Migration Letters
Volume: 20, No: S2(2023), pp. 1190-1198
ISSN: 1741-8984 (Print) ISSN: 1741-8992 (Online)
www.migrationletters.com

Indonesian Through-Flow Water Mass Circulation in the Makassar Strait and Lombok Strait, Indonesia

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Abstract

Indonesia through-flow has received much attention, largely because of its very important role in transporting mass, heat, and fresh water. The South Pacific water stream flows directly into the lower thermodynamics and deeper ITF components in the easternmost seas of Indonesia. In Indonesian waters, the excess regional freshwater enters the Pacific, which is subsequently altered by the mixture due to strong rushes to produce unique Indonesian waters. The aim of this study is to study the spatial patterns of marine water mass circulation in the waters of the Makassar Strait and the Lombok Strait as a basis for the development of ocean research. The research locations are in the waters of the Makassar Strait and the Lombok Strait, Indonesia. Temperature, salinity, and direction and current data from the ADCP OS75kHz and the SBE911Plus CTD instruments. The ITF in the Makassar Strait carries water masses originating from the North Pacific, namely North Pacific Subtropical Water (NPSW) thermomasses and North Pacific Intermediate Water thermomorphic underwater masses (NPIW). Domination by the southern stream component in the Makassar Strait due to the north-south-oriented stream configuration. The north-south component of the Makassar Strait's ITF stream dominates the flow from the Pacific Ocean to the Indian Ocean. On the Labani Cannel, the vertical spread of the current passing shows a higher current speed of the route in its northern part. This is due to the narrowing of the channel. Measured current speeds up to 1500 mm sec^{-1}. On the Lombok Strait, several layers of water are seen from its salinity. At a surface of less than 80 m, there is a water layer with a salinity of 33.8–34 PSU that tends to be homogeneous from the west to the east, with the direction of the current tending to the south. At the next layer, at a depth of over 80 m to 120 m, there are variations in the salinity of 34–34.6 PSU, with the value of the salinity tending to be homogenous on this layer in the dominant direction. The current movement that occurs in the waters of the Makassar Strait and the Lombok Strait is very complex.

Keywords: *Indonesia Through-Flow, Makassar Strait, Lombok Strait, Water Mass*

Introduction

The Indonesian Sea is the only low-latitude intersectional route known as the Indonesia throughflow (ITF). ITF is an important component of the Earth's climate system (Wyrtki,

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1961; Gordon, 1986). As part of the thermal circulation, ITF has received much attention, largely because of its very important role in transporting mass, heat, and fresh water. (Gordon, 1986, 2005; Broecker, 1991; Wijffels et al., 1992; Hirst & Godfrey, 1993; Schneider, 1998; Wajsowicz & Schneider, 2001; Gordon et al., 2003; Sprintall, 2014). Klaus Wrytk first described ITF in 1961 while on a sailing expedition in Banda waters (Purba & Faisal, 2020). It depicts that the ITF actually consists of several filaments of flow that occupy various levels of depth and cross the geometry of the island with vast shallow depths and deep dams. The largest seas in Indonesia are (from west to east) the shallow Java Sea, the deeper Flores Sea, Banda Sea, and Timor Sea, and the shallow Arafura Sea. In the Makassar Strait, the Dewakang threshold as deep as 680 m is only the upper part of the water to enter the Flores Sea and flow to the east towards the Banda Sea, or directly out into the Indian Ocean through the shallow Lombok Strait (300 m) (Godfrey, 1996; Gordon et al., 2008). The total net volume of ITF transport to the west and southwest all the time is the current flow from the Pacific Ocean to the Indian Ocean of 10–20 Sv (1Sv = 106 m^3s^{-1})

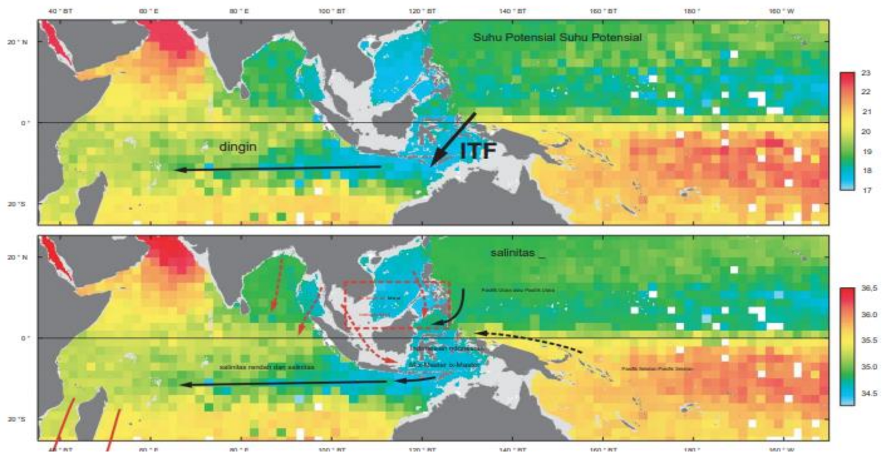


Figure 1. The temperature (image above) and salinity (image below) of the ITF input

Sorce; Gordon, 2005

ITF can be traced as a relatively cooler, fresher route, crossing the Indian Ocean near 12°LS. The weakening characteristic of ITF to the west is due to the lateral and vertical mixture of waters in the ITF route with the thermocouple waters of the Indian Sea. The South Pacific water stream flows directly into the lower thermodynamics and deeper ITF components in the easternmost seas of Indonesia. In Indonesian waters, the excess regional freshwater enters the Pacific, which is subsequently altered by the mixture due to strong rushes to produce unique Indonesian waters.

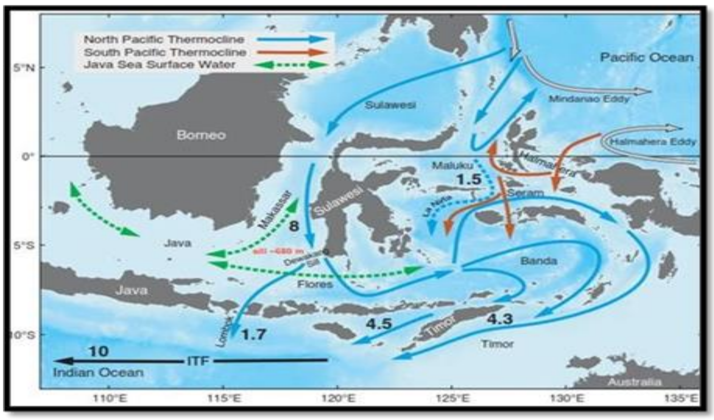


Figure 2. Map of the ITF line (*Source*: Gordon, 2005)

The ITF that crosses Indonesia's waters carries global water mass from the Pacific Ocean to the Makassar Strait and the Lombok Strait through the Sulawesi Sea. (Karl et al., 2015). According to Handayani et al. (2019), the ITF's Pacific Ocean water mass enters Indonesian waters, with the main variables of water mass being temperature and salinity. The waters are partly headed to the Banda Sea and partly directly to the Indian Ocean through the Lombok Strait. Makassar Strait and Lombok Strait are part of Indonesia's marine ecosystem and have a strategic role for fishing activities. (Mahzar et al., 2022). The potential of the Makassar Strait and the Lombok Strait is not only a biodiversity of high economic value but also its role in climatology. Research by Jufri et al. (2020) suggests that sea-level currents in the waters of the Makassar Strait during four seasons tend to fluctuate. The waters of the Makassar Strait and the Lombok Strait consist of coastal, oceanic, and a number of coral ecosystem spots. The flow of freshwater from the rivers in Kalimantan and ITF affects these marine ecosystems. The deep sea mass from the Pacific Ocean moves from the Pacific Ocean to the Sulawesi Sea into the Makassar Strait (2.540 m) and the Lombok Strait into the Indian Ocean. Part of the water mass moves into the Flores Sea and the Banda Sea through the Timor Trench (3.310 m) to the Sawu Sea (3.470 m) to the Indian Sea. (Jufri et al., 2020). The aim of this study is to study the spatial patterns of marine water mass circulation in the waters of the Makassar Strait and the Lombok Strait as a basis for the development of ocean research.

Methods

The research locations are in the waters of the Makassar Strait and the Lombok Strait, with data collection points between 115° 00'–120° 00' E and 1° 00' N–9°00' S. Temperature and salinity data obtained using CTD (conductivity, temperature, and depth) Seabird SBE911Plus The ADCP (Acoustic Doppler Current Profiler) Teledyne RDI Ocean Surveyor 75 kHz device, which was installed on the Baruna Jaya VIII Research Vessel, was used to get current data during the trip. The location and data capture point can be seen in Figure 3.

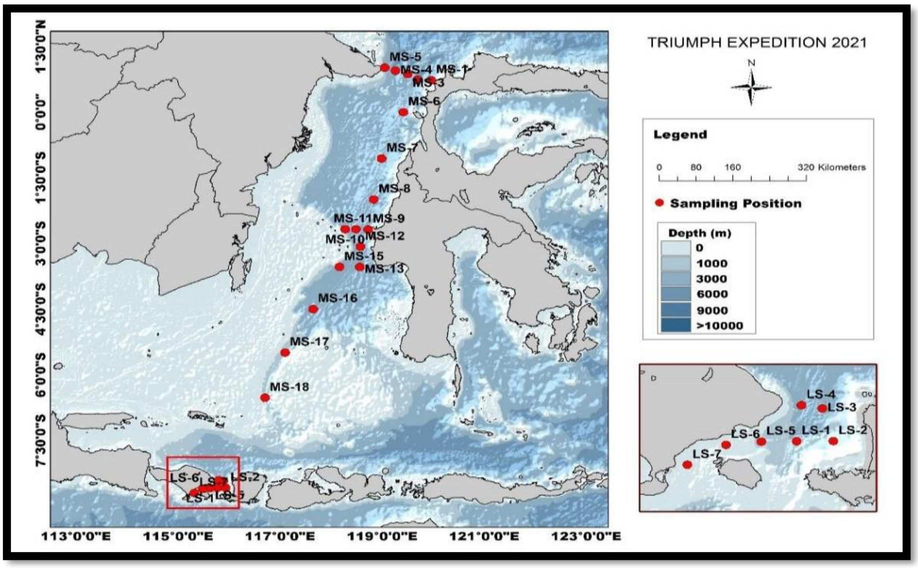
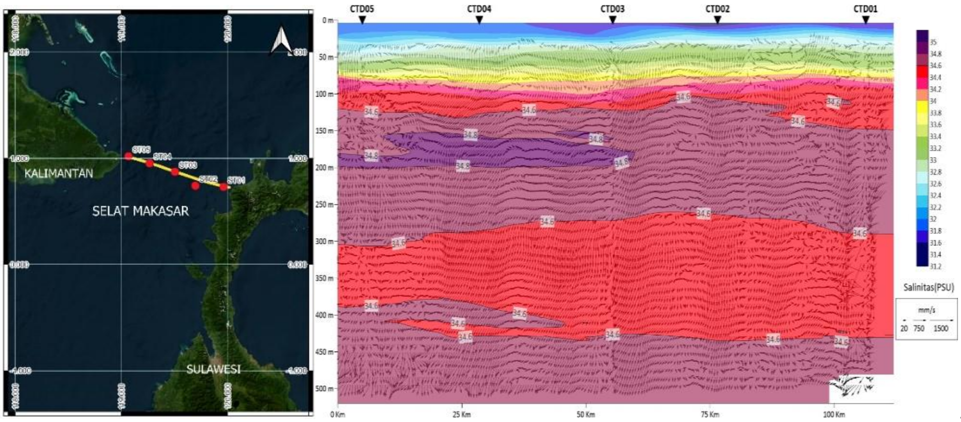


Figure 3. Location and data retrieval point

Temperature, salinity, and direction and current data from the ADCP OS75kHz and the SBE911Plus CTD instruments were put into ASCII format and processed in MS Excel. Graphs and maps were then made using Surfer Version 18 and QGIS Version 3.2.

Results and Discussion

The results of this study were made in a number of trajectory analyses that cut the Makassar Strait and also parallel to the Lombok Strait. On the Makassar Strait, there are three trajectories cutting: CTD01-CTD05, CTD09-CTD11, and CTD12-CTD14, and there is one trajectory cutting of the Lombok Strait: CTD25, 26, 29, and 30

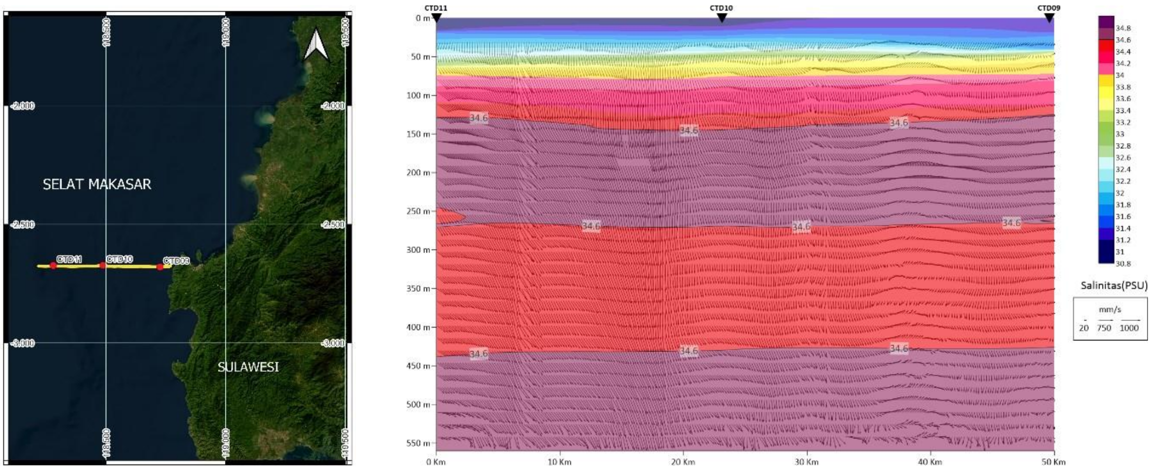


(a) (b)

Figure 4. (a) ADCP and CTD01-CTD05 tracks; (b) vertical spread graph of ADCP tracks and salinity (CTD01-CTD05)

The ITF in the Makassar Strait carries water masses originating from the North Pacific, namely North Pacific Subtropical Water (NPSW) thermomasses and North Pacific Intermediate Water thermomorphic underwater masses (NPIW). (Illahude and Gordon, 1996; Atmadipoera et al., 2009). On image 2(b) of the route in the northern part of the Strait of Makassar, several layers of water are seen from its salinity. At a surface depth of less than 50 m, there are water layers with a low salinity of 31–32 PSU in the eastern part of CTD01, CTD02, and CTD03 with lower salinities than in the western part of CTD04 and TCD05. The current direction of the surface layer indicates the dominant direction to the south on the western part of the track and varies on the eastern part due to seasonal winds (Ilahude & Gordon, 1996).

At a depth of 120–300 m, there is a water time layer with a maximum salinity of 34.6-34.8 PSU, which is the North Pacific Subtropical Water (Wyrtki, 1961), with the dominant direction of the flow to the South and Southwest. Next, at a distance of 300–400 m, the salinities are slightly lower (34.4–34.6 PSU) compared to the upper layer, with a dominant current direction to the south. At depths of more than 400 m, there are layers with a more stable salinity of 34.6 PSU (Iskandar & Purwandana, 2015), with a dominant flow towards the south.

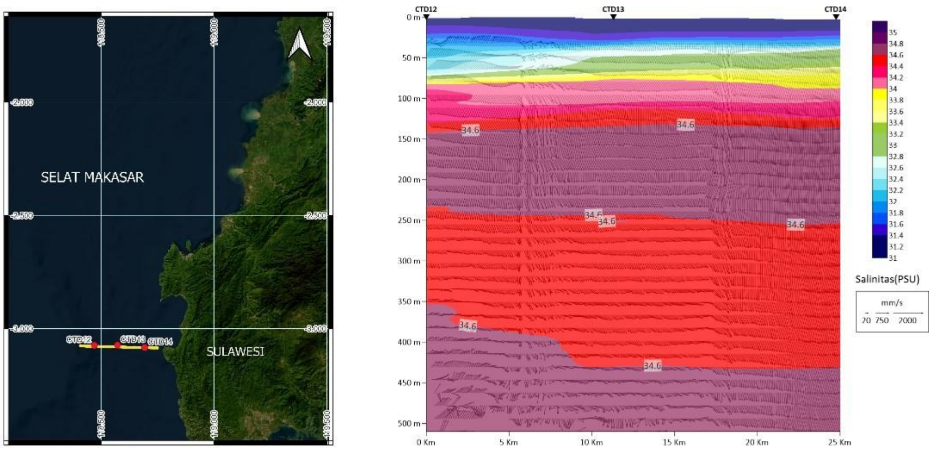


(a) (b)

Figure 5. (a) ADCP and CTD09-CTD11 tracks; (b) vertical spread graph of ADCP tracks and salinity (CTD09-CTD11)

In Figure 5(b) of the route in the middle of the Strait of Makassar, there are several layers of water seen from its salinity. On the surface section of less than 50 m depth, there is a layer of water with low salinities (31–32 PSU), which tends to be homogeneous from the west to the east, with the direction of the current dominating to the south.

At a depth of 150–270 m, there is a layer of water with a maximum salinity of 34.6 PSU and a dominant current direction to the south. Next, at depths of 270–430 m, the salinities are slightly lower than the upper layer, at 34.4–34.6 PSU in the direction of the main current to the south.



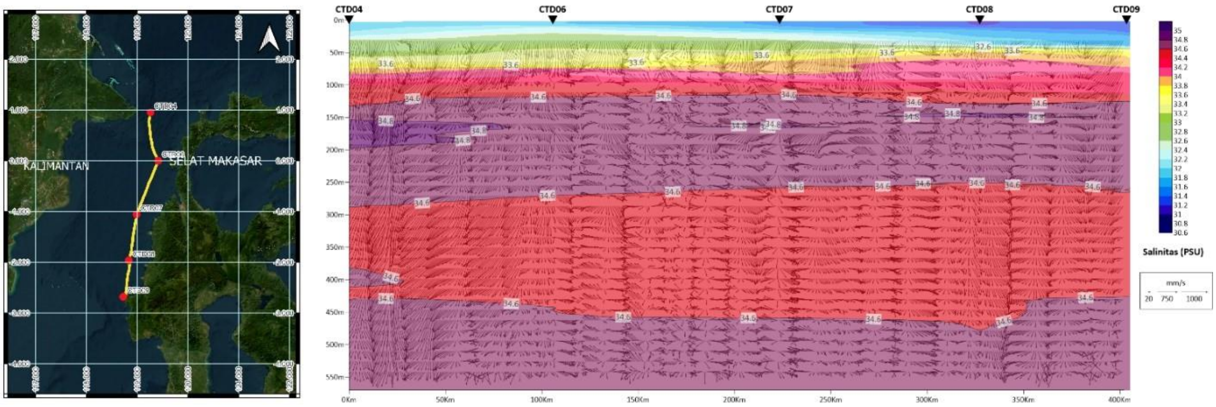
(a) (b)

Figure 6. (a) ADCP and CTD12-CTD14 tracks; (b) vertical spread graph of the ADCP tracks and the salinity of CTD12-CTD14

In Figure 6(b) of the route in the middle of the Makassar Strait (Lebani Channel), there are several layers of water seen from its salinity. On the surface part of a depth of less than 30 m, there is a water layer with a low salinity of 31–32 PSU, which tends to be homogeneous from the western part to the eastern part. On the next layer, at 30-80m depths, the salinities vary more than 32–34 PSU, with the salinity values in the western part lower than in the east direction of the dominant current to the south.

At a depth of 150–250 m, there is a water time layer with a maximum salinity of 34.6 PSU and a dominantly homogeneous trending current direction to the south. Next, at the depths of 250–400 m, the salinity is slightly lower than the upper layer, with salinity values of 34.4–34.6 PSU in the dominant direction of the current to the south.

If viewed as a whole layer from the surface up to 500 m, the dominant current direction to the south at an average speed of 1500 mm/second is in the eastern part (CTD14).



(a) (b)

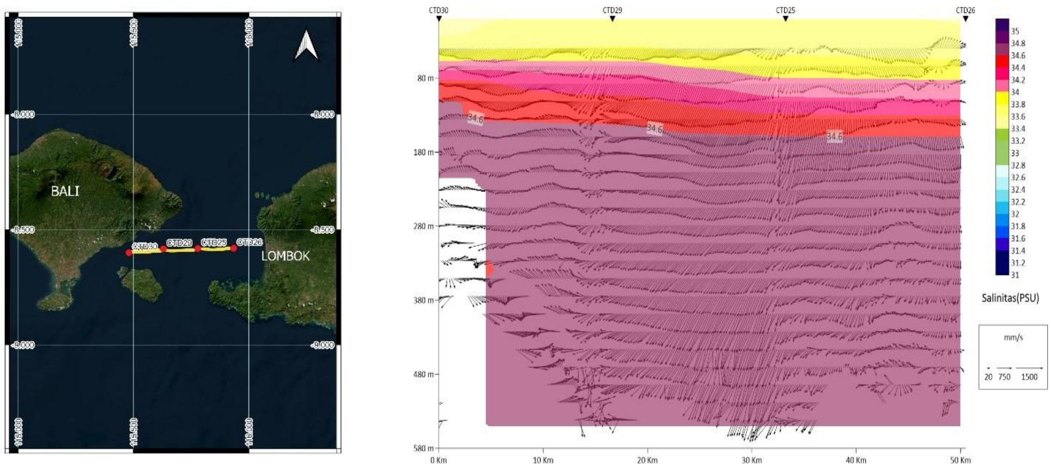
Figure 7. (a) ADCP and CTD04 tracks, CTD06, CTD07, CTD08, and CTD09

In Figure 7(b) of the route along the Strait of Makassar, there are also several layers of water seen in its salinity. On the surface of a depth of less than 30 m, there is a water layer with a low salinity of 31–32 PSU and a lower salinity in the section. On the next layer, at a depth of 30-80 m, there are salinities that vary more than 32–34 PSU, and the lower saltiness is in the north. On this layer, the dominant current goes to the south.

At a depth of 130–280 m, there is a time layer of water with a maximum salinity of 34.6 PSU and a dominant current direction to the south. Then, at a depth of 280–400 m, the salinities are slightly lower compared to the upper layer, with a salinity value of 34.4–34.6 PSU in the direction of the dominant currents to the south.

Domination by the southern stream component in the Makassar Strait due to the north-south-oriented stream configuration (Atmadipoera et al., 2016). According to Susanto et al. (2012), Gordon et al. (2012), Mayer dan Damm (2012), and Horhoruw et al. (2015), the north-south component of the Makassar Strait's ITF stream dominates the flow from the Pacific Ocean to the Indian Ocean. On the Lebani canal (Figure 6.a), the vertical spread of the current passing (Figure 6.b) shows a higher current speed of the route in its northern part (Figur 5.a). This is due to the narrowing of the channel. Measured current speeds up to 1500 mm sec^{-1}.

It appears from the whole picture that the vertical spread of the current in the area of the Basic Strait is on the weaker surface layer. The weakness of surface currents in the west is due to the pressure of water masses from the south of the Makassar Strait, which impedes the flow of surface water mass from the Pacific Ocean to the Indian Ocean, whereas in the east, the gradient to the north decreases due to a reversal of wind direction, so that the surface current intensifies. (Gordon et al., 2003).



(a) (b)

Figure 8. (a) ADCP and CTD25, CTD26, CTD29, and CTD30 tracks; (b) vertical spread graph of ADCP tracks and salinity of CTD25 and CTd26, TCD29, and CTD30

In Figure 8(b) of the route on the Lombok Strait, several layers of water are seen from its salinity. At a surface of less than 80 m, there is a water layer with a salinity of 33.8–34 PSU that tends to be homogeneous from the west to the east, with the direction of the current tending to the south. At the next layer, at a depth of over 80 m to 120 m, there are variations in the salinity of 34–34.6 PSU, with the value of the salinity tending to be homogenous on this layer in the dominant direction.

At a depth of more than 120 m, there is a water time layer with a maximum salinity of 34.6 PSU and a homogeneous direction of the current tending to dominate south, especially in the middle part of the track (CTD25).

While monsoon winds typically have an impact on the movement of surface currents in Indonesian waters, the Pacific Ocean water mass that crosses Indonesian waters to the Indian Ocean through the ITF affects the flow patterns in the waters of the Makassar Strait and the Lombok Strait in the deeper layers of water. (Bayhaqi et al., 2017). The intense thermochrome in Indonesian waters is visible as the temperature drops from approaching 26°–28°C at a depth of 75 m to 10°–12°C at 300 m. The contrasting levels of salinity from the northern and southern Pacific inputs resulted in a more varied salt profile in the Indonesian seas. Evolution of water mass stratification due to ITF flows negotiating Indonesian marine complex topography. Vertical mixing is a dominant factor on the water surface, with isopycnal mixing becoming dominant in the lower thermocline.

Conclusions

The current movement that occurs in the waters of the Makassar Strait and the Lombok Strait is very complex. In connection with these waters is a region with oceanographic characteristics that is located in the region and has two main current systems that pass through it, namely the ITF and the Indonesian monsun Stream, The interaction between the rainy western season, the wet eastern season, and the ITT affects the circulation system and current patterns in the water of the Makassar Straits and Lombok Straits.

Acknowledgment

Thank you to the National Research and Innovation Agency Indonesia and the First Institute of Oceanography, Ministry of Natural Resources of China.

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