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Research Article

Seasonal Variability of Thermocline, Sound Speed and Probable Shadow Zone in Sunda Strait, Indonesia

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ABSTRACT

The Sunda Strait is an important strait connecting Karimata and Java Seas with the Indian Ocean. The Sunda Strait is one of the busiest International Sea-lane in Indonesian Archipelago (ALKI). That is used for commercial shipping lanes and possibly for the military (submarines) cruise. For submarine operational purposes, a physical oceanographic dataset is needed which consisting of temperature, salinity, and sound speed. This article is analysing the seasonal variability of thermocline and sound speed, including a shadow zone estimation. The 0.1 °C gradient is applied for the thermocline layer determination during four seasons data in 2014. The dataset of INDESO Project (daily, 1/12°) has been used. In the North-West Season (January), thermocline layer (28 - 13.5 °C) occurs at 77 – 155 m depth, has a range of 1,542-1,504 m/s sound speed. Those reveals shallower (40 - 130 m depth) of the thermocline layer (29 - 15.8 °C) during the first Transitional Season (April), with the sound speed range of 1541-1511 m/s. During South-East Season (July), the thermocline layer (29 - 15.4 ^{o}C) has been deeper again (65-155 m depth), with 1,542-1,550 m/s of sound speed. While during the Second Transitional Season (October), the upper limit of thermocline layer (27 - 13.6 ^{o}C) is a little bit shallower (55 - 155 m depth), with the sound speed range of 1,538 - 1504 m/s. In annual average, the thermocline (29 - 13.6 ^{o}C) in Sunda Strait laying in between an upper limit layer of 40-70 m depths and a bottom limit layer of 130-155 m depth. Those layers depth are estimated to be a probable shadow zone area with the sound speed range upper limit of 1,542 m/s, and the lower limit of 1,504-1,511 m/s.

Keywords: *seasonal variability, thermocline, sound speed, probable shadow zone, Sunda Strait*

1. Introduction

Geographically, Indonesian seas is a very interesting research area. Every area of Indonesian Seas has physical characteristic properties of seawater that is very different from each other. Characteristics of seawaters in sea, strait, (coastal) bay are influenced by the seasonal/monsoon wind pattern (Mustikasari et al., 2015). According Wyrtki (1961) and Putri (2005), in general, from June to August is known as the Southeasterly wind (South-East Season), and from December to March is known as the Northwesterly wind (North-West Season).

Java Sea is higher than in the Indian Ocean. Java Sea and the southern part of South China Sea is the source of low-salinity

Sunda Strait lies between the island of Sumatra and Java and are associated with the Java Sea and Indian Ocean. Inside these waters there are small islands and volcanoes that are still active such as Mount Krakatau. In the northern part of the Java Sea, the depth of the sea is less than 50 meters, but in the southern part of the strait associated with the Indian Ocean has a depth of more than 100 meters (BRKP, 2003).

The Sunda Strait is the path that connects Java Sea with the Indian Ocean and the exchange of seawater mass between the Java Sea with the Indian Ocean happens. In general, the mass of water moves towards the Indian Ocean because the water level in the water mass. Runoff from major rivers in Sumatra, Kalimantan, and Java affects salinity more than rainfall. While the mass of the Indian

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Ocean water is characterised by high salinity due to the mass of water from the Red Sea and Persian Gulf (Wyrtki, 1961).

Acoustic waves are longitudinal waves that require a medium to propagate (mechanic wave). This means that there will be a rebound and a rapid change of acoustic wave propagation as it enters a propagating medium that has different density levels. Acoustic wave velocity, as it moves towards different seawater depths (sea water has different salinity and temperature levels in each depth) will undergo acceleration and deceleration (Lurton, 2002). In the waters of the Sunda Strait the speed of sound is greatly influenced by the salinity and temperatures that carry the waters of the Java Sea with the seawater from the Indian Ocean.

From another angle the Sunda Strait is one of the paths of the Indonesian Archipelagic Sea Lane (ALKI) that can be used for commercial and military voyages, including submarine training areas. This makes the Sunda Strait very important in term of International shipping. It is also strategic because of its proximity location to Jakarta which is the State Capital and is one of the entrances to the Indonesian archipelago (BRKP, 2003).

From the description above, the waters of the Sunda Strait has a unique characteristics with other areas and interesting area for oceanographic studies in addition to its strategic value. Therefore, it is necessary to do a research to show the condition and characteristics of the speed of sound in the current Sunda strait and in the surrounding area. In this paper, the authors will discuss the seasonal variability of sound speed in the Sunda Strait which later can be utilised for correction of bathymetric maps (Saputra et al., 2016).

The purpose of this paper is to Analyse the characteristics of thermocline in the Sunda Strait based on sea temperature profile data. Analysing the horizontal distribution, Vertical of the sound speed, temperature, seasonal salinity represented by one of the moons in each season then identifying the thermocline and shadow zone region based on the distribution of sound speed characteristics. The information of shadow zone region will useful for (underwater) navigation of submarine when diving/cruise in Sunda Strait (Sunaryo, 2004).

2. Material and Method

Research begins with study of theoritical literature about salinity, temperature, speed, sound, shadow zone and thermocline layer with a temperature gradient of 0.1º C for any difference in the depth of one meter (BTSPC, 1992; Nontji,1993).

This Research uses data from January 2014 to December 2014 with January, April, July, October as the main processed data. Those monthly periods are representing the seasonal time frames (Putri, 2005). Study area is the Sunda Strait with boundary of 4.5^o South – 6.83333^o South, and 104.5^o East – 106.083^o East.

This Research uses a model data (NC file) obtained from the INDESO (http://www.indeso.web.id), Ministry of Marine Affairs & Fisheries. This data has a spatial range between points of 1/12°, and a daily average temporal resolution. Furthermore, the data is divided into 36 depths, i.e. from 1 meter depth to 1062,4399 meters.

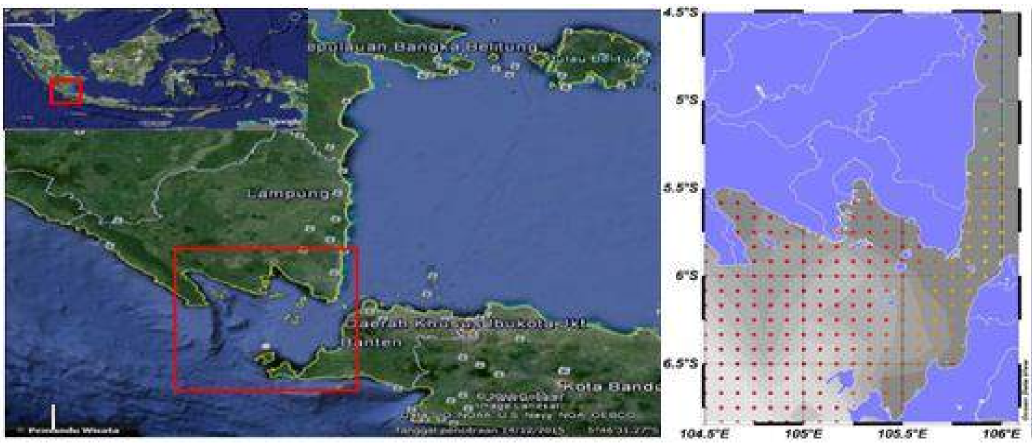

Figure 1. The sunda strait as study area (left); spatial distribution of dataset (right).

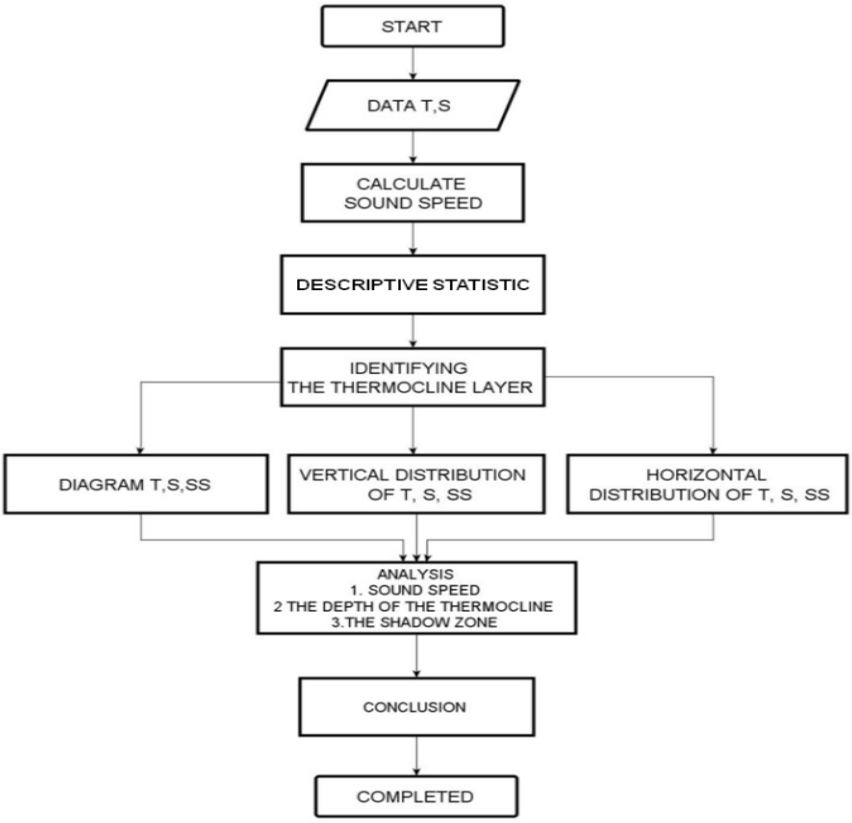

Figure 2. Research flowchart

Model data obtained from the INDESO site contains temperature and salinity data. The sound speed is derived using Ocean Data View (ODV) program version 453 based on temperature and salinity (Fofonoff & Millard, 1983). Next step, the data is exported from ODV to the Text file form in the form of data Depth. The result then opened in Microsoft Office Excel (2007) for smoothing and calculation of thermocline area with the existing literature benchmark is the temperature gradient 0.1^{o}C/m (IOC, SCOR and IAPSO. 2010). This calculation is done by dividing the difference between the temperature of the inner and the difference of the depth itself. The results are; temperature gradient data, lower limit and an upper limit of the sound and temperature velocities. The result of the smoothing count is converted to a txt file for next plot with ODV. Then ODV then used to view or plot the profile of the distribution of physical parameters in the form of temperature salinity and speed of sound vertically upright and transverse so that the condition of the layer can be seen. The plot results are then analysed descriptively. The result of the temperature gradient calculation, the lower limit of the upper bound is then presented in the graph and histogram in Microsoft Office Excel (2007). This data is also used in plotting in ODV i.e. for set ranges in determining the possibility of shadow zone region.

3. Results and Discussion

Profiles of temperature, salinity, and sound speed

The results of the plot diagram of temperature, salinity, Sound speed (T-S-S) in the form of vertical profiles of temperature, salinity, sound speed is presented in Figure 3-6, based on the image, any change of temperature against depth so that the formed coating mass water pattern that consists of three parts namely homogeneous layers, the layers of the thermocline and the layer inside were observed. This is caused by the penetration of sunlight getting smaller as we get deeper. From the picture plot diagram can also be seen that the temperature changes are very influential on the speed of sound. The more the temperature drops down also the speed of sound. The salinity change is visible from the surface to the thermocline layer and then tends to remain in the inner layer.

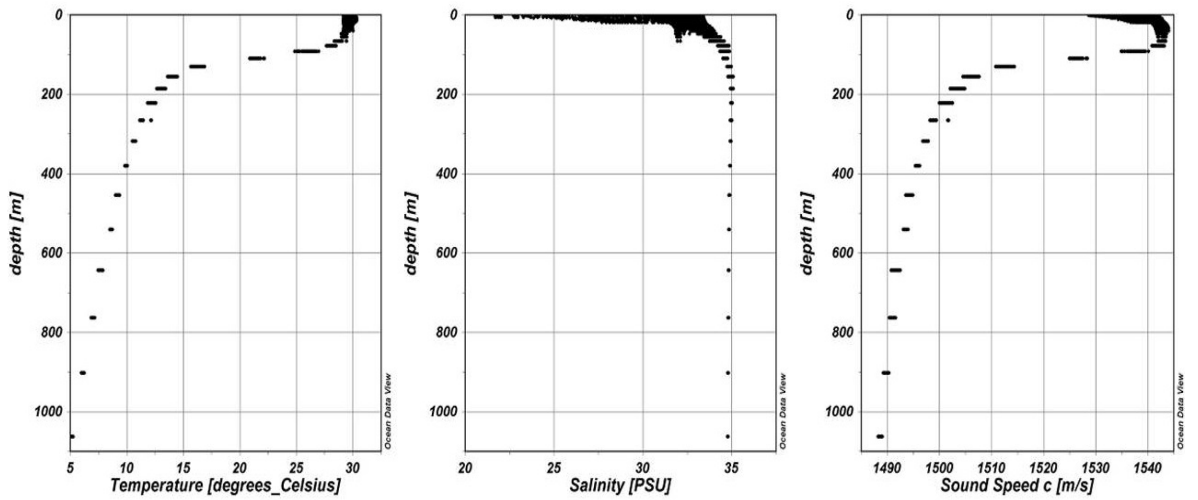

Figure 3. Profiles of the Temperature, salinity and sound speed in January 2014 (north-west season).

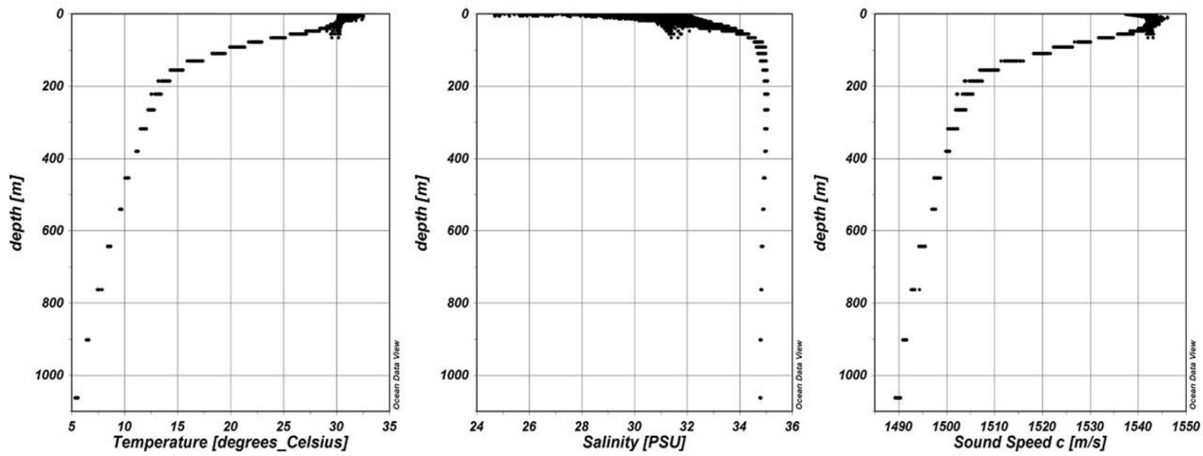

Figure 4. Profiles of the temperature, salinity and sound speed in april 2014 (first transitional season).

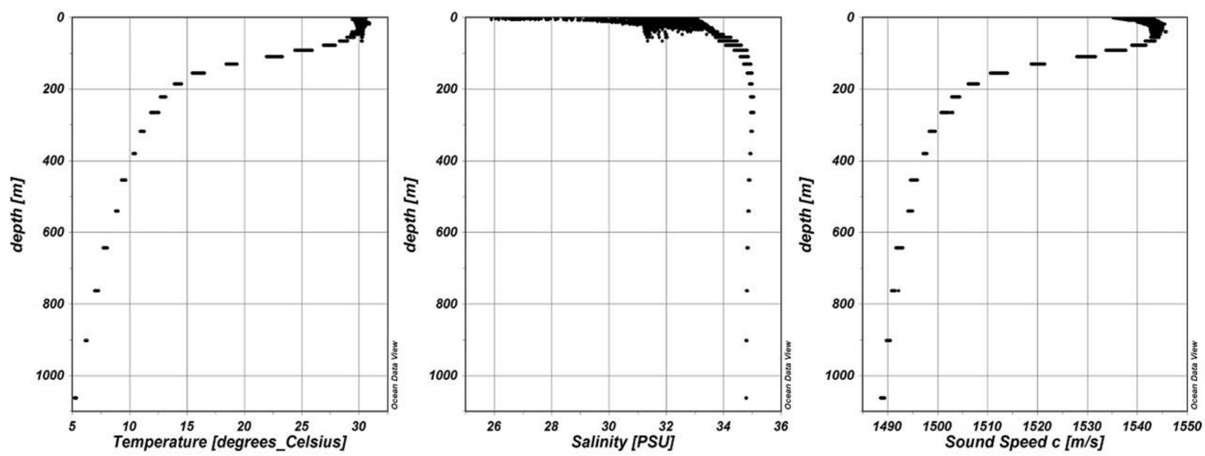

Figure 5. Profiles of the temperature, salinity and sound speed in July 2014 (south-east season).

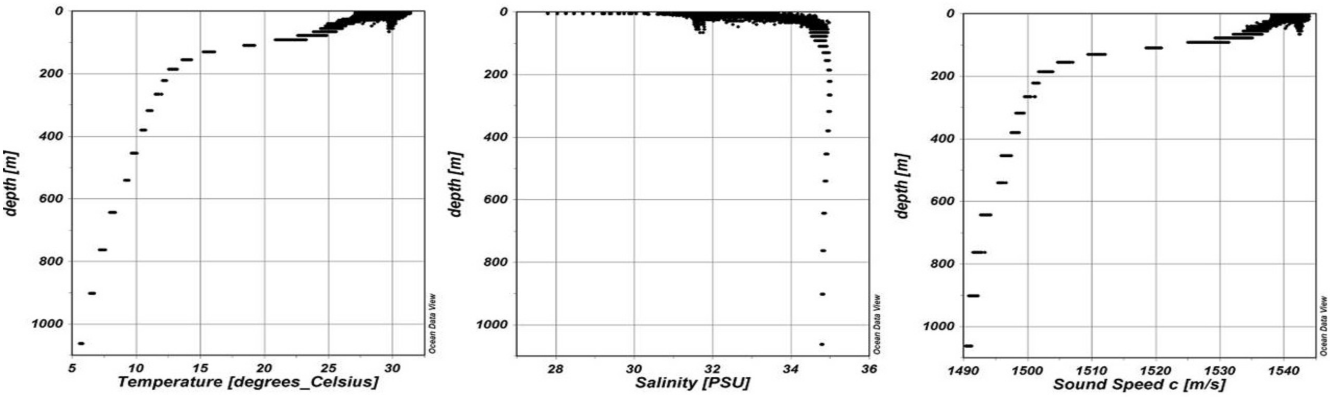

Figure 6. Profiles of the temperature, salinity and sound speed in October 2014 (second transitional season).

Vertical sections distribution

The above vertical distribution is taken from point A to point B where the depth varies in the initial 100 km position from point A (shallow sea), with depth up to 50 meter continues to depth more than 250 meter. The vertical temperature plot provides an overview of temperature changes to depths, ranging from 1m to 1000 m depth. The temperature distribution for all stations shows a relatively similar pattern. Temperatures on the surface are higher when compared to the temperature value below. Temperature decreases with increasing depth due to less sunlight penetration. In the plot of sound velocity there is similarity of image with the picture of temperature in each month. The salinity plot can be seen in the figure that the salinity increase is clearly visible on the surface layer and the thermocline while in the inner layers the salinity is stable

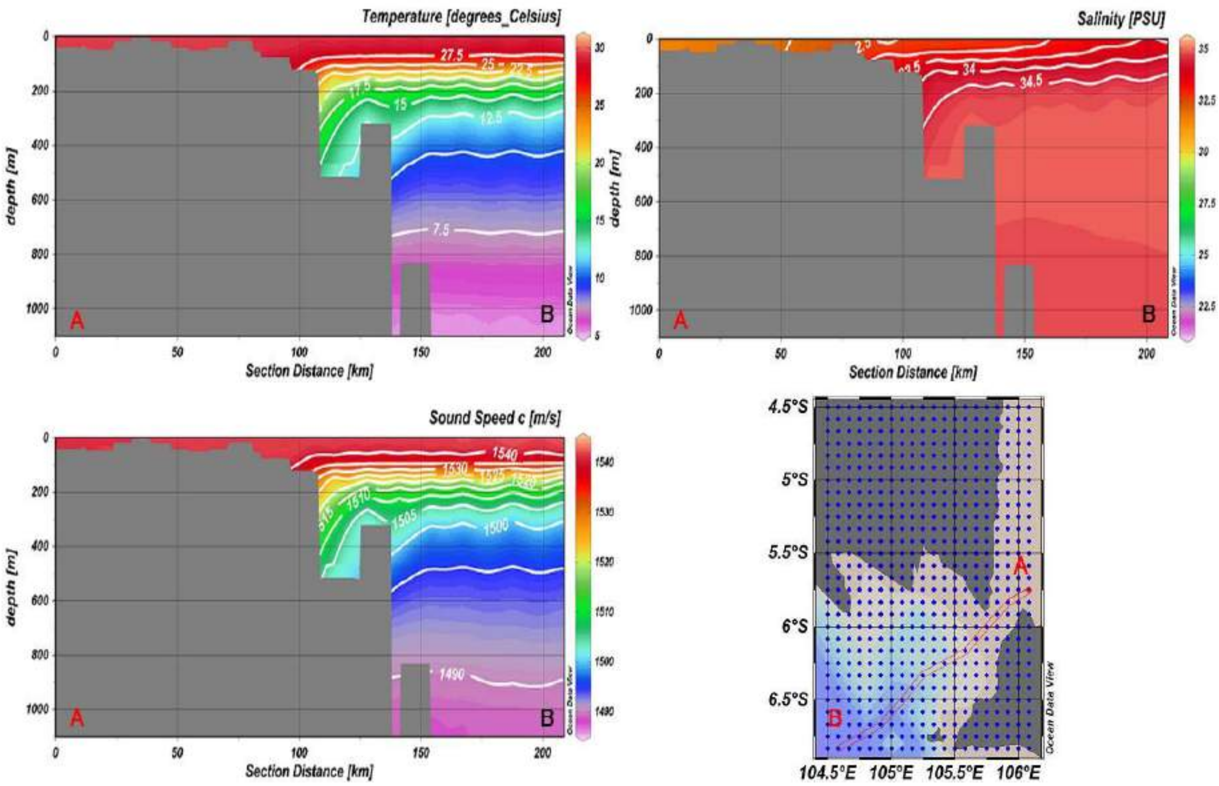

Figure 7. Temperature, salinity and sound speed vertical sections in sunda strait, during January 2014 (NW season)

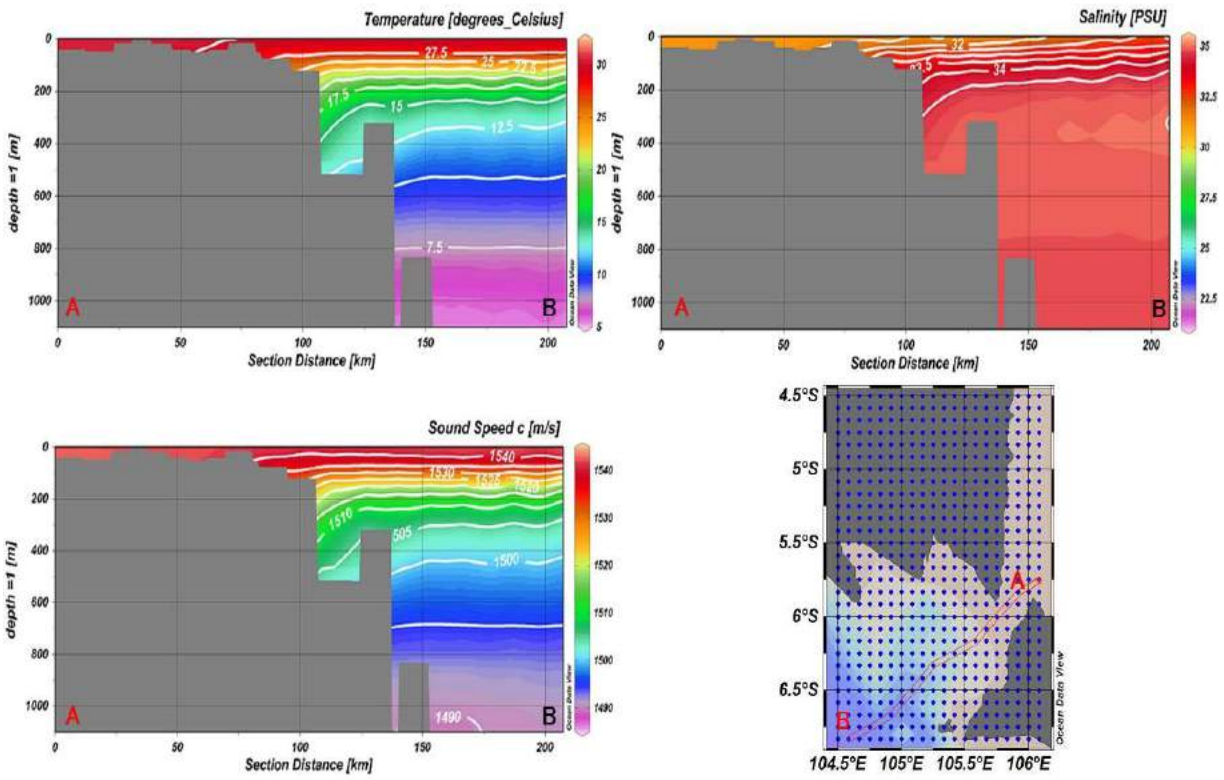

Figure 8. Temperature, salinity and sound speed vertical sections in sunda strait, during April 2014 (1st trans. season).

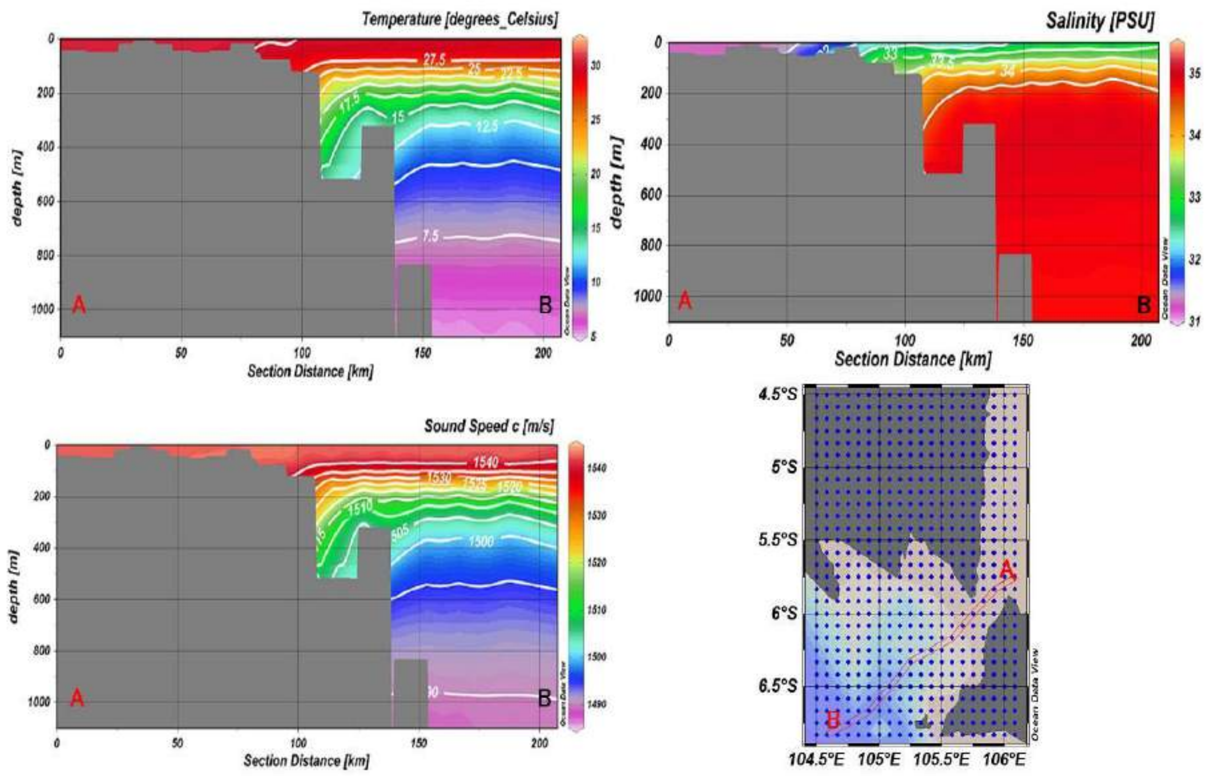

Figure 9. Temperature, salinity and sound speed vertical sections in sunda strait, during July 2014 (se season).

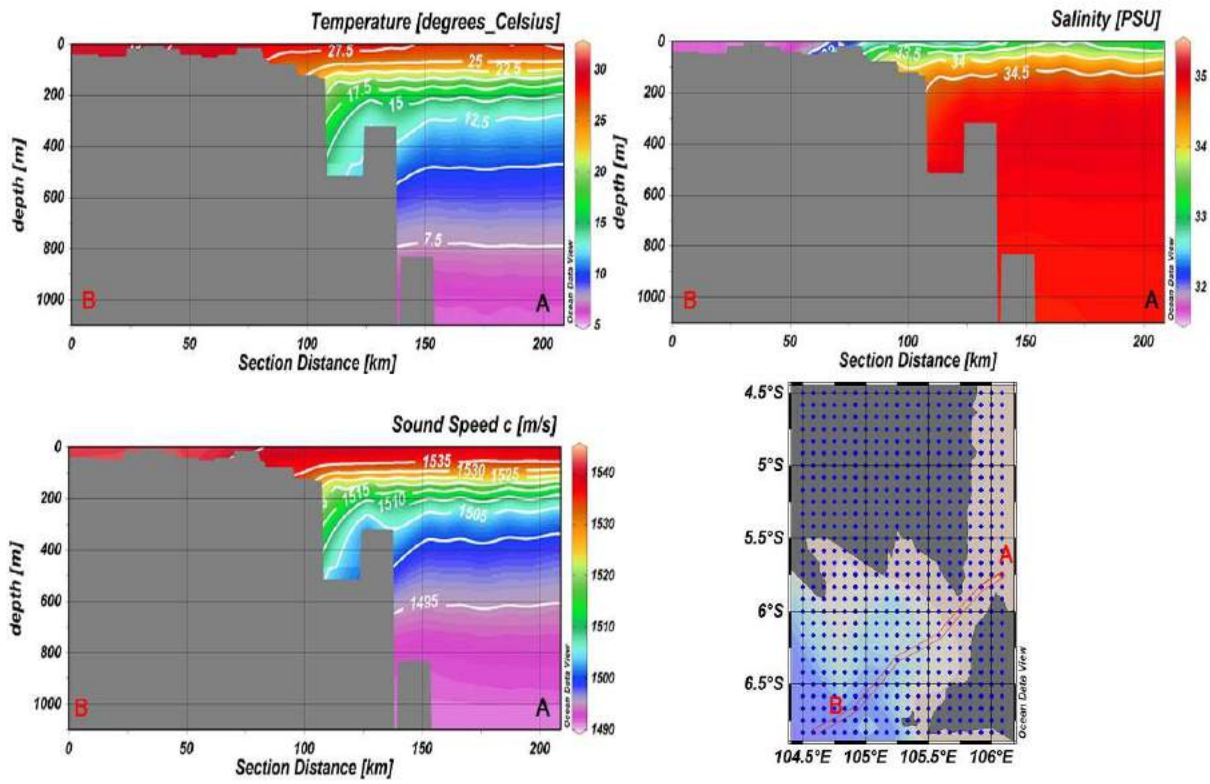

Figure 10. Temperature, salinity and sound speed vertical sections in sunda strait, during October 2014 (2nd trans. season).

Spatial horizontally distributions

1) Temperature: In January the distribution of horizontal temperature on the entire surface of the Sunda Strait ranged from 29.3-29.5ºC. At a depth of 47 m, still at 29.3ºC, this indicates that the period of water from the Indian Ocean has entered from the surface. In April the Sunda Strait is warmer with a temperature of 30.5ºC. Then enter into the strait, cooler temperatures are also seen at a depth of 47m where the temperature at the mouth of the strait is higher than in the south. In July the surface temperature at the mouth of the strait is about 30.25ºC up to the centre, after which the temperature drops from 30ºC. The depth of 47m temperature difference occurs in the mouth of the strait. In October the warmer temperatures were still recorded in the mouth of the strait up to the centre of the strait with a temperature of 30ºC, at a depth of 47m very clearly visible difference in temperature changes in the strait mouth. The temperature of the Java sea is about 30ºC, while the temperature of the Indian Ocean is around 25ºC.

2) Salinity: in January at the salinity surface from the Java sea entering the strait of Lampung with the level of 31 PSU. Heading south salinity up to 33 PSU. Up to a depth of 47 m the state is still equal to salinity ranging from 32 - 34 PSU. In April the salinity from the Java Sea entered deep into the depths of 31 PSU. At a depth of 47 m, the salinity of the Indian Ocean enters until it approaches the entrance of the strait with a value of 33.5 PSU. In July the salinity from the Java Sea enters to the middle of the Sunda Strait with a salinity of 31-31.5 PSU. At a depth of 47 m, salinity from the Indian Ocean enters up to the entrance of the Sunda Strait with a salinity of about 33.5 PSU. In October the salinity from the Java Sea enters until it approaches the exit of the strait with a salinity level of 32 PSU. At a depth of 47 m, the salinity of the Indian Ocean enters to the middle of the strait with a salinity of 34.5 PSU.

3) Sound Speed: In January the speed of sound in the surface ranged between 1541 m/s in almost all areas. While at a depth of 47 m the sound speed is 1543m/s. While at the mouth of the strait is about 1541 m/s. At a depth of 109 m, the sound speed is at 1526-1527 m/s. In April the sound speed on the surface is 1542 m/s, at the mouth of the strait 1541 m/s while in the south 1543 m/s. Down to a depth of 47 m, sound speed from the Indian Ocean to the centre of the strait, ranging from 1541 in the strait mouth to the north at a range of 1542 m/s.

At the middle at a depth of 109m the sound speed is 1520 m/s. In July, the sound speed on the surface was about 1542 m/s, a depth of 47m of sound speed ranging from 1544 m/s except at the mouth of the strait to the northern part, sound speed ranging from 1543 m/s down. At a depth of 109m, the sound speed ranges from 1531-1528 m/s. In October at the surface of the sound speed at the mouth of the strait ranging from 1542 m/s to the southward direction decreases to 1541 m/s up to the end of the strait down to 1540 m/s. At a depth of 47 m, the sound speed at the strait mouth and enter into the higher salinity of about 1542 m/s to the south of the strait sound speed down to 1537-1535 m/s.

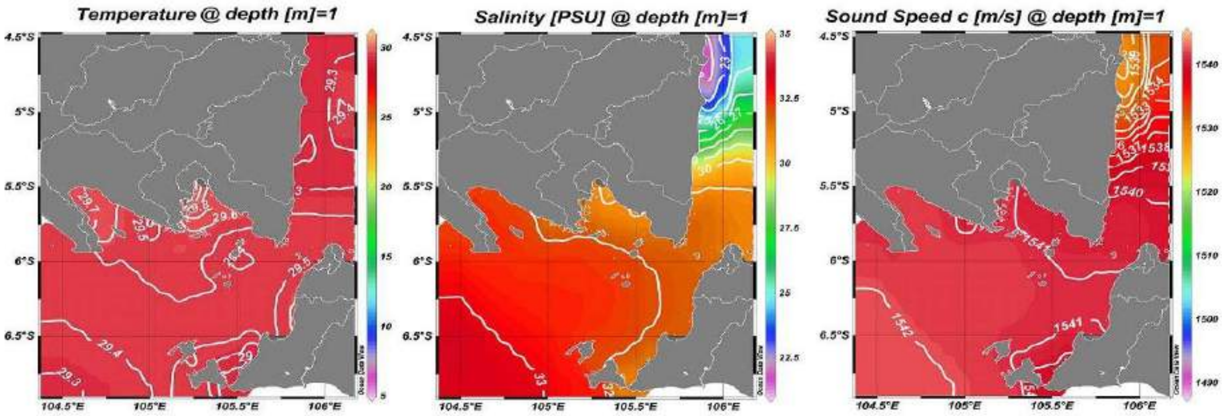

Figure 11. Spatial horizontally distribution of temperature, salinity and sound speed, in January 2014, at 1 m depth.

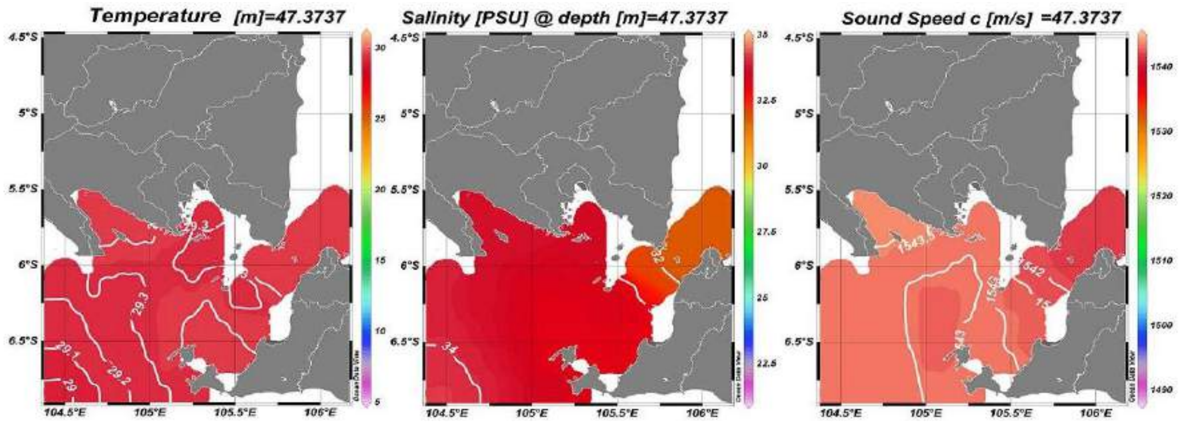

Figure 12. Spatial horizontally distribution of temperature, salinity and sound speed, in January 2014, at 47 m depth.

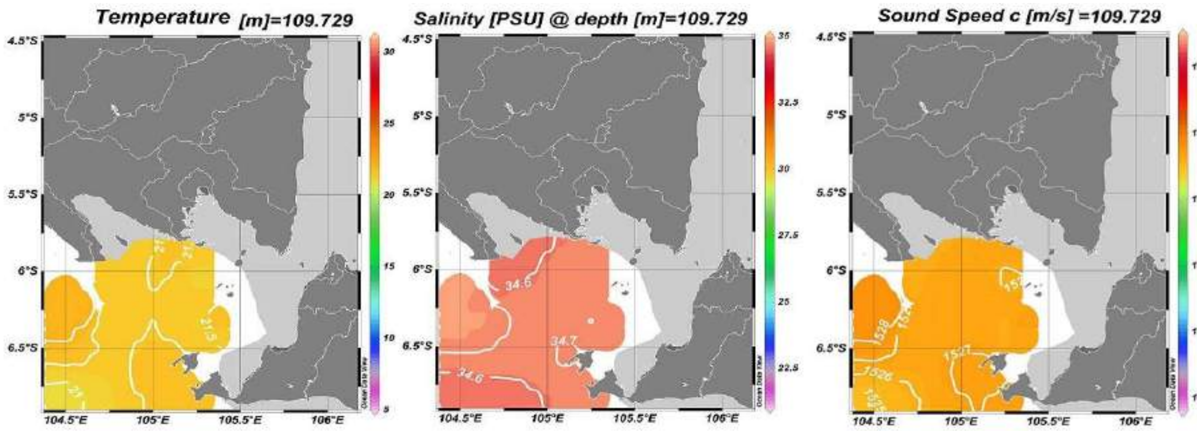

Figure 13. Spatial horizontally distribution of temperature, salinity and sound speed, in January 2014, at 109 m depth.

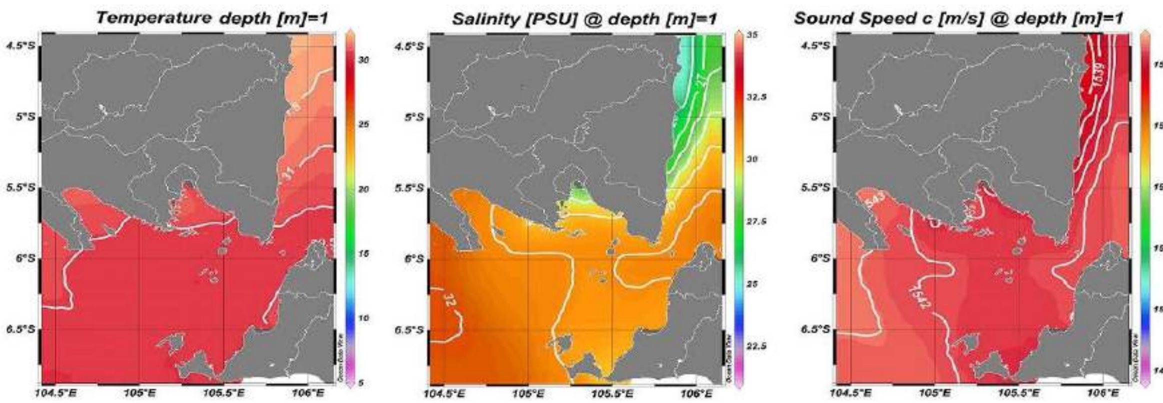

Figure 14. Spatial horizontally distribution of temperature, salinity and sound speed, in April 2014, at 1 m depth.

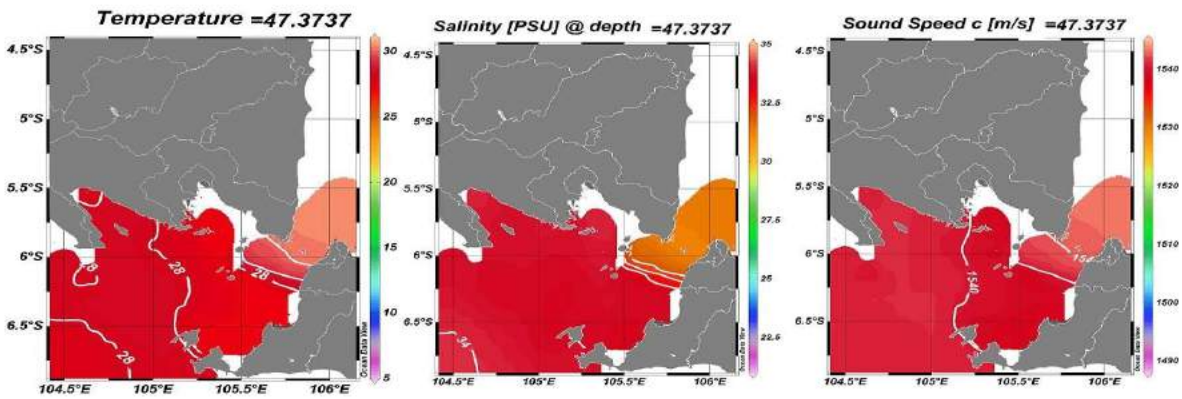

Figure 15. Spatial horizontally distribution of temperature, salinity and sound speed, in April 2014, at 47 m depth.

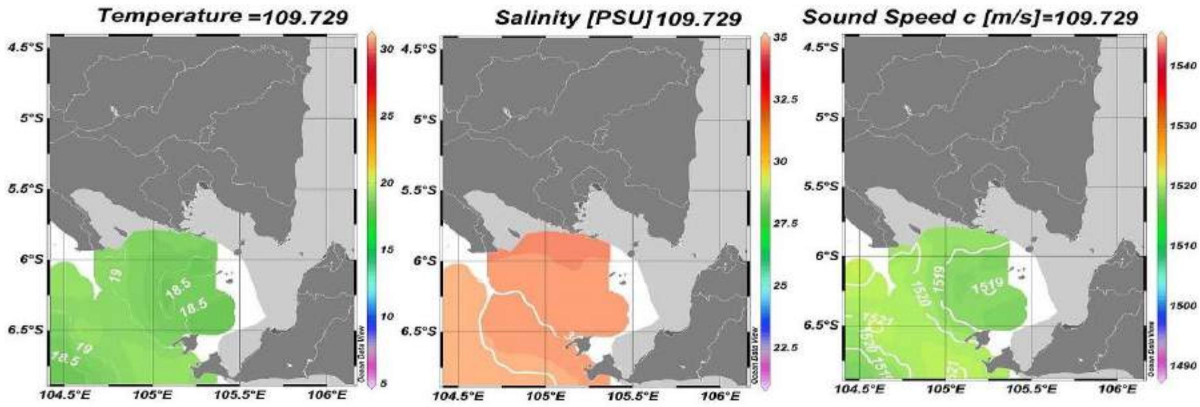

Figure 16. Spatial horizontally distribution of temperature, salinity and sound speed, in April 2014, at 109 m depth.

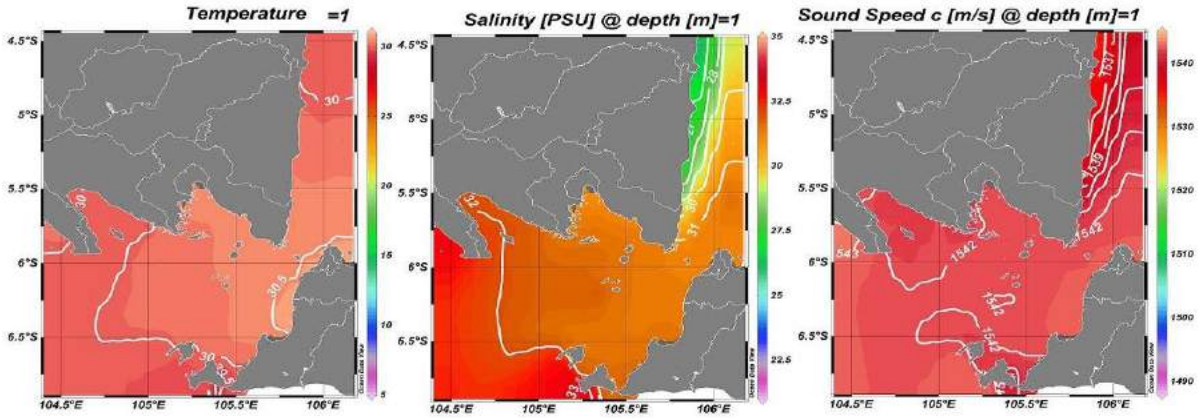

Figure 17. Spatial horizontally distribution of temperature, salinity and sound speed, in July 2014, at 1 m depth.

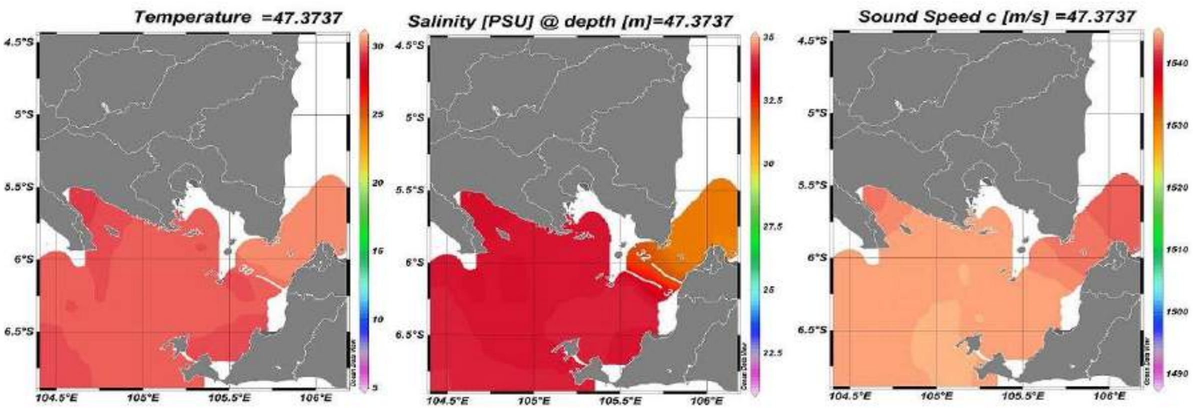

Figure 18. Spatial horizontally distribution of temperature, salinity and sound speed, in July 2014, at 47 m depth.

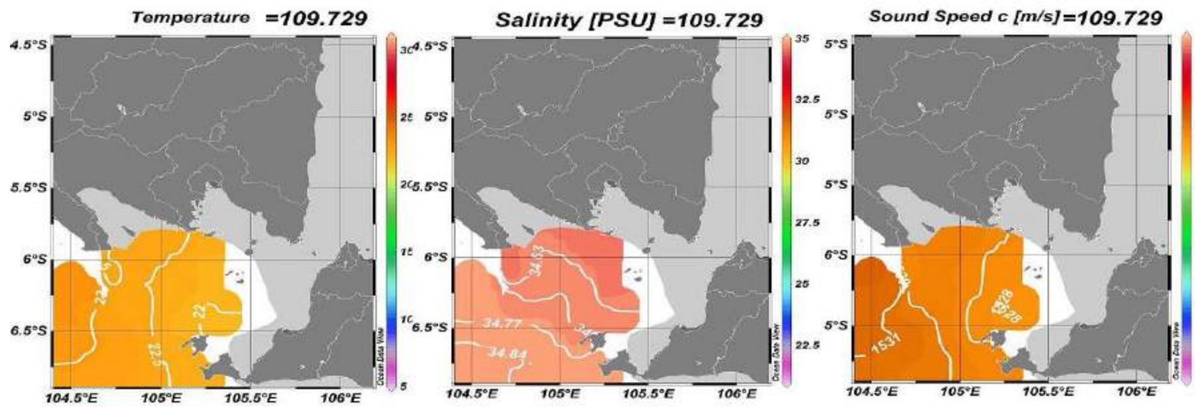

Figure 19. Spatial horizontally distribution of temperature, salinity and sound speed, in July 2014, at 109 m depth.

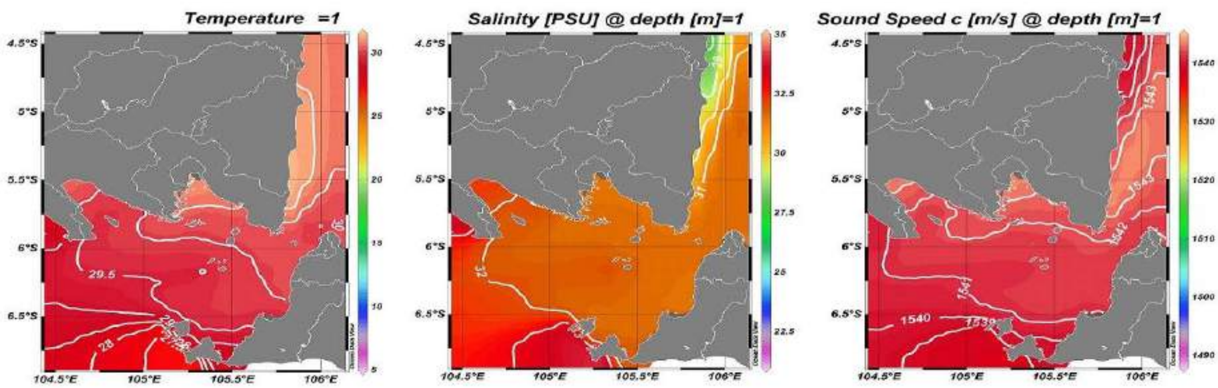

Figure 20. Spatial horizontally distribution of temperature, salinity and sound speed, in October 2014, at 1 m depth.

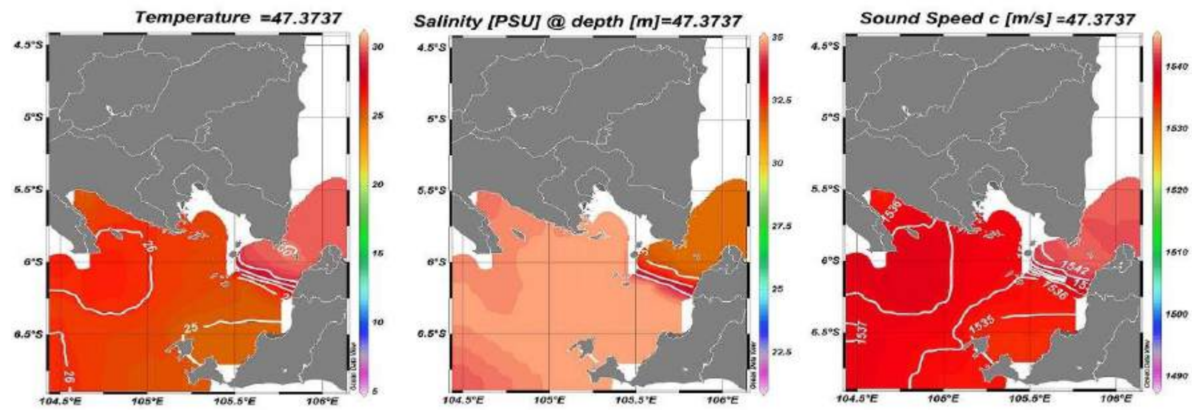

Figure 21. Spatial horizontally distribution of temperature, salinity and sound speed, in October, at 47 m.

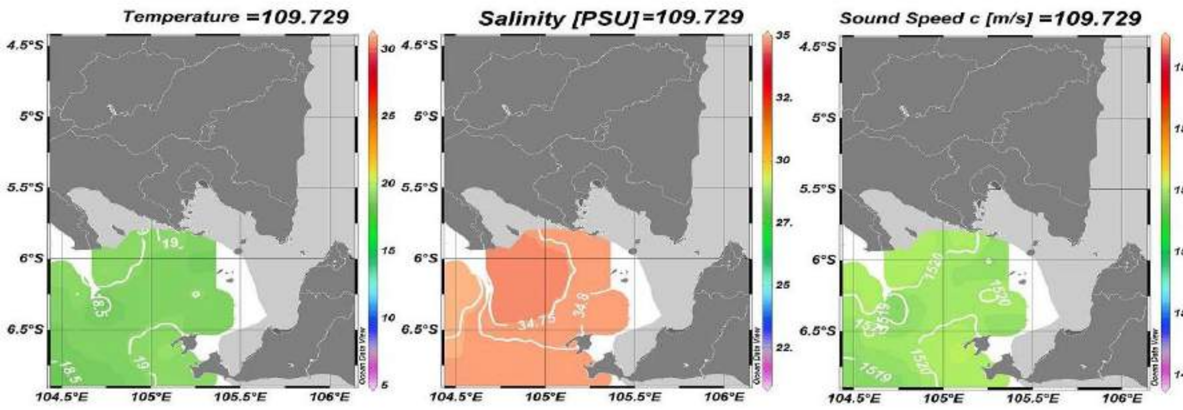

Figure 22. Spatial horizontally distribution of temperature, salinity and sound speed, in October 2014, at 109 m depth.

Thermocline region and probable shadow zone area

1) January: 1) January: in January thermocline layer occurs at a depth of 155.85 m – 77.85 m with the temperature at the top at 28.08ºC and the lower temperature of 13.59°C. While shadow zone occurs at the speed of sound between 1542.005-1504.50 m/s layer thermocline and the approximate area of shadow zone occurs in January has a thickness of 77.99 m and the temperature gradient 0.185°C/m.

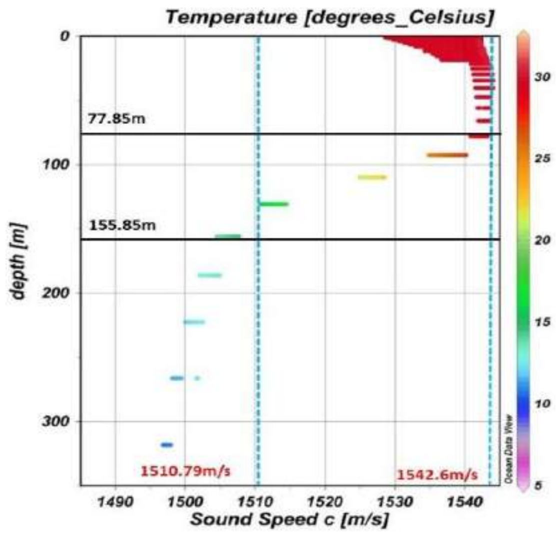

Figure 23. Sound Speed range estimated based on thermocline limit, in January 2014.

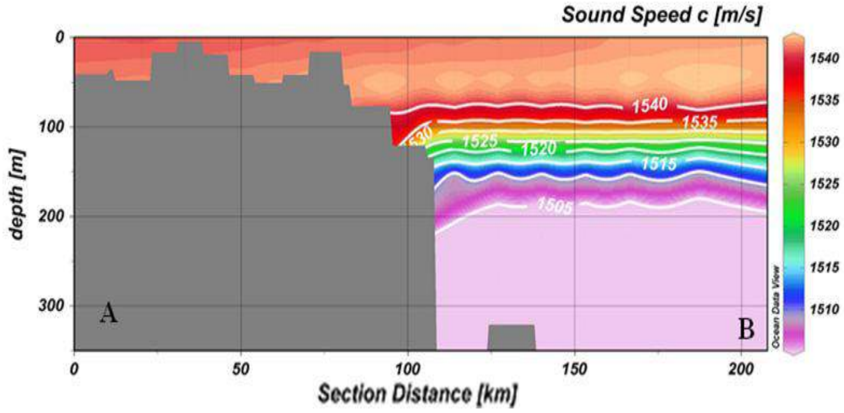

Figure 24. Approximate Territory Of The Shadow Zone In January.

2) April: In April, the upper limit of the thermocline layer occurs at a depth of 40.34 m while the lower limit is set at a depth of 130.66 m with temperature from 29.34 - 15.89ºC. Approximate territory of the shadow zone occurs at sound speed of 1541.49-1511.38 m/s temperature Gradient in the area is the 0.149 ºC/m thick layer of 90.32 m.

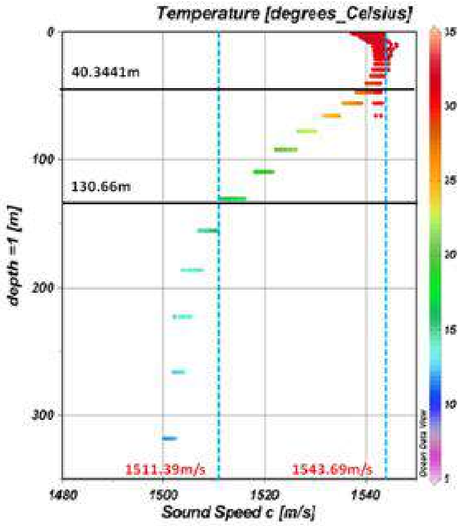

Figure 25. Sound Speed range estimated based on thermocline limit, In April 2014.

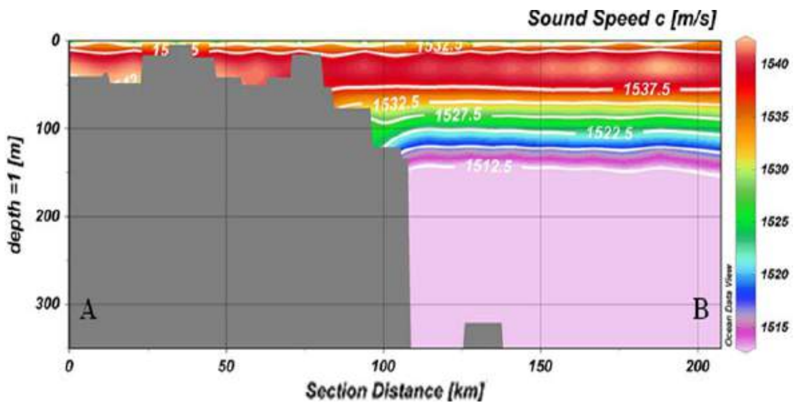

Figure 26. Approximate territory of the shadow zone April.

3) July: In July thermocline occurs at a depth of 155.85-65.80 m. With temperature ranges from 29.27-15.47ºC. The upper limit of the sound speed 1542.56m/s and lower limit 1510.59 m/s. Thermocline Layer and the approximate area of shadow zone has a thickness of 90.04 m with a gradient of temperature 0.153°C/m.

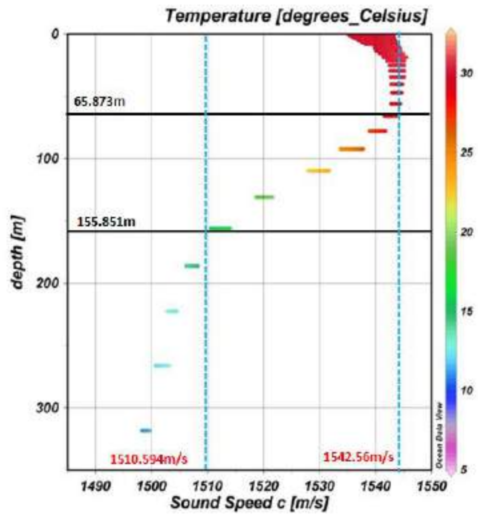

Figure 27. Sound Speed range estimated based on thermocline limit, in July 2014.

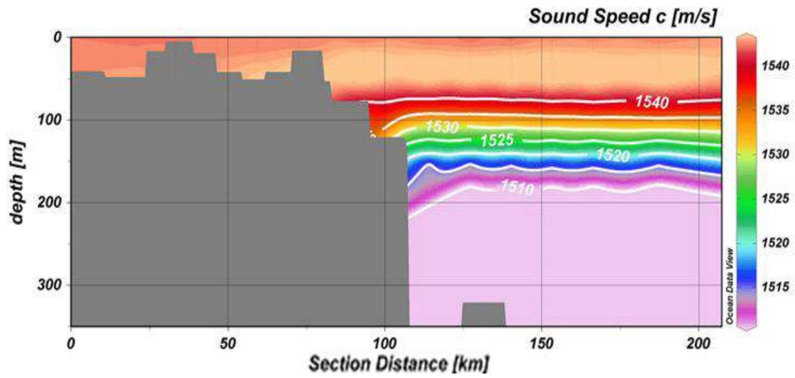

Figure 28. Approximate Territory Of The Shadow Zone In July.

4) October: The thermocline layer in October occurs at a temperature of 27.21ºC, depth of 55.76 m up to a temperature of 13.60ºC at a depth of 155.85m. Sound speed was recorded at 1538.20 m/s - 1504,74 m/s with area thickness of 100.08m and temperature gradient of 0.135ºC/m.

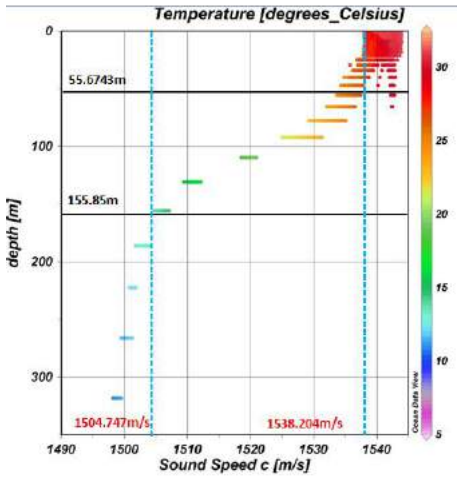

Figure 29. Sound Speed range estimated based on thermocline limit, in October 2014.

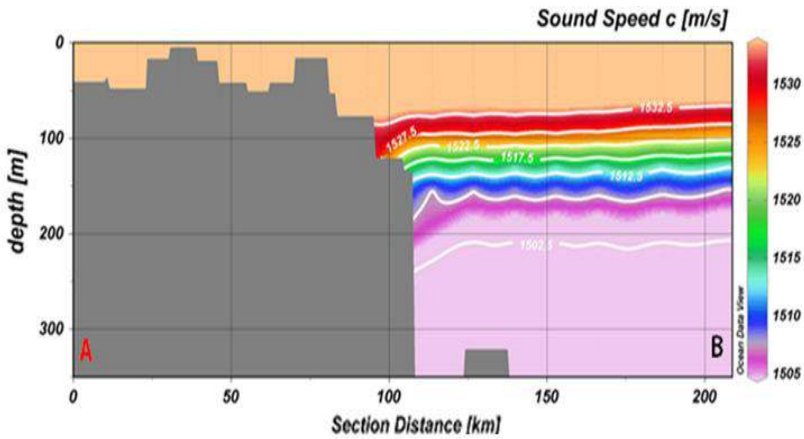

Figure 30. Approximate territory of the shadow zone In October.

Table 1. Thermocline layer structure in sunda strait.

Month	Upper Limit			Lower Limit			thickness	Temperature Gradient
	m	m/s	ºC	m	m/s	ºC	m	ºC/m
January	77.854	1542.005	28.085	155.851	1504.506	13.595	77.9971	0.18577
April	40.344	1541.499	29.385	130.666	1511.388	15.892	90.3219	0.14939
July	65.807	1542.563	29.279	155.851	1510.594	15.472	90.0437	0.15333
October	55.764	1538.204	27.213	155.851	1504.747	13.604	100.0867	0.13597

From the table 1 above we can observe that the deepest thermocline layer occurred in January starts at a depth of 77.854 m. While the thermocline layer in April is the shallowest with a depth of 40.3444 m. The thickest layers of thermocline occurs in October with a thickness of 100 m at a depth of 55.764 m down to 155.851 m. The thinnest layer of guests going in January with thickness 77.9 m which occurred at a depth of 77.854 m up to 155,851 m.

Thermocline layer upper limits distribution showed that the speed of sound has a range of between 1538 m/s up to 1542 m/s with temperatures between 27ºC to 29ºC. The distribution of the lower limit of the range in sound speed 1504-1511 m/s has a temperature between ~13°C to 16ºC. While the temperature Gradient occurs relatively above 0.13°C. with the highest gradient occurs in January and lowest in October. The findings about thermocline layer and probable shadow zone characteristics are in line with what founded by Sunaryo (2004), Teliandi et al. (2013), and Sidabutar et al. (2014).

The monthly difference values of the thermocline layer vertical boundaries, and its

The Thermocline layer and the probable Shadow zones that occur in the Sunda Strait

thickness indicates that seawaters of the Sunda Strait is very dynamic, and still affected by the existence of seasonally (monsoon) wind. This monsoonal wind brings seawater mass from the Java Sea and South China Sea, and also from Indian Ocean into Sunda Strait, and make a monthly/ seasonaly changing of thermocline layer (Pond and Pickard, 1983). The thermocline layers structure characteristic in Sunda Strait, reveals in respectively from the thickest to thinnest: October (100.0867 m), April (90.3219 m), July (90.0437 m), and January (77.9971 m). According to Harsono (2005), Wicaksana et al. (2015), and Siregar et al. (2017): In October, the wind in Sunda Straits is coming southeasterly from South Coast of Java, and also coming northeasterly from North Coast of Java (2-4 m/s). In April, the wind is coming southwesterly from Indian Ocean (2-3 m/s). Wind of July is the same pattern with October, only the wind speed is stronger (3-5 m/s). While the January wind is the same pattern with happens in April, only wind speed is stronger (3-5 m/s).

4. Conclution

are strongly influenced by the seasonal conditions in Indonesia. This can be indicated by the difference values of the upper and lower limits of thermocline structures. The potential for shadow zones are reveals in the thermocline depth range of 40 m to 77 m (upper limit) and 130 m up to 155 m (lower limit), with thickness of 77 m up to 100 m. The sound speed/velocity in the thermocline area has range of 1538 m/s up to 1542 m/s at the upper limit, and has range of 1504 m/s up to 1511 m/s at the lower boundary of thermocline layers.

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