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Analysis of sea currents, sea temperature, and sea salinity variations in the malacca strait during january and july 2022 using vertical sections

Muh. Nur Hidayat[1], *Reza* Wafdan[2], *Marwan* Ramli[3], *Zainal A.* Muchlisin[1,4,7], *Sugianto* Sugianto[5], *Makwiyah A.* Chaliluddin[6], *Thaib* Rizwan[6], and *Syamsul* Rizal[1,2,7,*]

[1]Graduate School of Mathematics and Applied Sciences, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia
[2]Department of Marine Sciences, Faculty of Marine and Fisheries, Universitas Syiah Kuala, Banda Aceh, 23111, Indonesia
[3]Department of Mathematics, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia
[4]Department of Aquaculture, Faculty of Marine and Fisheries, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia
[5]Department of Soil Sciences, Faculty of Agriculture, Universitas Syiah Kuala, Banda Aceh, 23111, Indonesia.
[6]Department of Fisheries Resource Utilization, Faculty of Marine and Fisheries, Universitas Syiah Kuala, Banda Aceh, 23111, Indonesia
[7]Research Center for Marine Sciences and Fisheries, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia

Abstract. This study analyzes the sea currents, temperature, and salinity in the Malacca Strait during the northeast (NE) and southwest (SW) monsoons of 2022, represented by monthly average data from the Copernicus Marine Service (CMEMS) data portal for January and July, respectively. Vertical sections are created to visualize the layer structure and variations of sea parameters within the water column. The findings reveal differences in sea currents, temperature, and salinity between the NE and SW monsoons. July (SW monsoon) records consistently warmer temperatures than January (NE monsoon), both at the sea surface and seabed. Surface salinity is higher in July than in January, while seabed salinity is greater in January than in July. In January, the salinity-influenced mixed layer depth (MLD) appears to be thicker than the temperature-influenced MLD. There are no significant differences in the thickness of the temperature- and salinity-influenced MLDs during July. These variations in sea currents, temperature, and salinity at different depths provide a comprehensive understanding of the marine environmental structure and dynamics of the Malacca Strait.

* Corresponding author: srizal@usk.ac.id

1 Introduction

The Malacca Strait (MS) is a vital and strategic waterway for many countries because it is a major transportation route for oil and commodities, and it supports a variety of activities, including aquaculture, fishing, shipping, oil drilling, and energy generation [1]. According to Wang et al. [2], the Strait of Malacca is one of the most important maritime transportation routes in the world. However, they are also vulnerable to a variety of risks, including political instability, military conflict, piracy, terrorism, and vessel incidents. These risks can disrupt global trade and have a significant impact on the global economy.

The MS is highly influenced by changes in wind season. The southwest monsoon (SWM) occurs between June and September, while the northeast monsoon (NEM) takes place between December and February [3]. It is known that monsoon winds influence ocean circulation [4,5]. Several studies have been conducted in the MS, such as simulations of currents and tides [1,6,7].

The monsoon in the MS undergoes seasonal changes, shifting from SWM in summer (June to September) to NEM in winter (November to March), with two transitional periods in spring (April to May) and autumn (October) [8]. The monsoon has a major influence on both living and non-living processes in the Strait of Malacca, including nutrient availability and biological productivity [9]. The winter NEM is the most productive season in the Strait of Malacca because of strong mixing of the water column, which brings nutrient-rich deep water to the surface [10]. This nutrient-rich water supports the growth of phytoplankton and other marine organisms, which in turn support the marine food web.

In contrast to the winter NEM, during the summer SWM, the water column is well-stratified, meaning that the layers of water are clearly separated and do not mix easily, preventing the upward flow of nutrients to the surface layer. This results in low biological productivity. The strong SWM pushes the warm surface layer away from the coast, preventing the nutrient-rich deep water from reaching the surface.

The seasonal variation in nutrient availability and biological productivity in the Strait of Malacca has important implications for fisheries and other marine industries. For example, fish catches are typically higher during the winter NEM season when biological productivity is high. It is important to understand the seasonal variation in biophysical processes in the Strait of Malacca in order to manage its marine resources sustainably.

Sea temperature, salinity, and currents are basic parameters that influence the ecological and environmental conditions in the MS. Several studies have investigated these variables. Mansor et al. [11] showed that surface water in the MS in March is fresher and warmer than in August, while at the bottom depth in March it is more saline and cooler than in August. In addition, the mixed layer depth for both months did not exceed about 15 m for temperature and salinity, with a thermocline and halocline layer observed below the mixed layer depth. In the water column, Rizal et al. [3] showed that the temperature pattern in the MS shows a vertical gradient with values of 29°C at the surface and 19°C at the bottom. Meanwhile, salinity in the MS ranges from 31.5 at the surface to 34.5 at the bottom. Regarding ocean currents, Rizal et al. [12] found that for the bottom current, current speed ranges from 0-20 cm/s to the northwest. For the surface and layers 30-50 m, current magnitude is generally larger in February than in August. Whereas for the bottom layer, the current magnitude between February and August is relatively the same.

The definition of mixed layer depth (MLD) is closely tied to the homogeneous nature of the upper ocean layer. This uppermost stratum of the ocean undergoes thorough mixing, resulting in uniform temperature, salinity, and density throughout [13]. This well-mixed layer is formally referred to as the mixed layer itself. The boundary demarcating the lower limit of this mixed layer is known as MLD, and it typically extends to depths of several tens of meters [14].

The mixed layer constitutes the segment of the ocean that experiences direct influence from atmospheric mechanisms. Its significance in controlling air-sea interactions and climate dynamics is substantial. An indispensable parameter in the realms of physical, chemical, and biological oceanography is the MLD, as described by Giunta et al. [15]. MLD exhibits spatiotemporal variations across different time scales, as documented in several studies [16,17]. These fluctuations in MLD have significant ramifications for biological activity and play a pivotal role in shaping the dynamics of oceanic-air interactions [18,19]. Essentially, the MLD serves as the foundation for critical processes, including heat and freshwater exchanges between the ocean and the atmosphere, as well as influencing phenomena such as water mass formation [20], subduction from surface layers to greater depths [21], phytoplankton blooms [22,23], primary production [24], and regulation of seasonal ecosystems [25].

This research focuses on investigating the seasonal variations in sea temperature, sea salinity, and sea currents within the Malacca Strait. To gain deeper insights, we employ vertical sections and collect temperature and salinity profiles at various depths. This approach enables us to conduct a comprehensive comparison of conditions at the sea surface and the sea bottom during January and July, representing the NEM and SWM of the year 2022, respectively. Additionally, we examine sea temperature and sea salinity at a specific location within the Malacca Strait, situated at latitude 4°N and longitude 100°E, to determine the MLD.

Our specific research inquiries are outlined as follows. Firstly, to what extent does the difference between sea surface temperature and sea bottom temperature vary in January and July 2022? Secondly, what are the variations in sea surface salinity compared to sea bottom salinity during January and July 2022? Thirdly, how does the magnitude of sea currents differ between the sea surface and sea bottom in January and July 2022? Fourthly, what is the relationship between the MLD and temperature fluctuations in January and July 2022? Fifthly, how does the MLD change in response to salinity variations during January and July 2022?

2 Materials and Methods

The research was conducted in the Malacca Strait, focusing on vertical data collection at latitude 4°N, as depicted in Figure 1. This study utilized monthly average data of sea temperature, sea salinity, and sea currents, collected for January and July 2022. The data were sourced from the Copernicus Marine Service (CMEMS) data portal [26,27].

This research employed vertical section analysis for sea currents, sea temperature, and sea salinity in the Malacca Strait. Vertical sections are a graphical way to illustrate how a water property changes both vertically and horizontally. This is achieved by contouring data on vertical slices of the sea. Vertical section analysis is a type of spatial analysis along a vertical profile in the sea, spanning from the sea surface to the seabed. Vertical sections enable the identification of patterns, trends, and variations in oceanographic parameters at various depths. The analysis aims to understand the vertical structure and variations of sea currents, sea temperature, and sea salinity in the Malacca Strait in both January and July. Furthermore, station profiles at longitude 100°E and latitude 4°N were derived to provide a clearer view of the conditions of the isotherm and isohaline layers, as well as mixed layer depth (MLD) in January and July.

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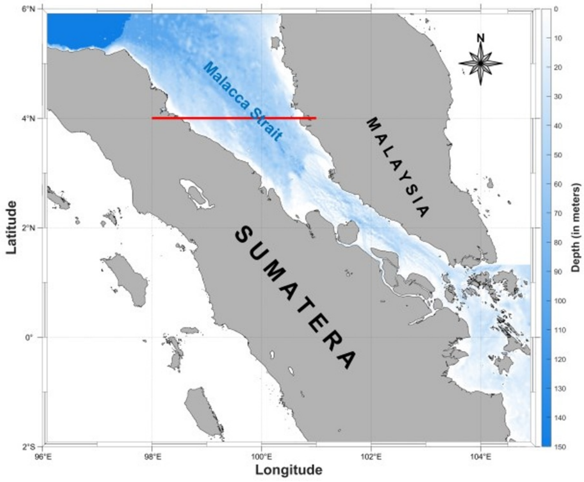

Fig. 1. Research location in the Malacca Strait. The study focuses on the cross-section (red line) at latitude 4°N. Colors indicate varying depths from 0 to 150 meters. Data derived from SRTM15+ [28].

3 Results and Discussion

Figure 2 shows vertical profiles detailing sea temperature, salinity, and currents within the 0 to 65-meter depth range for January and July 2022. Figures 2(a) and 2(d) delineate sea temperature vertical profiles for January and July, respectively, depicting temperature gradients through color variations. In January, temperatures spanned from 28.6°C (at the seabed) to 30.8°C (at the sea surface), while in July, they ranged from 29°C (at the seabed) to 31.4°C (at the sea surface). This indicates that both at the sea surface and at the seabed, the sea temperature in July is higher compared to January. This research correlates with the findings of Amiruddin et al. [29], Haridhi et al. [30,31], and Isa et al. [32,33].

Amiruddin et al. [29] observed that Sea Surface Temperature (SST) during the NEM typically stays between 28 to 29°C, while during the SWM, it elevates to around 30°C. Their investigation is grounded in the comprehensive world ocean database spanning from 1900 to 2005. In a separate study, Haridhi et al. [30,31] identified a marked impact of the monsoon system on SST in Sumatra. They noticed SST reaching its peak during the SWM (August) and hitting its lowest point during the NEM (February) due to prevailing wind patterns.

Meanwhile, Isa et al. [32] reported that SST during the NEM averaged around 28.5°C, whereas during the SWM, it reached approximately 29.9°C. In another study by Isa et al. [33], who analyzed 33 years of satellite-derived AVHRR data, they highlighted cooler temperatures prevailing in the MS and the Andaman Sea from December to February, averaging around 28−29°C, indicating lower SSTs during the NEM. However, temperatures surged to about 29.5°C in March, likely due to increased solar radiation. Comparatively, SST values were higher in July when contrasted with those recorded in January.

Meanwhile, Amiruddin et al. [29] compared vertical sections between the NEM and SWM, noting that seabed temperatures during the NEM were lower compared to those recorded during the SWM. These findings align with our study outcomes. Figure 2(b) and 2(e) present vertical sections depicting sea salinity for January and July, respectively, where color variations represent differences in sea salinity. In January, salinity ranged from 29 PSU (at the sea surface) to 34.2 PSU (at the seabed), while in July, it varied from 31.4 PSU (at the sea surface) to 33.8 PSU (at the seabed). This indicates higher surface salinity in July compared to January, while higher seabed salinity is observed in January than in July.

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Amiruddin et al. [29] compared salinity vertical sections during the NEM and SWM, revealing that surface salinity is higher during the latter compared to the former. However, their findings indicated higher seabed salinity values during the NEM than the SWM. This echoes our observations of elevated surface salinity in July compared to January, while January exhibits higher seabed salinity than July. Similarly, Mansor et al. [11] reported analogous results. According to Mansor et al. [11], surface salinity is higher during the SWM (31.5 PSU) than the NEM (30.45 PSU). Conversely, seabed salinity values are higher during the NEM (33.95 PSU) than the SWM (31.75 PSU).

At the sea surface, during the NEM, according to Amiruddin et al. [29], SSS is around 31 PSU. The low salinity during the NEM is caused by the influx of low-salinity water around 30.5 PSU from the west coast of Peninsular Malaysia. During the SWM, the movement of high-salinity water from the Andaman Sea increases SSS to more than 32 PSU in the Strait of Malacca.

Figure 2(c) and 2(f) show vertical cross-sections illustrating sea currents in January and July, respectively. The varying colors represent differences in sea current intensity. During January, sea currents range from 0 to 0.25 m/s, while in July, they fluctuate between 0 and 0.1 m/s. Both surface and seabed sea currents exhibit higher strength in January compared to July. These observations align with the study conducted by Rizal et al. [12]. Rizal et al. [12] demonstrated that the current intensity in February (representing the NEM) was greater than that observed in August (representing the SWM), both at the sea surface and at the seabed.

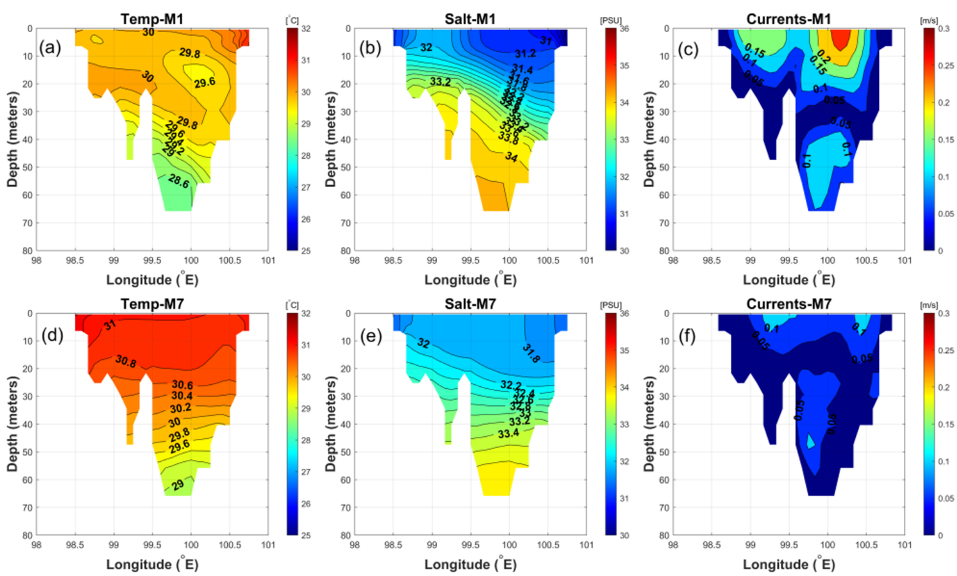

Fig. 2. Vertical sections for (a) Temperature (Temp-M1), (b) Salinity (Salt-M1), and (c)

Currents (Currents-M1) in January and (d) Temperature (Temp-M7), (e) Salinity (Salt-M7), and (f) Currents (Currents-M7) in July 2022 across the Malacca Strait at latitude 4°N. The location is indicated in Fig. 1 by the red line in the Malacca Strait. Colors on the map and the temperature color bar represent temperature differences in °C. Similarly, colors on the map and the salinity and sea currents color bars represent salinity differences in PSU and sea current velocities in m/s, respectively.

Figure 3 is a derivation from Figure 2, delineating temperature and salinity in January and July 2022 at latitude 4°N and longitude 100°E, respectively. In January, the isotherms appear relatively shallow, whereas the isohalines extend to about 10 meters. Within Figure 3(a), the MLD variations influenced by temperature and salinity are evident, with the salinity-induced

MLD being thicker than that caused by temperature. The upper well-mixed layer in the ocean arises due to turbulent mixing processes propelled by surface wind stress, along with heat loss and freshwater influx from the atmosphere [34]. This contributes to the creation of a relatively warm and fresh thin mixed layer, influenced by precipitation and surface heating [35].

Figure 3(b) exhibits isotherm and isohaline layers in July, showcasing similarities extending to roughly 20 meters. Notably, there are no substantial disparities in MLD thickness influenced by temperature and salinity in July. Furthermore, Figure 3(a) and 3(b) illustrate that the isotherm and isohaline layers, as well as the MLD, are deeper and thicker in July than in January. These findings correspond with the results presented by Mansor et al. [11].

In their study, Mansor et al. [11] showed that the MLD concerning temperature in the Malacca Strait measured approximately 10.35 meters in March (representing the NEM). Conversely, during August (representing the SWM), the MLD for temperature in the Strait increased to around 13.6 meters. Likewise, the MLD for salinity in the Malacca Strait during March registered at 10.35 meters, whereas in August, it measured approximately 12.5 meters. Both datasets indicate that the MLD was shallower in March when compared to August.

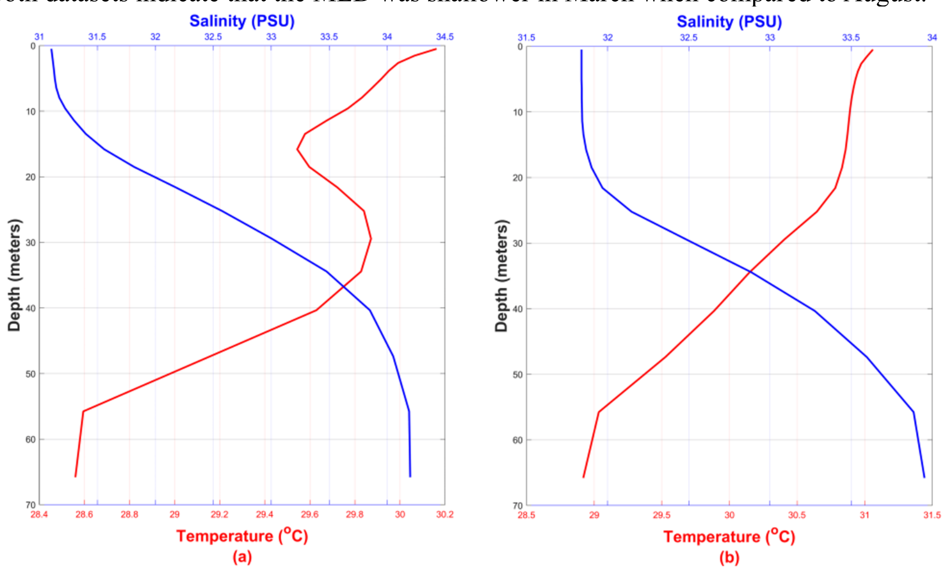

Fig. 3. Temperature profiles (red color) and salinity profiles (blue color) for (a) January and (b) July 2022 at latitude 4°N and longitude 100°E in the Malacca Strait.

4 Conclusion

The Malacca Strait's sea conditions exhibited considerable seasonal changes between January and July 2022. January revealed temperatures ranging from 28.6°C to 30.8°C, while July experienced higher temperatures, ranging between 29°C and 31.4°C, consistently showcasing warmer conditions at both surface and seabed levels compared to January. Salinity levels varied similarly, with January showing a range of 29 PSU to 34.2 PSU, contrasting with July's range of 31.4 PSU to 33.8 PSU. While surface salinity was higher in July, seabed salinity peaked in January. The sea currents also demonstrated noticeable differences between these months, with January recording stronger currents, reaching 0 to 0.25 m/s compared to July's weaker 0 to 0.1 m/s, particularly notable within specific longitudes in January. Figure 2 data collectively emphasizes distinct seasonal trends in temperature, salinity, and currents, providing a foundation for further investigation into the underlying factors driving these fluctuations and their implications on the local marine environment and ecosystems. The study delves into the temporal patterns of ocean thermal and salinity profiles at latitude 4°N and longitude 100°E during January and July 2022. January reveals shallower isotherms and isohalines, extending approximately 10 meters deep, with the salinity-influenced mixed layer depth appearing thicker than the temperature-influenced one. Contrastingly, July depicts isotherm and isohaline layers extending to about 20 meters, showcasing no significant differences in the mixed layer depth influenced by temperature and salinity. The data highlights considerable depth and thickness variations in July compared to January, emphasizing a distinct seasonal shift in the ocean's thermal and salinity structure in this location. These findings are critical for understanding the ocean's response to seasonal variations and their broader impact on the marine environment and ecosystems in the Malacca Strait. Additionally, they offer crucial insights into the implications of climate change on marine ecosystems in this region, warranting further research to comprehend their long-term effects. Studies like those outlined by Giunta and Ward [15] can lay the groundwork for a comprehensive understanding of MLD and its global implications.

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References

1. Y. Haditiar, M.R. Putri, N. Ismail, Z.A. Muchlisin, M. Ikhwan, S. Rizal, Heliyon **6**(9) (2020)
2. S. Wang, H. Jia, J. Lu, D. Yang, Reliab. Eng. Syst. Saf. **235**, 109254 (2023)
3. S. Rizal, P. Damm, M.A. Wahid, J. Sündermann, Y. Ilhamsyah, T. Iskandar, Am. J. Environ. Sci. **8**(5), 479-488 (2012)
4. Y. Haditiar, Z. Zulfandi, T. Iskandar, I. Setiawan, S. Sugianto, S. Rizal, *Simulation of wave refraction in the western waters of Aceh, Indonesia*, in IOP Conference Series: Earth and Environmental Science, IOP Publishing **216**, 1, 012014 (2018)
5. H.A. Haridhi, M. Nanda, C.R. Wilson, S. Rizal, Reg. Stud. Mar. Sci. **8**, 114-121 (2016)
6. Y. Haditiar, M.R. Putri, N. Ismail, Z.A. Muchlisin, S. Rizal, Eng. J. **23**(6), 129-143 (2019)
7. Y. Haditiar, S. Rizal, F. Abdullah, *Current simulation in the Malacca Strait and part of South China Sea due to wind*, in 2016 12th International Conference on Mathematics, Statistics, and Their Applications (ICMSA), IEEE 47-50 (2016)
8. M.S. Idris, H.L. Siang, R.M. Amin, M.J. Sidik, J. Mar. Syst. **236**, 103799 (2022)
9. K.K. Liu, S.Y. Chao, P.T. Shaw, G.C. Gong, C.C. Chen, T.Y. Tang, DSR I: Oceanogr. Res. Pap. **49**(8), 1387-1412 (2002)

10. C. Du, Z. Liu, S.J. Kao, M. Dai, Geophys. Res. Lett. **44**(22), 11-510 (2017)
11. K.N.A.A.K. Mansor, N.H. Roseli, F.S.M. Ali, M.F.M. Akhir. J. Coast. Res. **39**(5): 921–932 (2023)
12. S. Rizal, I. Setiawan, T. Iskandar, Y. Ilhamsyah, M.A. Wahid, M. Musman, Sci. Malays. **39**(4), 519-524 (2010)
13. A.B. Kara, P.A. Rochford, H.E. Hurlburt, J. Geophys. Res. Oceans. **105**(C7), 16803–16821 (2000)
14. I. Bessa, A. Makaoui, K. Hilmi, M. Afifi, Model. Earth Syst. Environ. **4**(1), 151–160 (2018)
15. V. Giunta, B. Ward, J. Geophys. Res. Oceans. **127**(4), e2021JC017904 (2022)
16. S. Lim, C.J. Jang, I.S. Oh, J. Park, J. Mar. Syst. 96–97, 1–14 (2012)
17. C.P. Abdulla, M.A. Alsaafani, T.M. Alraddadi, A.M. Albarakati, Ocean Sci. **14**(4), 563–573 (2018)
18. X. Costoya, M. deCastro, M. Gómez-Gesteira, F. Santos, PLoS ONE, **9**(6) (2014)
19. A. Srivastava, S. Dwivedi, A.K. Mishra, Oceanol. **60**(2), 169–186 (2018)
20. J. Yu, B. Gan, Z. Jing, L. Wu, J. Climate. **33**(24), 10419–10436 (2020)
21. J.C. Marshall, R.G. Williams, A.J.G. Nurser, J. Phys. Oceanogr. **23**(7), 1315–1329 (1993)
22. A. Calbet, M.D. Agersted, S. Kaartvedt, M. Møhl, E.F. Møller, S. Enghoff-Poulsen, M.L. Paulsen, I. Solberg, K.W. Tang, K. Tönnesson, D.E. Raitsos, T.G. Nielsen, Sci. Rep. **5**(1), 11240 (2015)
23. O. Schofield, M. Brown, J. Kohut, S. Nardelli, G. Saba, N. Waite, H. Ducklow, Phil. Trans. R. Soc. A. **376**(2122), 20170173 (2018)
24. S. Itoh, I. Yasuda, H. Saito, A. Tsuda, K. Komatsu, J. Mar. Syst. **151**, 1–14 (2015)
25. T. Xue, I. Frenger, A.F. Prowe, Y.S. José, A. Oschlies, Biogeosci. **19**(2), 455-475 (2022)
26. P.Y. Le Traon, A. Reppucci, E.A. Fanjul, L. Aouf, A. Behrens, M. Belmonte, A. Bentamy, L. Bertino, V.E. Brando, M.B. Kreiner, M. Benkiran, T. Carval, S.A. Ciliberti, H. Claustre, E. Clementi, G. Coppini, G. Cossarini, M. De Alfonso Alonso-Muñoyerro, A. Delamarche, G. Dibarboure, F. Dinessen, M. Drevillon, Y. Drillet, Y. Faugere, V. Fernández, A. Fleming, M.I. Garcia-Hermosa, M. García Sotillo, G. Garric, F. Gasparin, C. Giordan, M. Gehlen, M.L. Gregoire, S. Guinehut, M. Hamon, C. Harris, F. Hernandez, J.B. Hinkler, J. Hoyer, J. Karvonen, S. Kay, R. King, T. Lavergne, B. Lemieux-Dudon, L. Lima, C. Mao, M.J. Martin, S. Masina, A. Melet, B. Buongiorno Nardelli, G. Nolan, A. Pascual, J. Pistoia, A. Palazov, J.F. Piolle, M.I. Pujol, A.C. Pequignet, E. Peneva, B. Pérez Gómez, L. Petit de la Villeon, N. Pinardi, A. Pisano, S. Pouliquen, R. Reid, E. Remy, R. Santoleri, J. Siddorn, J. She, J. Staneva, A. Stoffelen, M. Tonani, L. Vandenbulcke, K. von Schuckmann, G. Volpe, C. Wettre, A. Zacharioudaki, Front. Mar. Sci. **6**, 234 (2019)
27. J.M. Lellouche, E. Greiner, O. Le Galloudec, G. Garric, C. Regnier, M. Drevillon, M. Benkiran, C.E. Testut, R. Bourdalle-Badie, F. Gasparin, O. Hernandez, B. Levier, Y. Drillet, E. Remy, P.Y. Le Traon, Ocean Sci. **14**(5), 1093-1126 (2018)
28. B. Tozer, D.T. Sandwell, W.H. Smith, C. Olson, J.R. Beale, P. Wessel, Earth Space Sci. **6**(10), 1847-1864 (2019)
29. A.M. Amiruddin, Z.Z. Ibrahim, S.A. Ismail, Res. J. Environ. Sci. **5**(1), 49–58 (2011)
30. H.A. Haridhi, M. Nanda, C.R. Wilson, S. Rizal, Reg. Stud. Mar. Sci. **8**(2016), 114-121 (2016)

31. H.A. Haridhi, M. Nanda, Y. Haditiar, S. Rizal, Ocean Coast. Manage. **154**, 46–54 (2018)
32. N.S. Isa, M.F. Akhir, I. Khalil, P.H. Kok, N.H. Roseli, J. Sustain. Sci. Manag. **15**(4), 66-77 (2020)
33. N.S. Isa, M.F. Akhir, P.H. Kok, N.R. Daud, I. Khalil, N.H. Roseli, Reg. Stud. Mar. Sci. **39**, 101402 (2020)
34. T. Ezer, J. Geophys. Res. Oceans **105**(C7), 16843–16855 (2000)
35. Y. Ushijima, Y. Yoshikawa, J. Phys. Oceanogr. **49**(7), 1769– 1787 (2019)