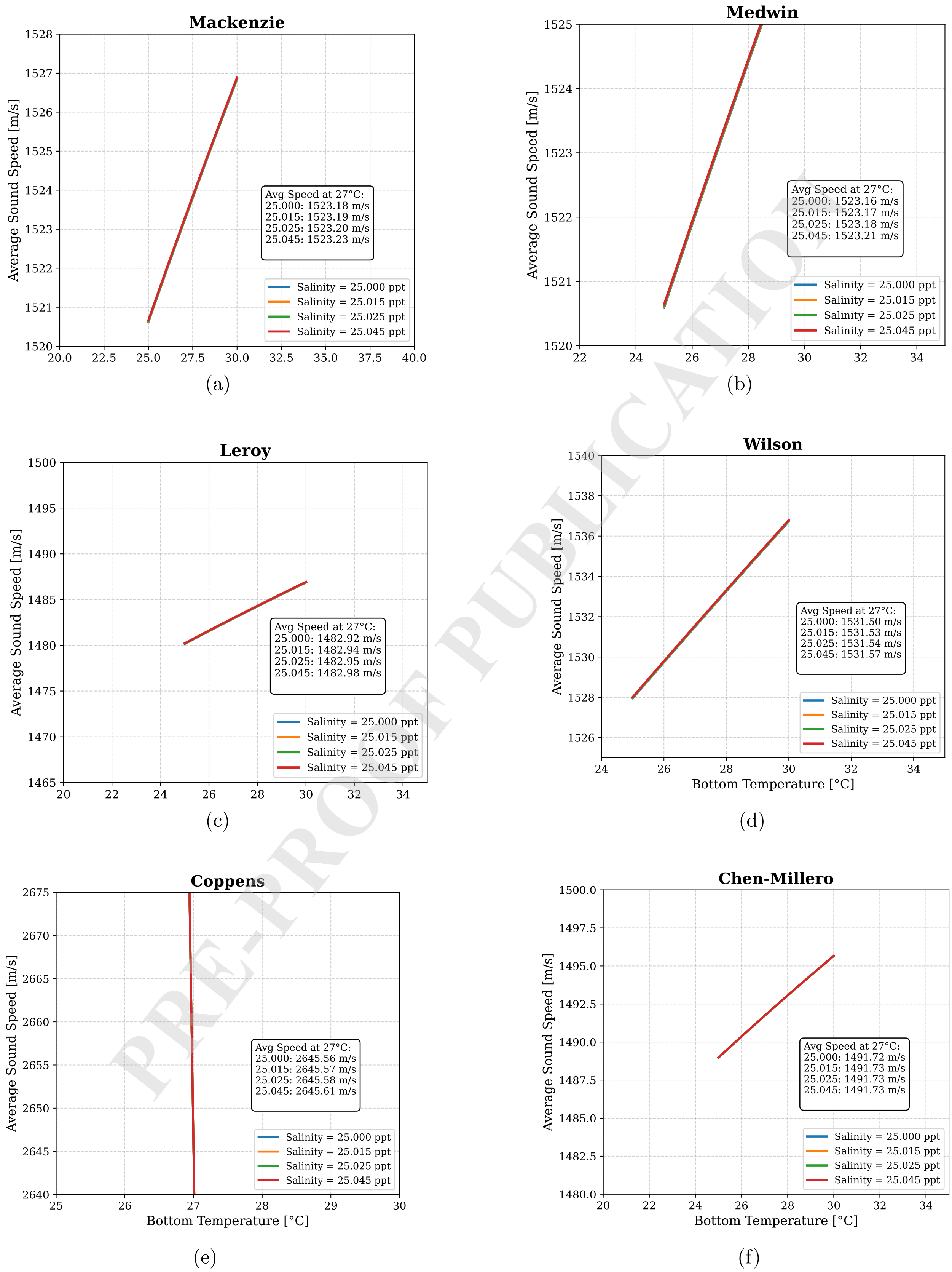


Figure 14: Average sound speed variation due to Salinity changes for Mixed layers: (a) Mackenzie, (b) Medwin, (c) Leroy, (d) Wilson, (e)Coppens , (f) Chen-Millero .

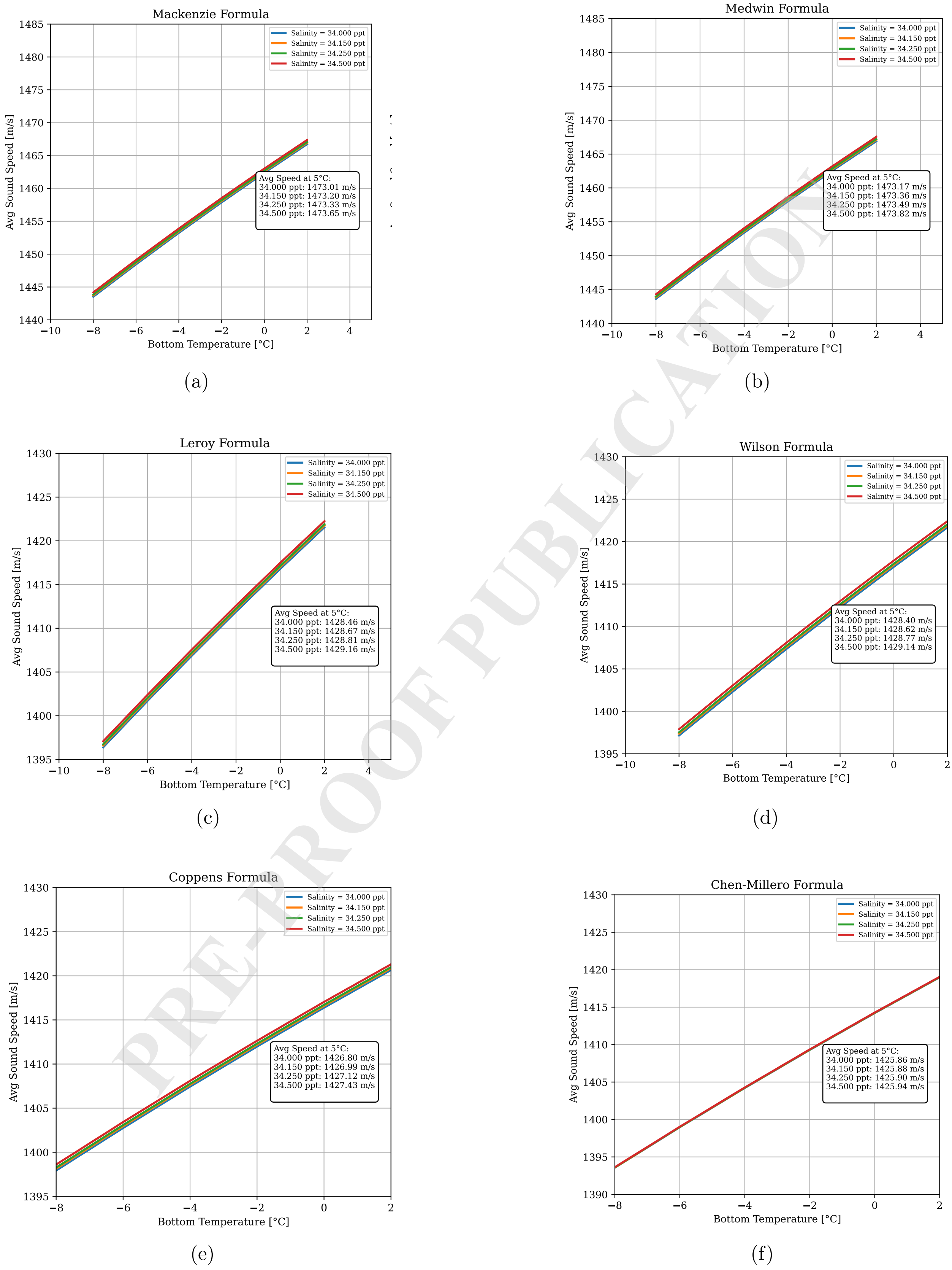


Figure 15: Average sound speed variation due to Salinity changes for Thermocline layers: (a) Mackenzie, (b) Medwin, (c) Leroy, (d) Wilson, (e)Coppens , (f) Chen-Millero .

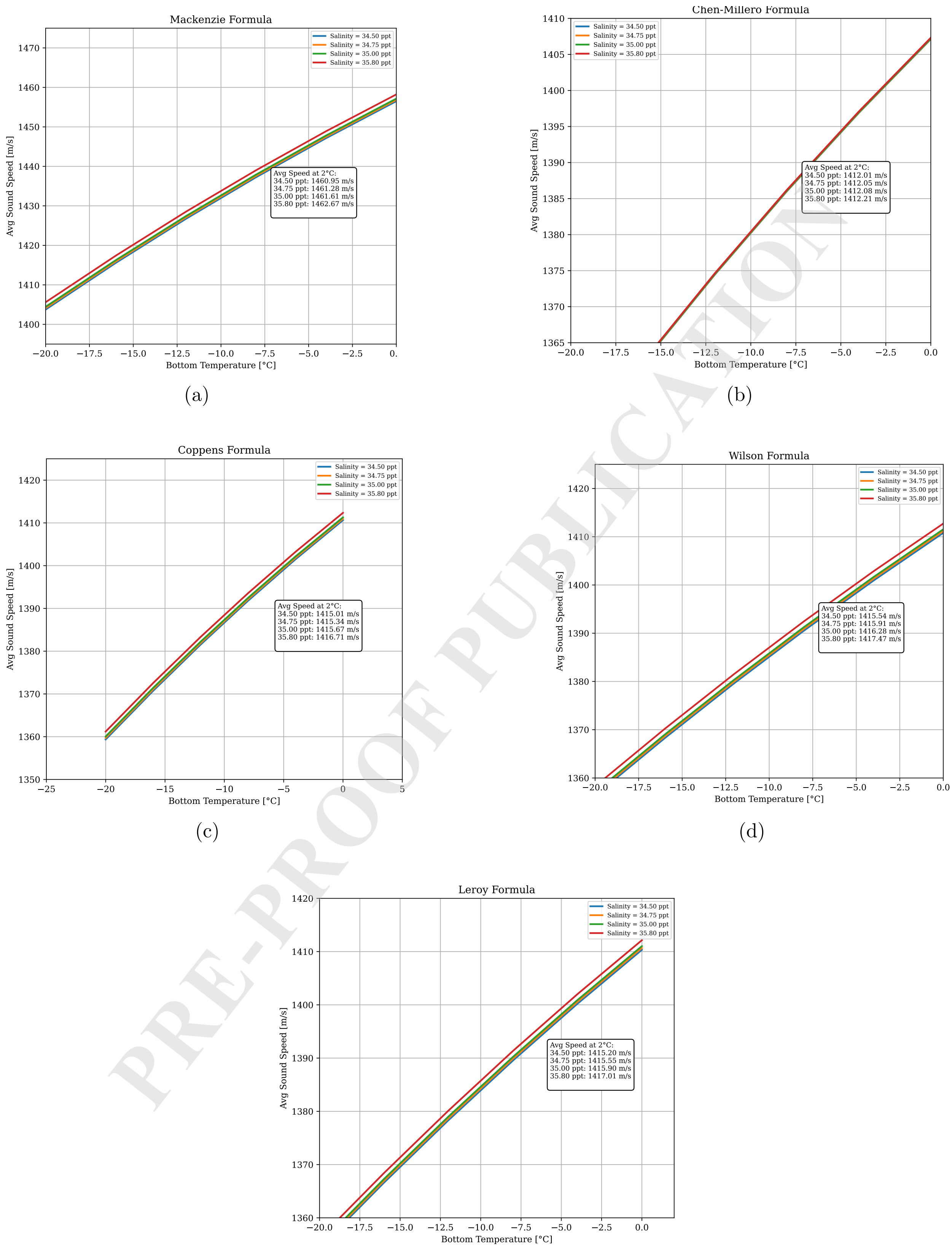


Figure 16: Average sound speed variation due to Salinity changes for Deep layers: (a) Mackenzie, (b) Medwin, (c) Leroy, (d) Wilson, (e)Coppens , (f) Chen-Millero .

Table 3: Analysis of Environmental parameter influence on Oceanic Layers

Oceanic Layer	**Temperature Effect**	**Depth Effect**	**Salinity Effect**	**Constrain effect on formulas**	**Parameter Role**
Mixed Layer	1°C rise in the temperature can cause a significant impact on the average speed around 2.0 m/s to 2.5 m/s	10 m rise can cause the arise of average sound speed is only 0.08 m/s to 0.085 m/s	Salinity has a minimal effect of only 0.049 m/s to 0.068 m/s for variation of 0.045 ppt.	The Mackenzie and Medwin formulas shown a high sensitivity in the Mixed layer where temperature effect is around 0.32%.	Mixed layers temperature is the most domination parameter among them and depth and salinity effect can be ignored as they influence the speed just 0.04% and 0.003%
Thermocline Layer	1°C rise in the temperature cause fluctuation on average speed around 1.5 m/s to 2 m/s	10 m rise can cause the arise of average sound speed is only 0.16 m/s to 0.166 m/s	Salinity effect is only 0.73 m/s to 0.90 m/s for a variation of 0.5 ppt	In Thermocline layer, formulas like Wilson, Leroy and Coppens shows sensitivity to all parameters like for temperature it is 0.3% and for depth is 0.05% (specially for Wilson)	In Thermocline layer temperature effects starts to fall and slowly around 0.5 m/s, depth and salinity started to influence the speed more the increment can be shown almost 0.8 m/s and 0.3 m/s
Deep Layer	1°C temperature hikes the average speed is just 1.0 m/s to 1.2 m/s	10 m rise in depth causes a change in average speed is 4.8 m/s to 5.3 m/s	salinity is 1.20 m/s to 1.35 m/s for a small variation of 0.3 ppt	Mackenize, Coppens and Chen-Millero shows a sensitivity and this time is for depth around 0.6	Deep layer temperature is considered as the weakest impact and depth has the highest effect around 0.6% and salinity effect also increase to 0.01% which is higher than the temperature effect of 0.001%

6 Conclusion

This work has drawn attention to the fact that the three main environmental parameter has different effect on acoustic sound speed based on the oceanic layer. When the signal passes from the layer close to surface, it has the maximum effect due to temperature and salinity effect can be ignored but as we start thinking of going deeper the temperature effects gradually falls and other two parameter which are depth and salinity effect began to increase in the deepest of the ocean. The sound seed is very sensitive to depth and temperature and depth effect becomes same and also minimal. This understanding can be crucial for deploying and developing underwater communication networks much more effectively as this ecological variation can introduce unpredictable noise which will also bring an effect on the speed, direction, supervision and the timing of the marine communication and can also helps in the development of more optimization sonar and navigation algorithms.

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Authors' contributions

Khondoker Munim Salehin contributed in experimental data analysis and manuscript drafting. Md. Khalid Mahbub Khan contributed in manuscript writing, modeling, and also in conceptualization. Dr. Anisur Rahman supervised as well as conceptualized the entire research.

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