Fisheries Journal, 15 (2), 668-678 (2025)
http://doi.org/10.29303/jp.v15i2.1400

COMPARATIVE ANALYSIS OF WATER COLUMN TEMPERATURE USING SEISMIC INVERSION AND *WORLD OCEAN ATLAS* (WOA) METHODS IN WAIPOGA WATERS, PAPUA

Analisis Perbandingan Suhu Kolom Perairan Menggunakan Metode Inversi Seismik Dan *World Ocean Atlas* (WOA) Di Perairan Waipoga, Papua

Dias Kusdiana[1*], Henry Munandar Manik[1], Tumpal Bernhard Nainggolan[2], Yulinar Firdaus[3]

[1]Department of Marine Science and Technology IPB University, [2]Geological Resources Research Center BRIN Bandung, [3]Center for Marine Geological Survey and Mapping KESDM Bandung

[*]Corresponding Author: 581diaskusdiana@apps.ipb.ac.id

(Received February 3th 2025; Accepted April 27th 2025)

ABSTRACT

Seismic oceanography is a combination of earth sciences consisting of seismic science and oceanography. Phenomena in the water column can be studied using seismic oceanography. One of them is measuring the temperature in the water column. This study aims to analyze the differences in water column temperature measurements using the seismic inversion method and temperature measurements using data from the World Ocean Atlas (WOA). To process the data, several software are needed, including ProMAX 2D for processing seismic data, Hampson-Russell for processing synthetic seismograms, and Ocean Data View and Matlab for processing temperature distributions. The average absolute error or Mean Absolute Error (MAE) is used as a criterion for the accuracy of the inversion temperature against observation data. The results of the temperature difference analysis show that the temperature obtained from measurements using WOA data shows a smaller value than the temperature measurement using the seismic inversion method. The results of temperature measurements using WOA data range from 27.5–29.4°C, and for inversion, range from 30.8–29.3°C. The verification results show good accuracy with the mean absolute error (MAE) value of WOA against seismic inversion ranging from 1.9–3.4°C.

Key words: Marine Acoustics, Seismic Inversion, Seismic Oceanographic, Stratification

ABSTRAK

Seismik oseanografi merupakan penggabungan ilmu bumi yang terdiri dari ilmu seismik dan ilmu oseanografi. Fenomena pada kolom perairan dapat dipelajari menggunakan ilmu seismik oseanogafi. Salah satunya yakni pengukuran suhu pada kolom perairan. Penelitian ini bertujuan untuk menganalisis perbedaan pengukuran suhu kolom perairan dengan menggunakan metode inversi seismik dan pengukuran suhu menggunakan data dari *World Ocean Atlas* (WOA). Untuk mengolah data diperlukan beberapa perangkat lunak diantaranya, ProMAX 2D untuk pengolahan data seismik, Hampson-Russell untuk mengolah seismogram sintetik, Serta *Ocean*

Data View dan MatLab untuk mengolah sebaran suhu. Galat mutlak rata-rata atau *Mean Absolute Error* (MAE) digunakan sebagai kriteria akurasi suhu hasil inversi terhadap data observasi. Hasil analisis perbedaan suhu menunjukkan bahwa suhu yang didapatkan dari pengukuran menggunakan data WOA menunjukan nilai yang lebih kecil dari pengukuran suhu menggunakan metode inversi seismik. Hasil pengukuran suhu menggunakan data WOA berkisar pada rentang 27,5–29,4℃ dan untuk inversi berkisar pada rentang 30,8–29,3℃. Hasil verifikasi menunjukkan akurasi yang cukup bagus dengan nilai galat mutlak rata-rata (MAE) WOA terhadap inversi seismic berkisar 1,9–3,4°C.

Kata Kunci: Akustik Kelautan, Seismik Inversi, Seismik Oseanografi, Stratifikasi

INTRODUCTION

Information on physical oceanographic parameters can so far be obtained through satellite imagery measurements, direct measurements in the field, and acoustic surveys. The structure of the water column needs to be known in an effort to study large-scale thermohaline circulation which is recognized to play an important role in global climate change. Thermohaline circulation has an important role as a driver of the world's climate because this circulation flows heat, oxygen, and other biochemical components (Groeskamp *et al*., 2016). Physical oceanographers usually investigate the fine structure of the ocean using vertical profiles of temperature and salinity (Nakamura *et al*., 2006).

Methods and technologies have been widely developed to study physical oceanographic parameters such as hydrographic methods using *Conductivity-Temperature-Depth* (CTD), *Expendable Bathythermograph* (XBT), mooring systems, profiling systems (eg *Argo drifter),* microstructures to measure turbulent mixing (Bouruet-Aubertot *et al*., 2018) and the use of remote sensing methods that utilize satellite imagery. In general, seismic reflections in the water column are considered noise *and* are therefore often not used (Adrianus *et al*., 2021). However, in the last decade, several studies have shown that the marine seismic reflection method can be used to study the water column and important information can be found in the water column reflection (Putra *et al*., 2022).

Seismic is an acoustic technology that uses low frequencies and has deep penetration (Lubis *et al*., 2017; Safitri *et al*., 2020). The principle of wave propagation can be used to identify subsurface conditions, this principle is used in the seismic method which is one of the methods of active geophysics (Buana *et al*., 2010). The seismic method can be divided into two methods, namely the seismic refraction method and the seismic reflection method. The differences in these methods are divided based on the propagation of the waves (Ustiawan *et al*., 2019). Determination of geological structures that have shallow depths can use seismic refraction while seismic reflection is for deep geological structures (Priyantari & Suprianto, 2009). Seismic oceanography uses low-frequency sound waves (1-100 Hz) emitted by *an air gun*. *The air gun* is a source of acoustic waves in marine seismics that spread from the surface of the sea then through the water column to the bottom of the water. At a certain distance, the hydrophone array will receive some of the emitted seismic waves. The reflection occurs because there is an acoustic impedance contrast. Information about the water column and the bottom of the water can be obtained from the received signal (Manik & Hadi, 2011).

Seismic oceanography provides a more detailed picture of the structure of the water column in a seismic section in a wide range. The seismic oceanography acquisition system allows for high lateral and vertical resolution of around 10 m (Biescas *et al*., 2008). So it is expected that this method provides another alternative in measuring parameters and 2 oceanographic physics processes and provides a new perspective on oceanographic processes. Quantitative information in the form of temperature and salinity values from seismic data inversion has been successfully obtained in several seismic oceanography studies. The difference in acoustic impedance between layers causes water column reflection so that seismic data inversion is possible because it is a product of the difference in sound speed and density, while sound speed and density are functions of temperature, salinity, and pressure (Ruddick *et al*., 2009). The accuracy of the inversion method based on several recent studies is quite accurate, the temperature ranges from 0.1 to 0.03°C and salinity ranges from 0.1 psu to 0.01 psu. Research on inversion of oceanographic seismic data in general in Indonesian waters is still very limited. In addition, the results of seismic inversion have not been widely used, such as to identify water column stratification. Therefore, this study aims to analyze the differences in water column temperature measurements using the seismic inversion method and measurements using data from *the World Ocean Atlas* (WOA).

RESEARCH METHODS

Time and Location of Research

Data processing was carried out from February–September 2024 at the Center for Marine Geological Survey and Mapping (BBSPGL) Bandung. Data acquisition was carried out by a research team from the Ministry of Energy and Mineral Resources. in 2018 using multichannel seismic survey equipment in Waipoga Waters, Papua. The seismic data used in the study was line-04. The research location map is presented in Figure 1.

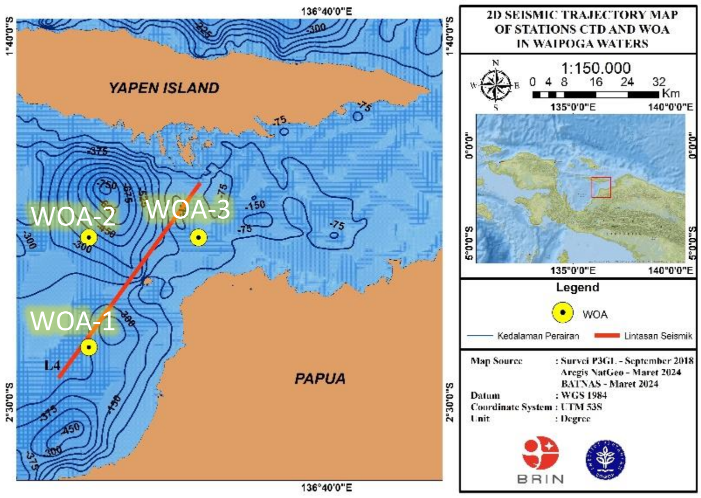

Figure 1. Research Location Map

Tools and materials

The materials used in this study include several data. The main data used are seismic field data in seg-d format . *Climatological* temperature and salinity data from *the World Ocean Atlas* version 2018 (WOA-18) from *the National Oceanic and Atmospheric Administration* (NOAA). The equipment used to process the research data consists of a computer equipped with several data processing software such as *ProMAX, SBE Data Processing, MatLab, Hampson-Russel, Ocean Data View, Arcmap, MS Excel* .

Data Acquisition

Data acquisition involved the use of an 800 in³ air gun to generate acoustic waves by firing compressed air into the water column at a sampling frequency of 2 ms. *The air gun* was fired at consistent intervals and depths. A Sercel 408XL hydrophone array with channels spaced 12.5 m apart received the reflected acoustic waves from the water column and the bottom. The channels used were located at a depth of 7 m and 100 m from the air gun. Data acquisition was carried out along the seismic line with the vessel moving at a speed of 5 knots. The seismic data acquisition setup is shown in Figure 2 (Minakov *et al*., 2017).

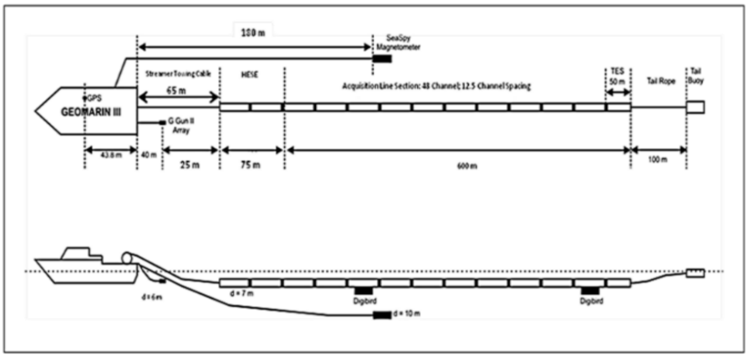

Figure 2. Marine Seismic Acquisition Scheme

Data processing

a. Synthetic Seismogram Processing

Synthetic seismograms were used to analyze the relationship between seismic data and WOA data. These data were processed using *Hampson-Russell Software* (HRS), which includes programs such as *GeoView*, *SeisLoader*, *Well Explorer*, *View 3D*, *eLog*, *AVO*, *EMERGE*, *ISMap*, *Pro4D*, *ProMC*, and *STRATA*. In this study, log data processing was performed using *GeoView* and *eLog*. *GeoView* serves as the log database and initial platform for other HRS programs, while *eLog* allows log manipulation such as editing, smoothing, and log correlation.

b. Temperature Distribution Processing

Ocean Data View (ODV) software. The process of creating a temperature distribution in ODV involves several steps: first, preparing a spreadsheet file with the extension*.txt, then creating a new worksheet in ODV, importing the spreadsheet, defining sections, and finally creating the temperature distribution.

c. Inversion of Seismic Data into Temperature and Salinity

Seismic data inversion is performed to determine the physical characteristics that cause reflection in the water column, in this case acoustic impedance as a function of the speed of sound and density. Seismic trace is the result of the convolution of the source wavelet with the reflection coefficient plus noise. According to Yilmaz (2001), for this matter, the following problem can be used:

$$T(i) = \sum_j r(j) * W(i - j + 1) + n(i) \qquad (1)$$

Where *r* is the reflection coefficient, *W* is the seismic *wavelet*, *n* is the noise, * is the convolution operator.

Seismic inversion can be interpreted as a process to determine the reflection coefficient value *r based on* seismic *wavelet* data *W*. The reflection coefficient in equation (1) is a manifestation of acoustic impedance *Z* with the following formulation:

$$R(j) = \frac{Z(j) - Z(j-1)}{Z(j) + Z(j-1)} \qquad (2)$$

By knowing the reflection coefficient value, the acoustic impedance value (Z) can be obtained. To obtain the acoustic impedance inversion value, an initial value is required which is obtained from the CTD data with the following formulation:

$$Z(j) = \rho(j) \times V(j) \quad \text{.....(3)}$$

Where ρ is the density (kg/m^3) and V is the speed of sound (m/s). The inversion of the speed of sound into temperature and salinity is based on the Leroy equation (1969) as follows:

$$C = 1492.9 + 3(T - 10) - 6 \times 10^{-3}(T - 10)^2 - 4 \times 10^{-2}(T - 18)^2 + 1.2(S - 35) - 10^{-2}(T - 18)(S - 35) + Z/16 \quad \text{.....(4)}$$

With C being the speed of sound (m/s), T being the temperature (°C), S being the salinity (psu), and Z being the depth (m). Next, equation (4) is transformed into a quadratic form $\mathrm{aT}^2 + \mathrm{bT} + \mathrm{c} = 0$as follows:

$$(-0.046)T^2 + (4.91 - 10^{-2} \times S)T \; (1.38 \times S + (Z/61) + 1401.04 - C) = 0 \quad \text{...(5)}$$

So the solution for the temperature value is:

$$T_{(1,2)} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \quad \text{.....(6)}$$

Where T is the temperature (°C), a, b, and c are the coefficients of the terms in the quadratic equation.

Accuracy of Inversion Method

The accuracy of the inversion method in this study uses the *Mean Absolute Error* (MAE) criterion, namely the average absolute difference between observation data and inversion data. In this study, the data used as a comparison is temperature data from CTD and WOA. This method is also used by Papenberg *et al.*, (2010) with the following formulation:

$$MAE = \frac{\sum_{n=1}^{N} |T_{obs}(n) - T_{inv}(n)|}{N}$$

Where $T_{obs}$is the observation temperature (°C), $T_{inv}$is the inversion temperature (°C), and N is the number of data used for the calculation.

RESULTS

WOA Temperature Measurement

The Waipoga Waters temperature from WOA data varies less vertically with a range of 27–29°C. The transverse profile of WOA temperature measurements is presented in Figure 3 and for the vertical graph can be seen in Figure 4.

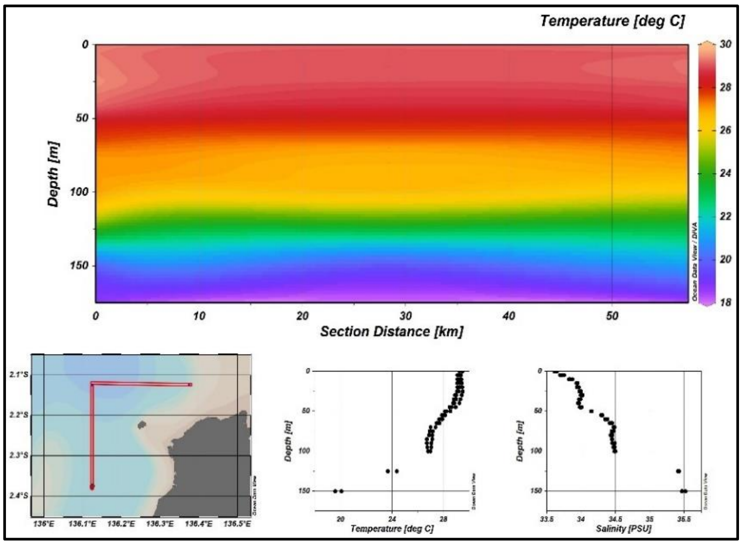

Figure 3. Transverse Profile of WOA Temperature

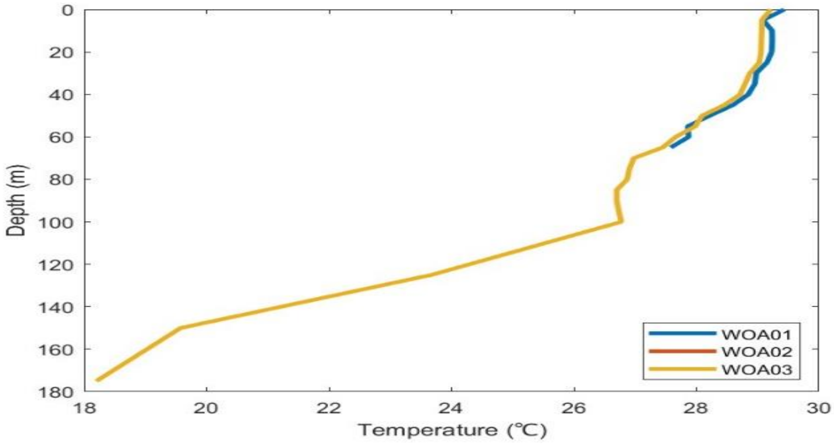

Figure 4. Vertical Graph of WOA Temperature

Inversion Temperature Measurement

The results of the inversion temperature measurements range from 30.8–29.3℃. The measurement results can be seen in Figure 5.

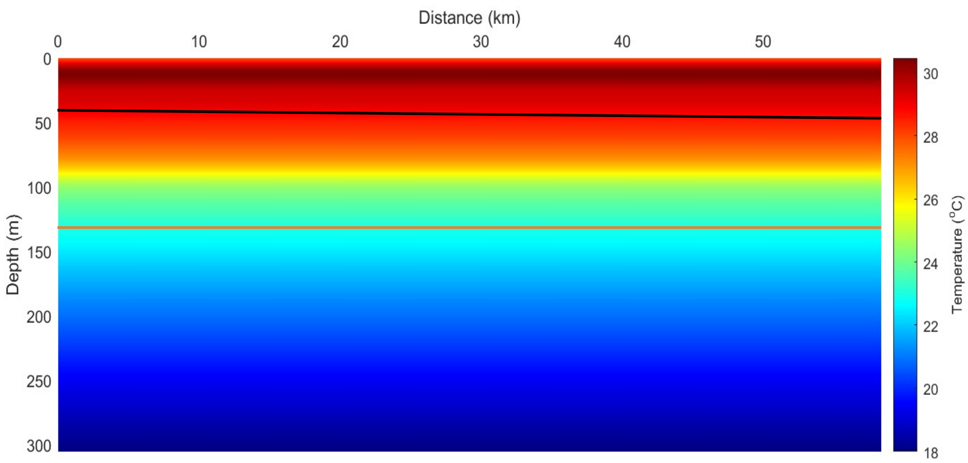

Figure 5. Transverse Profile of Temperature Result of Inversion

Temperature Comparison Between WOA and Inversion

The results of temperature measurements using WOA data range from 27.5–29.4℃ and for inversion range from 30.8–29.3℃. The comparison between the inversion temperature value and the WOA temperature value, overall shows that the inversion temperature value is slightly higher than the WOA temperature value. The temperature difference graph between WOA and inversion can be seen in Figure 6.

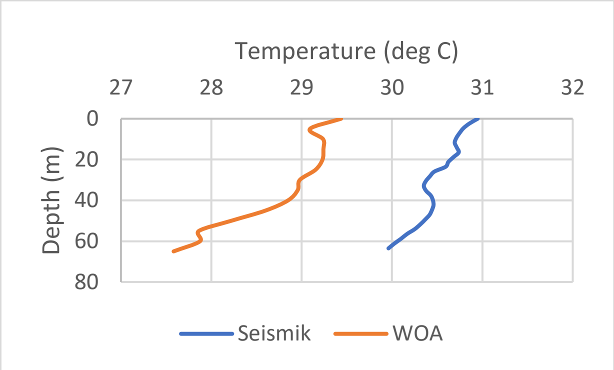

Figure 6. Comparison of WOA and Inversion Temperatures

MAE Verification Test

In the prediction process, *Mean Absolute Error* (MAE) can show the average absolute error that occurs in the process. The quality of the model can be determined from the magnitude of the MAE value. The smaller the value, the better. The absolute error value found on the seismic path has a value of 1.93 for WOA. While at the station point not located directly on the seismic path has a value range of 3.1–3.9 (WOA-2 and WOA-3). The results of the MAE verification test can be seen in Figure 7 for WOA-1 and Figure 8 for WOA-2 and WOA-3.

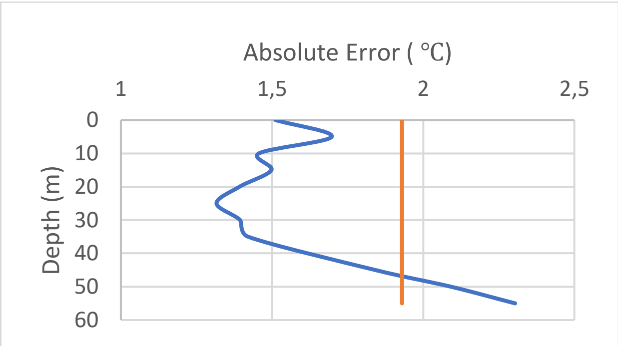

Figure 7 . Absolute Error WOA-1

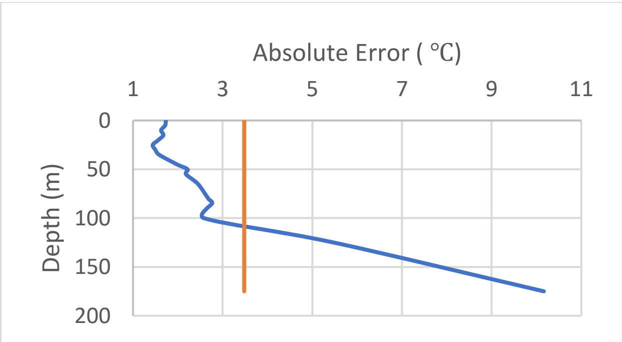

Figure 8. Absolute Error of WOA 2 and 3

Acoustic Impedance

The acoustic impedance ranges from 105.3–139.8 ((ft/s)*(g/cc)). As shown in Figure 9.

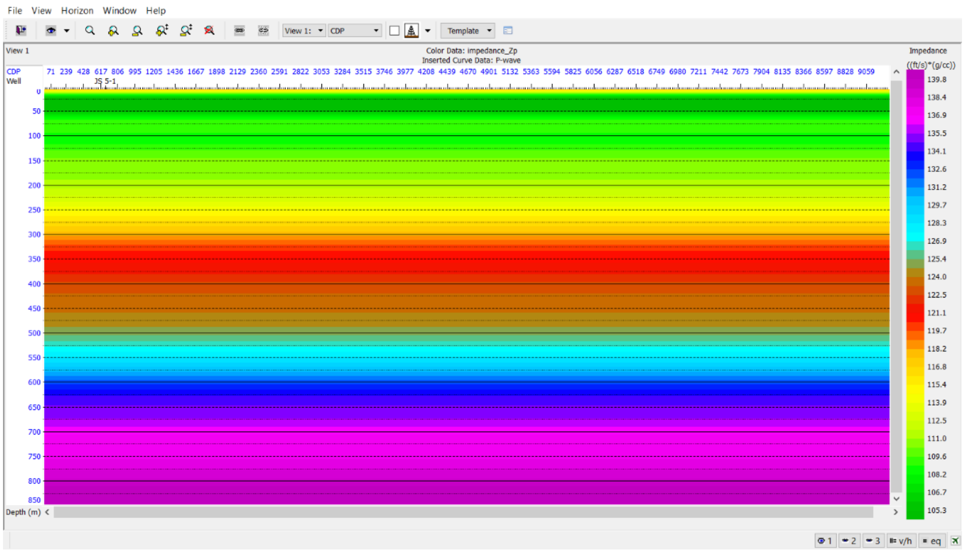

Figure 9. Acoustic Impedance

DISCUSSION

The Eastern Waters of Indonesia have unique oceanographic properties because the waters above them are influenced by the monsoon wind system which varies seasonally and in the waters there is a mass of water from the Pacific Ocean to the Indian Ocean known as ARLINDO or the Indonesian Throughflow (Ejha *et al*., 2017). According to Siadari *et al*., (2017) and Yuza *et al*., (2020), the dynamics and variability of the Waipoga Waters (including the Cendrawasih Bay waters) are more influenced by the presence of the western Pacific Ocean which is located near the equator. Seasonal variations in the monsoon winds clearly affect ocean currents, which are caused by changes in wind direction on the surface of the northern sea of Papua. In addition, the trade winds that move predominantly westward throughout the year also contribute, making the northern waters of Papua a warm water pool of the Western Pacific Ocean with an average sea surface temperature above 28°C (Deckker, 2016). The variability of physical parameters in the Papua region such as zonal currents, transport volume, temperature and salinity can also be influenced by the *El Nino Southern Oscillation* (ENSO) phenomenon (Zhang *et al*., 2020). The temperature of Waipoga Waters from WOA data varies less vertically with a range of 27–29°C. Based on vertical temperature, it is divided into two layers, namely the mixed layer *and* the thermocline layer . The mixed layer is formed at a depth of 0–50 m with a temperature of around 30°C and tends to be homogeneous due to the mixing of water masses due to the influence of wind, currents, and tides. The base of the mixed layer is the thermocline layer, which is the layer between the warm water mass on the surface and the colder water mass below. The thermocline layer is formed starting from a depth of 50–100 m with a temperature difference of 5.1–12.5°C every 100 m or 0.05°C per meter. Based on the results of temperature inversion in Figure 5, the water column layer is divided into two parts, namely the mixed layer and the thermocline layer. The two layers are divided by two boundary lines, namely the mixed layer boundary (black) and the thermocline layer boundary (red line). The temperature value in the mixed layer ranges from 28.4–30.9°C on the surface and decreases to 27.9°C at the lower limit of the mixed layer depth with an average of 29.4°C. The temperature profile shows that the thermocline layer depth pattern is inversely proportional to the mixed layer depth. This is because when the surface layer is not mixed by the process on the surface, the temperature will rapidly decrease with depth. The temperature value in the thermocline layer ranges from 18.94–27.9°C on the surface and decreases to 17.8°C at the lower limit of the mixed layer depth with an average of 21.74°C.

The results of temperature measurements using WOA data range from 27.5–29.4℃ and for inversion range from 30.8–29.3℃. The comparison between the inversion temperature value and the WOA temperature value, overall shows that the inversion temperature value is slightly higher than the WOA temperature value. This is because the WOA temperature and salinity data used in the inversion are average data for September so that the values will not be exactly the same as the data at the time of seismic data acquisition. According to Tang *et al*., (2016), there is uncertainty *when* converting from the time domain to the depth domain which results in a difference between the inversion depth and the actual depth which affects the difference in temperature values. In addition, WOA data is a climatological average which will cause the loss of high-frequency components (seen from the *smooth temperature profile against depth*) while in the inversion data, there are still high-frequency components. *Mean Absolute Error* (MAE) is an evaluation method that is often used in data science. This method calculates the average absolute difference between the predicted value and the actual value. In simple terms, MAE shows the average absolute error that occurs in the prediction process. The smaller the MAE value, the better the quality of the model. Figure 7 shows the absolute error profile against depth at the WOA data point that is right on the seismic track (WOA-1), while Figure 8 shows the absolute error profile against depth at the WOA data point that is near the seismic track. The absolute error value found on the seismic track has a value of 1.93 for WOA. While at the station point not right on the seismic track has a value range of 3.1–3.9 (WOA-2 and WOA-3). Based on these error values, it can be seen that the inversion method has difficulty finding the right inversion value. In seismic oceanography studies, the impedance layer reflects the thermohaline structure. Acoustic impedance is the ability of rocks to pass seismic waves (Hijria & Danusaputro, 2016). For Waipoga waters, acoustic impedance ranges from 105.3–139.8 ((ft/s)*(g/cc)). As shown in Figure 9, the impedance value is relatively low (green) in the 0–150 m layer and increases with depth, becoming higher (purple). According to Sinha (2016) Layers with lower acoustic impedance are caused by less temperature and salinity variations in the layer. Buffet *et al*., (2017), said that reflection in the water column is caused by differences in sound speed impedance which is influenced by temperature and salinity. Errors in the inversion process can occur if the CTD data is not taken exactly at the seismic line location. (Firdaus *et al*., 2021).

CONCLUSION

The results of the temperature difference analysis show that the temperature obtained from measurements using WOA data shows a smaller value than the temperature measurement using the seismic inversion method. The results of temperature measurements using WOA data range from 27.5–29.4℃ and for inversion range from 30.8–29.3℃. The absolute error value found on the seismic path has a value of 1.93 for WOA. While at the station point not located right on the seismic path has a value range of 3.1–3.9 (WOA-2 and WOA-3). Based on these error values, it can be seen that the inversion method has difficulty finding the right inversion value. Based on the test results, it can be concluded that if a station point is further away from the seismic path line, the resulting *error error will be greater*.

ACKNOWLEDGEMENTS

The author would like to thank the National Research and Innovation Agency for providing facilities and research sample data that were very helpful in the process of this research. In addition, the author also expresses his deep gratitude to the supervisors who have provided support, suggestions, and constructive input, as well as effective strategies, so that the author can complete this paper.

REFERENCES

Adrianus, A., Manik, H.M., & Nainggolan, T.B. (2021). Atenuasi Derau Acak dan Koheren Pada Data Seismik 2D Perairan Aru, Papua. *Jurnal Ilmu dan Teknologi Kelautan Tropis*, *13*(1), 57–69. https://doi.org/10.29244/jitkt.v13i1.32796

Anak Penguang, A.S., Lubis, L.A., Hermana, M., & Ghosh, D.P. (2017). Study of Rock Physics and Seismic Attributes of Hydrocarbon Reservoirs in Sabah Basin. *IOP Conference Series: Earth and Environmental Science*, *88*(012009). https://doi.org/10.1088/1755-1315/88/1/012009

Biescas, B., Sallarès, V., Pelegrí, J.L., Machín, F., Carbonell, R., Buffet, G., Dañobeitia, J.J., & Calahorrano, A. (2008). Imaging Meddy Fine Structure Using Multichannel Seismic Reflection Data. *Geophysical Research Letter*, *35*(11). https://doi.org/10.1029/2008GL033971

Buana, T.W., Wiyono, W., Murdohardono, D., & Sudarsono, U. (2010). Pendugaan Pergeseran Vertikal di Daerah Porong dan Sekitarnya dengan Seismik Gelombang “S” (*Shear Wave*). *Buletin Geologi Tata Lingkungan*, *20*(1), 45–53.

Buffet, G.G., Krahmann, G., Klaeschen, D., Schroeder, K., Sallares, V., Papenberg, C., & Zitellini, N. (2017). Seismic oceanography in the Tyrrhenian Sea: Thermohaline Staircases, Eddies, and Internal Waves. *Journal of Geophysical Research: Oceans*, *122*(11), 8503–8523. https://doi.org/10.1002/2017JC012726

Firdaus, R., Manik, H.M., Atmadipoera, A.S., Zuraida, R., & Purwanto, C. (2021). Pencitraan Struktur Halus Termohalin Menggunakan Seismik Refleksi Multikanal di Utara Laut Maluku. *Jurnal Ilmu dan Teknologi Kelautan Tropis*, *13*(1), 151–162. https://doi.org/10.29244/jitkt.v13i1.32346

Groeskamp, S., Abenathey, R.P., & Klocker, A. (2016). Water Mass Transformation by Cabbeling and Thermobaricity. *Geophysical Research Letter*, *43*(20), 10835–10845. https://doi.org/10.1002/2016GL070860

Hijria, T.V., & Danusaputro, H. (2016). Analisis Persebaran Zona Reservoir Lapangan DT-1 Menggunakan Metode Inversi Impedansi Akustik dan Atribut Variansi. *Youngster Physics Journal*, *5*(1), 1–12.

Leroy, C.C. (1969). Development of Simple Equations for Accurate and More Realistic Calculation of the Speed of Sound in Seawater. *The Journal of the Acoustical Society of America*, *46*(1B), 216–226. https://doi.org/10.1121/1.1911673

Manik, H.M., & Susilohadi, S. (2011). Application of Seismic Data Processing for Seabed Imaging. *International Journal of Remote Sensing and Earth Sciences*, *7*(1). https://doi.org/10.30536/j.ijreses.2010.v7.a1545

Minakov, A., Keers, H., Kolyukhin, D., & Tengesdal, H.C. (2017). Acoustic Waveform Inversion for Ocean Turbulence. *Journal of Physical Oceanography*, *47*(6), 1473–1491. https://doi.org/10.1175/JPO-D-16-0236.1

Papenberg, C., Klaeschen, D., Krahman, G., & Hobbs, R.W. (2010). Ocean Temperature and Salinity Inverted from Combined Hydrographic and Seismic Data. *Geophysical Research Letter*, *37*(4). https://doi.org/10.1029/2009GL042115

Priyantari, N., & Suprianto, A. (2009). Penentuan Kedalaman *Bedrock* Menggunakan Metode Seismik Refraksi (Studi Kasus di Desa Kemuning Lor, Kecamatan Arjasa, Kabupaten Jember), *Jurnal Ilmu Dasarvol*, *10*(1), 6–12.

Putra, T.I.R., Juita, E., & Rezki, A. (2022). Analisis Seismistas Wilayah Kabupaten Kepulauan Mentawai Berdasarkan Data Gempa Bumi Periode 2011–2021. *Jurnal*

Multidisiplin Indonesia, *1*(3), 804–824. https://doi.org/10.58344/jmi.v1i3.73

Safitri, D., Nainggolan, T.B., & Manik, H.M. (2020). Common Reflection Surface Methods In Low Fold Coverage Seismic Data of Complex Marine Geological Structures. *IOP Conference Series: Earth and Environmental Science*, *429*(012032). https://doi.org/10.1088/1755-1315/429/1/012032

Siadari, E.L., Dewi, D.M.P.R., & Putra, I.D.G.A. (2017). Pengaruh Suhu Permukaan Laut Dan Angin Terhadap Distribusi Klorofil-A di Perairan Papua tahun 2002–2016. *Prosiding Seminar Nasional Sains Atmosfer (SNSA) 2017 Penguatan Sains dan Teknologi Atmosfer dalam Mewujudkan Keunggulan dan Kemandirian IPTEK Nasional*, 100–105.

Sinha, S.K., Dewangan, P., & Sain, K. (2016). Acoustic Reflections in the Water Column of Krishna-Godavari Offshore Basin, Bay of Bengal. *The Journal of Acoustical Society of America*, 139(5), 2424–2431. https://doi.org/10.1121/1.4947429

Tang, Q., Hobbs, R., Zheng, C., Biescas, B., & Caiado, C. (2016). Markov Chain Monte Carlo Inversion of Temperature and Salinity Structure of an Internal Solitary Wave Packet From Marine Seismic Data. *Journal of Geophysical Research: Oceans*, *121*(6), 3692–3709. https://doi.org/10.1002/2016JC011810

Ustiawan, A.B., Nainggolan, T.B., & Setyawan, R. (2019). Interpretasi Struktur Geologi di Perairan Aru Selatan, Maluku Berdasarkan Data Seismik 2D *multi channel*. *Jurnal Geosains dan Teknologi*, *2*(2), 53–60. https://doi.org/10.14710/jgt.2.2.2019.53-60

Vladoiu, A., Bouruet-Aubertot, P., Cuypers, Y., Ferron, B., Schroeder, K., Borghini, M., Leizour, S., & Ismail, S.B. (2018). Turbulence in the Sicily Channel from Microstructure Measurements. *Deep Sea Research Part I: Oceanographic Research Papers*, *137*, 97–112. https://doi.org/10.1016/j.dsr.2018.05.006

Yilmaz, O. (2001). Seismic Data Analysis: Processing, Inversion, and Interpretation of Seismic Data. *Society of Exploration Geophysics*, *10*. https://doi.org/10.1190/1.9781560801580

Yuza, N.H., Nainggolan, T.B., & Manik, H.M. (2020). Multiple Attenuation Methods in Short-Offset 2D Marine Seismic Data: A Case Study in Cendrawasih Bay. *IOP Conference Series: Earth and Environmental Science*, *429*(012031). https://doi.org/10.1088/1755-1315/429/1/012031

Zhang, L., Wu, J., Wang, F., Hu, S., Wang, Q., Jia, F., Wang, F., & Hu, D. (2020). Seasonal and Interannual Variability of the Currents off the New Guinea Coast from Mooring Measurements. *Journal of Geophysical Research: Oceans*, *125*(12). https://doi.org/10.1029/2020JC016242