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Temperature-Salinity stratification in the Eastern Indian Ocean using argo float

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Abstract. The spatial and temporal of Temperature and Salinity in the Eastern Indian Ocean (EIO) are studied by using Argos data. EIO consisting of Pacific seawater mass which passing through Indonesian seas and mix with Indian Ocean itself that form complex formation. It reveals link among ITF, SEC, Leeuwin Current, and SJC and routes into global circulation. The purpose of this study is to describe the main physical properties variability based on Argo Floats data. The dataset is used from 80 Argo Floats during 1999-2016 within area south of Java to west of Australia with depth range 0-2000 meters. The result shows that vertical temperature and salinity profile quite homogeny near Sunda Island-West Australia. Monthly spatial distribution of temperature is founded 15-30^0 C, and varying in lesser Sunda. Vertical profile in 4 sections is shallow at near Java, but shows differences in 25 horizontal. Salinity profile is having range 25-34 psu. ITF is contributing to EIO mixing. Finally, salinity is a parameter that affects the EIO dynamics especially in near Australia basin. The SEC variability showed clear in between 10^{0}S to 15^{0}S.

1. Introduction

East of Indian Ocean (EIO), also known as South Indian Ocean (SIO) [1] is relatively complex and of the representation of unique characteristic in Indian Ocean. EIO covering south of Java Island, Timor Seas, and Western Australia. The presence of several inputs and its dynamics principally controlled by Pacific and Indian Ocean itself has been confirmed. Seawater mass via Indonesia i.e. ITF [2, 3], come from Indian Ocean itself (South Equatorial Currents; SEC), and Leeuwin currents flows southward [4, 5, 6, 7]; South Java Current (SJC) [8] and also monsoonal periodic [9]. EIO becomes area that water mass from Indian and Pacific Oceans meet [10] and flow water mass from east boundary to west. Both ITF and Leeuwin play important roles in global and regional circulation scales. The mixing and process lead to understand the pattern linkage into global circulation. A proper representation of EIO is particularly important. EIO consists of tropical and sub-tropical area [11] which temperature and salinity play important issues in term of physical, biological, and chemical processes in the ocean. A good representation of the mixed layer in the Southern Ocean is particularly important feature because various mechanisms add to force the circulation in EIO area.

From the previous research, subsurface data could not be collected over whole ocean basins simultaneously [12] because limited instrument and time. Argo Floats (AF) as dynamics in situ measurement brings a new era in oceanographic observation. The Argo program is a major component of the Global Ocean Observing System and strives to monitor the evolving temperature and salinity fields of the upper ocean [13, 14, 15]. Since AF launched in 1999, there are 3,814 AF worldwide operating (update July 2017). For wide range spectrum of research [16] such as for Mixed Layer Depth (MLD) stratification, [17] for mesoscale eddies, and near real time access data, AF becomes one of instrument to describe ocean phenomena. This method is used vary widely, and become important measurement for in situ observation. Argo observations in the Indian Ocean are creating new insights from many different authors on a variety of subjects especially in oceanography fields.

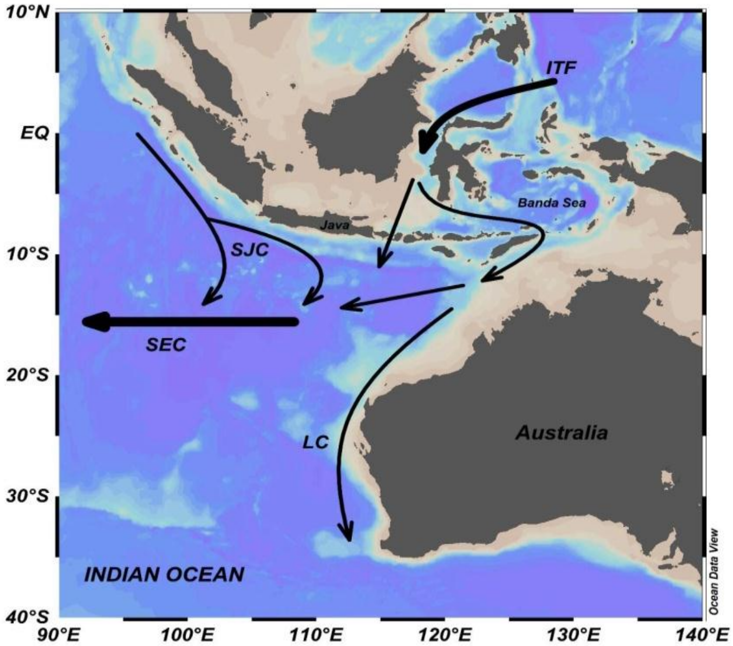

Figure 1. Schematic circulation in East of Indian Ocean (after [18]). SJC (South Java Currents) flows around Sumatera and Java, SEC (South Equatorial Currents), LC (Leeuwin Currents) from ITF flows southward, ITF (Indonesia Troughflow) is a part of Makassar flows.

Studying of Indian Ocean dynamics using AF is much more effective and cheaper than by using research vessels. ITF and SEC occurred along the year, but ITF is at its peak during Southeast Monsoon. A strong ITF current leads to LC current strengthen, meanwhile SJC at its peak on Northwest Monsoon season. The meeting of all the currents will result a changing pattern of monthly and yearly ocean variability in Indian Ocean. In this study we attempt to investigate the dynamics of EIO by investigating spatial and temporal temperature and salinity from Argos data. The objectives of this research are to enhance the water properties in EIO. Here we will concentrate on the different source and pattern near Indonesia-Australia basin. The EIO define between the northwest coast of Australia and the Indonesian islands of Java and Sumatra is termed the Indo-Australian Basin.

2. Method

Area of Study is laying in the Eastern Indian Ocean near basin Indonesia-Australia (90.0 E-130.0 E and 0.0-30.0 S) (figure 2). The northern boundary is limited to Sumatera, Java, and islands near Bali, while the eastern boundary is Australia. Vertical structure and spatial distribution investigated using Argos profile from August 1999 to June 2016. Each floats diving into a depth (typically 1,000 to 2,000 m) and drifts freely. In every 10 days, it swimming up to the surface and acquisitioning temperature, conductivity (salinity), and pressure. The accuracy of Argo for temperature is 0.005^{0}C and 0.01 PSU for salinity. Argo Files is downloaded from the Argos server www.argoweb.whoi.edu. These data were collected and made freely available by the International Argo Program and the national programs that contribute to it (http://www.argo.ucsd.edu, http://argo.jcommops.org). The Argo Program is part of the Global Ocean Observing System. We only use good quality coverage for analysis [19]. Complete documentation can be seen in http://www.argodatamgt.org.

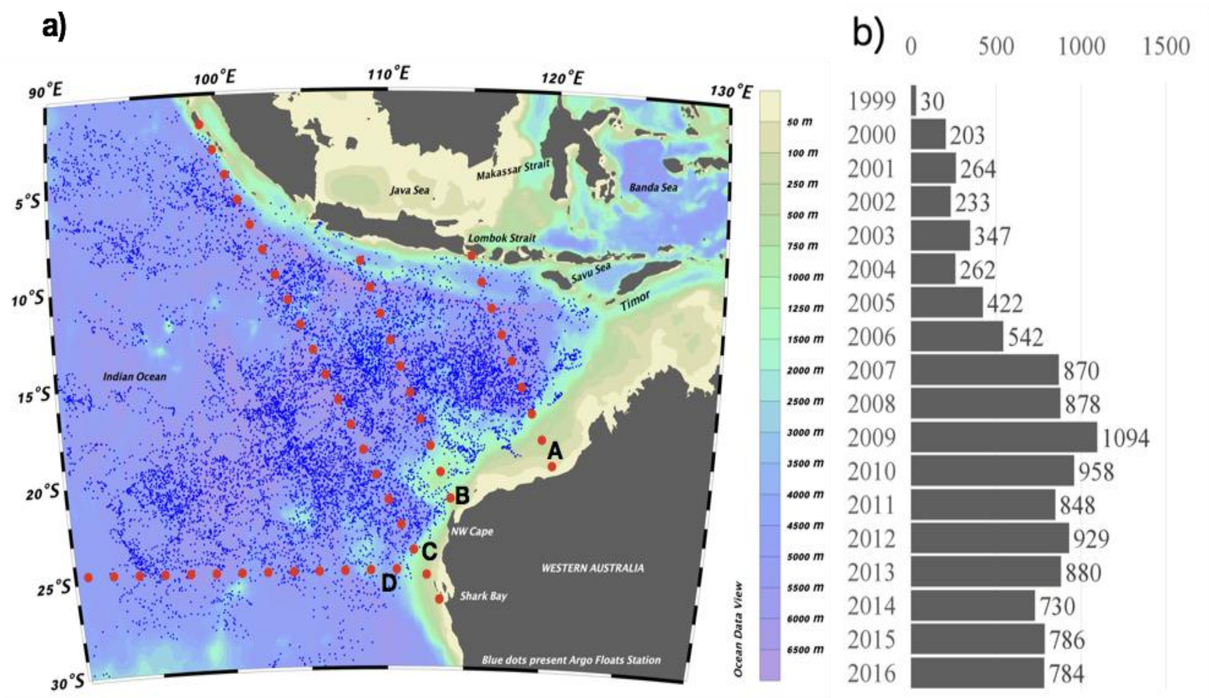

Figure 2. Area of EIO and Argos distribution, a) Distribution of Argos and four section in EIO area and b) Argo counts from 1999-2016 (bottom topography these water masses is dominated by the presence of Indonesia basin or south Java Basin, Perth Basin, and West Australia Basin with depth from 50-4000 meters

The number of profiles increases since launched in 1999. We also visualize with Ocean Data View [20]. We only use pressure (P), temperature (T), and salinity (S) in good quality data and probably good quality data to analyze [17]. Here we visualize vertical and spatial structure of temperature and salinity. We analyze 4 vertical sections to describe some phenomena in East of Indian Ocean. Three sections are over Indonesia-Australia, and 1 is over Australia. Section A (115^0 E) is located near Bali-NW Cape as ITF representative; Section B (110^0 E) is located in Lesser Sunda-NW Cape as ITF-SCJ-Leeuwin characteristics; Section C (100^0 E) is located in Sumatera-Shark Bay as SEC-Leeuwin; Section D is located at Shark Bay (25^0 S) as a Leeuwin boundary (22^0 S-34^{0}S). There are 11,332 data stations acquired from 80 AF. In this study, we only investigating 0 - 500 m depth and represent mixed layer, thermocline and halocline layers, and deep layer.

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3. Results

3.1. T-S Profile

The location of water masses, and their relative position to each other can be identified using Temperature and Salinity (T-S) diagram. T-S profile shows the difference characteristic of density for each station. For Argo stations that close to each other like the ones around Savu and Java Seas has a similarity on its seawater characteristics. If it compared to station around West Australia Sea, shows a large range of characteristics differences. These because the presence of mixing forms a large range of characteristics differences in the EIO [21]. The water masses in EIO forms by Indonesian Upper Water (IUW), Indonesia Intermediate Water (IMW), South Indian Central Water (SICW), Antartic Intermediate Water (AAIW).

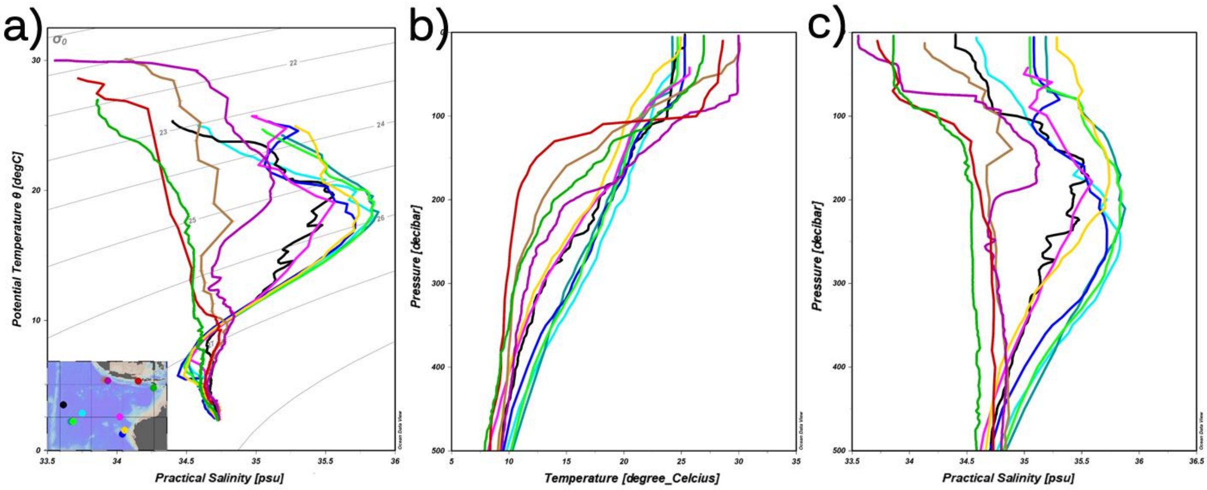

Figure 3. Temperature and Salinity profile from several path in EIO (inset) a) T-S diagram assumed some watermass properties. Four dots near Java island to describe South Java Currents (SJC) and ITF, three dots assumed near Australia (Leeuwin and ITF), and three dots in the centre of EIO to find out the SEC, b) and c) Temperature and Salinity vs depth profiles up to 500 meters.

See Figure 3 (inset picture). Seawater mass in the outflow area of ITF (red is near Lombok and green dot near Savu) directly affected by seawater mass from the North Pacific [2]. Seawater mass in this station has mean temperature about 28°C, with its mean salinity is 33.75 PSU. The same mean values have been found also from several research [8,22]. A drastic descending of temperature found in the ITF outflow area (15°C, in 200 m depth). Seawater mass characteristics in the EIO supplied from varies watermass. Two main source flows from Subtropical Indian Ocean (SIC) and Australasian Mediterranean Sea [23].

3.2. Temporal and vertical Stratification of Temperature and Salinity

EIO entrances and follows some different paths before link/joint to equatorial currents flows to Western Africa. From sections analysis in Figure 4, temperature and salinity throughout lesser Java and Bali having a very unique pattern profiles.

Temperature and salinity profile from 2000-2016 shows unique water mass characteristics. The thermocline layer in sections A, B, and C founded in 150-400 meter, in section D it found from 150-500 m depth. The temperature at the surface (mixed layer) ranged from 22.5°C-30°C with the lowest temperature in section D (Subtropical area). Vertical temperature profile tended to fluctuate in section C which is from South Sumatera Sea to Australian Sea with monthly interval. The value of temperature on the mixed layer changes monthly, with the mean value 27.5°C. The same pattern also found in section B and C.

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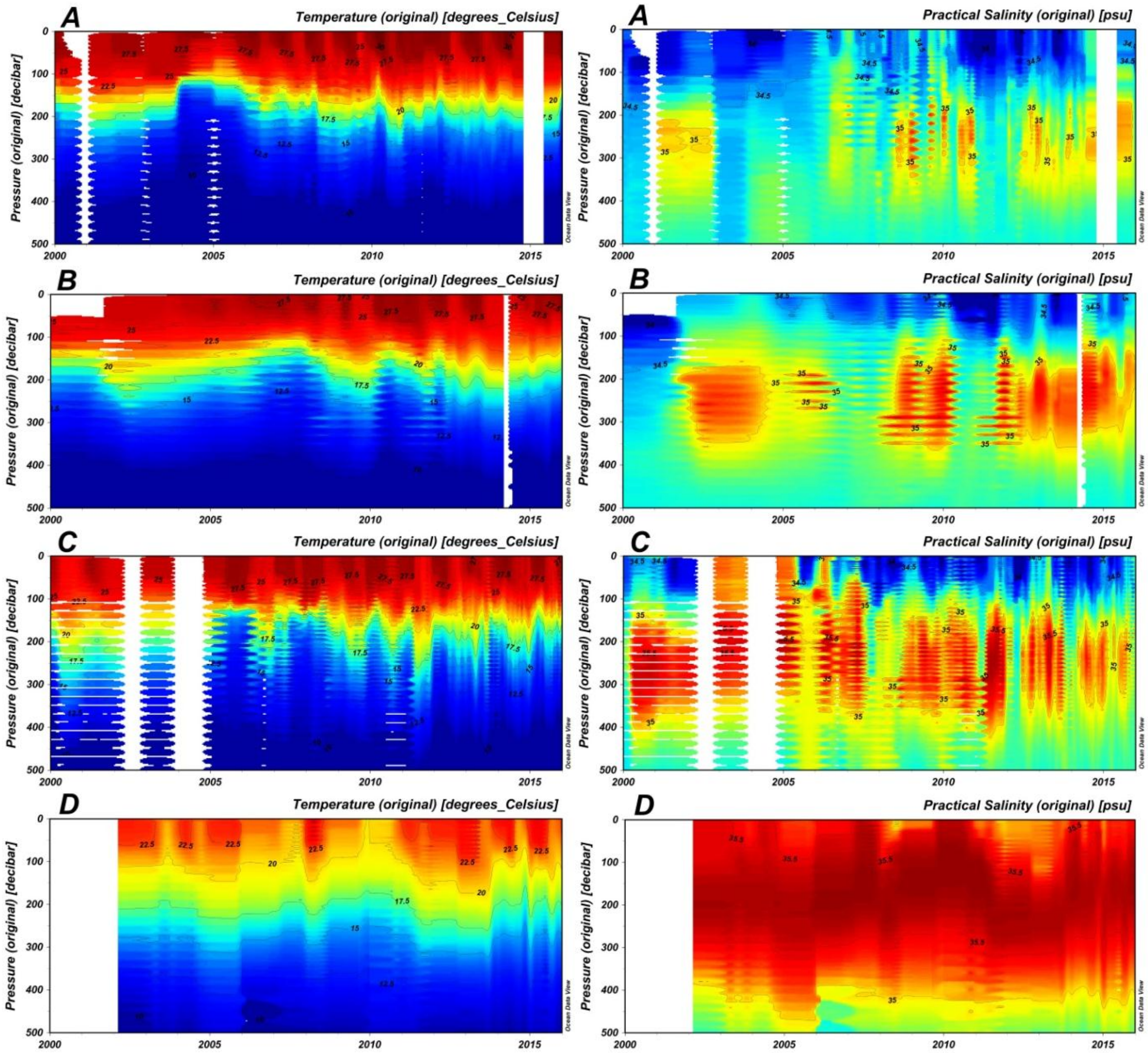

Figure 4. Vertical section over time (left) Temperature, (right) Salinity

The salinity profile (34 – 35.5 PSU) is more vary than temperature. Halocline layer found about 200 meter depth. The salinity profile doesn't have similar pattern with temperature profile. A fluctuated salinity distribution found in section C with halocline condition developed differently every month.

For section A, the profile of Bali Strait-NW Cape, with a deeper mixed layer (100-150 meter) and thermocline range from 50-75 meter depth. In the surface, water temperature is higher around Bali Strait shows that there is water mass added from Makassar and Banda Seas. Profiles A to C show insignificant differences, but profile D shows a very different water temperature characteristics. As regards the distribution of heat content, the distribution in the whole deep appears to be uniform, values ranging from 10-15^{o}C.

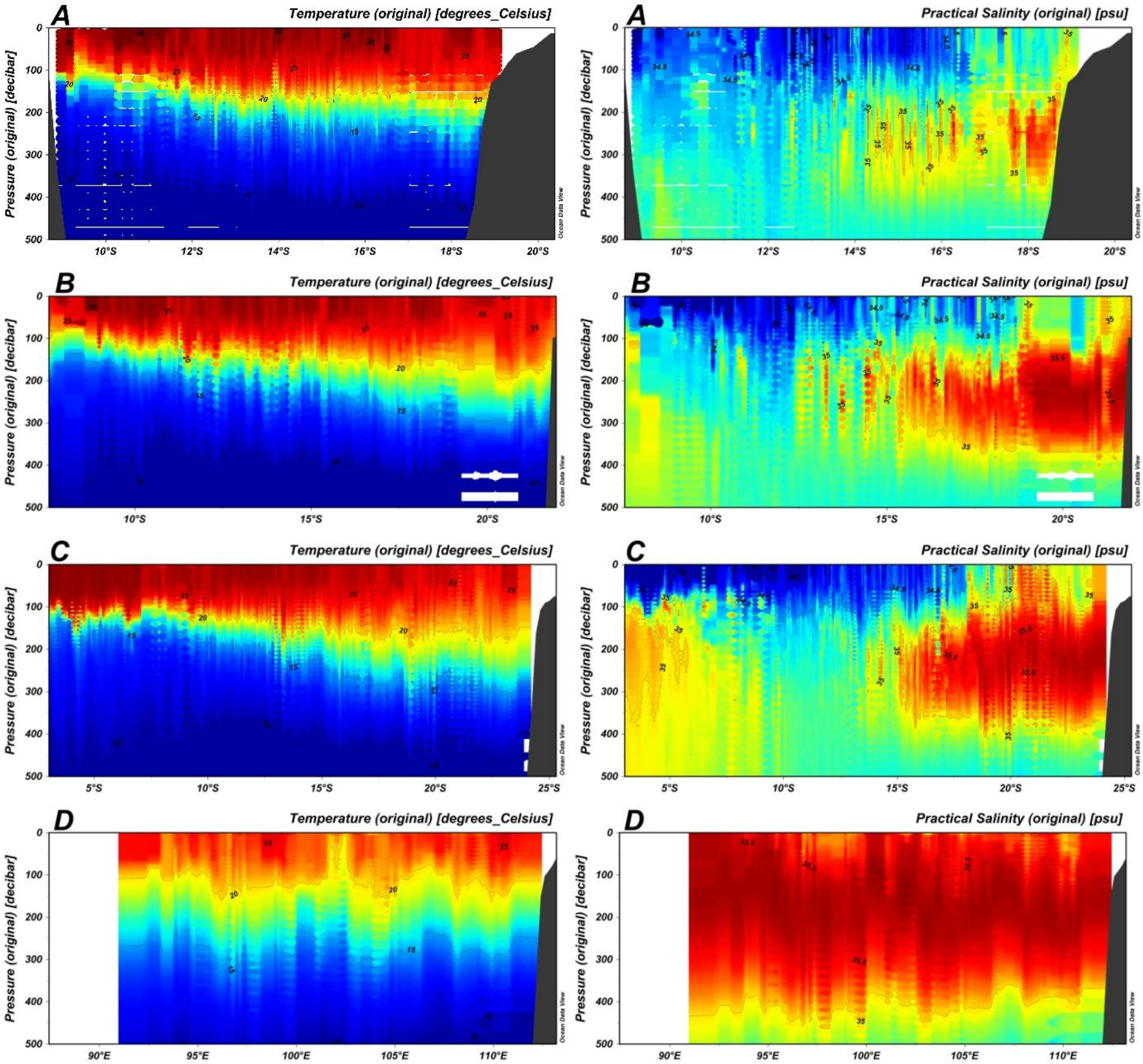

Figure 5. Stratification water mass (left) Temperature, (right) salinity

Salinity profile for section A to C displaying a higher salinity around Australia Seas (35-35.5 PSU), meanwhile salinity around Indonesia Seas is lower (34-34.5). The lower salinity around Indonesia Seas caused by the input of freshwater from SJC. The semi-annually reversing SJC plays an important role in distributing freshwater into and out of the southeast Indian Ocean [24]. For section D (25^{o}S) shows a very different profile than the other section, it's because section D is approximately the boundary of subtropical and tropical zone. The vertical stratification of salinity shows the presence of a salinity maximum zone in the southern of the section. The minimum salinity value is observed near Java within the mixed layer. The vertical distribution of temperature and salinity content is very similar to that in section A and C, especially in the upper layers.

3.3. Spatial variability of Temperature

In the surface layer, SST shows a very distinctive difference in 15^{o}S, 20^{o}S, and 30^{o}S. On January to April, ITF strengthen and causes the temperature arises to about 30^{o}C. The changing temperature also shows in West Sumatra (5^0S), especially the rising temperature started from April. The rising temperature also altering the boundary at 17^oS and then expands to about 20^oS, but LC with maximum transport is around 22^oS [1].

Spatially, the changing of temperature on the surface is very dynamic especially in the seas close to Indonesia region. The boundary of temperature is very clear in $15^{o,}$ 20^o, 25^o. The heat carried by the (ITF), as it follows its circuit route through the basins and multiple narrow impacts of both the Pacific and IO [25] and moved water mass from Pacific to IO [26]. The total distance ITF in IO to southward path from 10^0S until 20^0S near the NW Cape 1110 km.

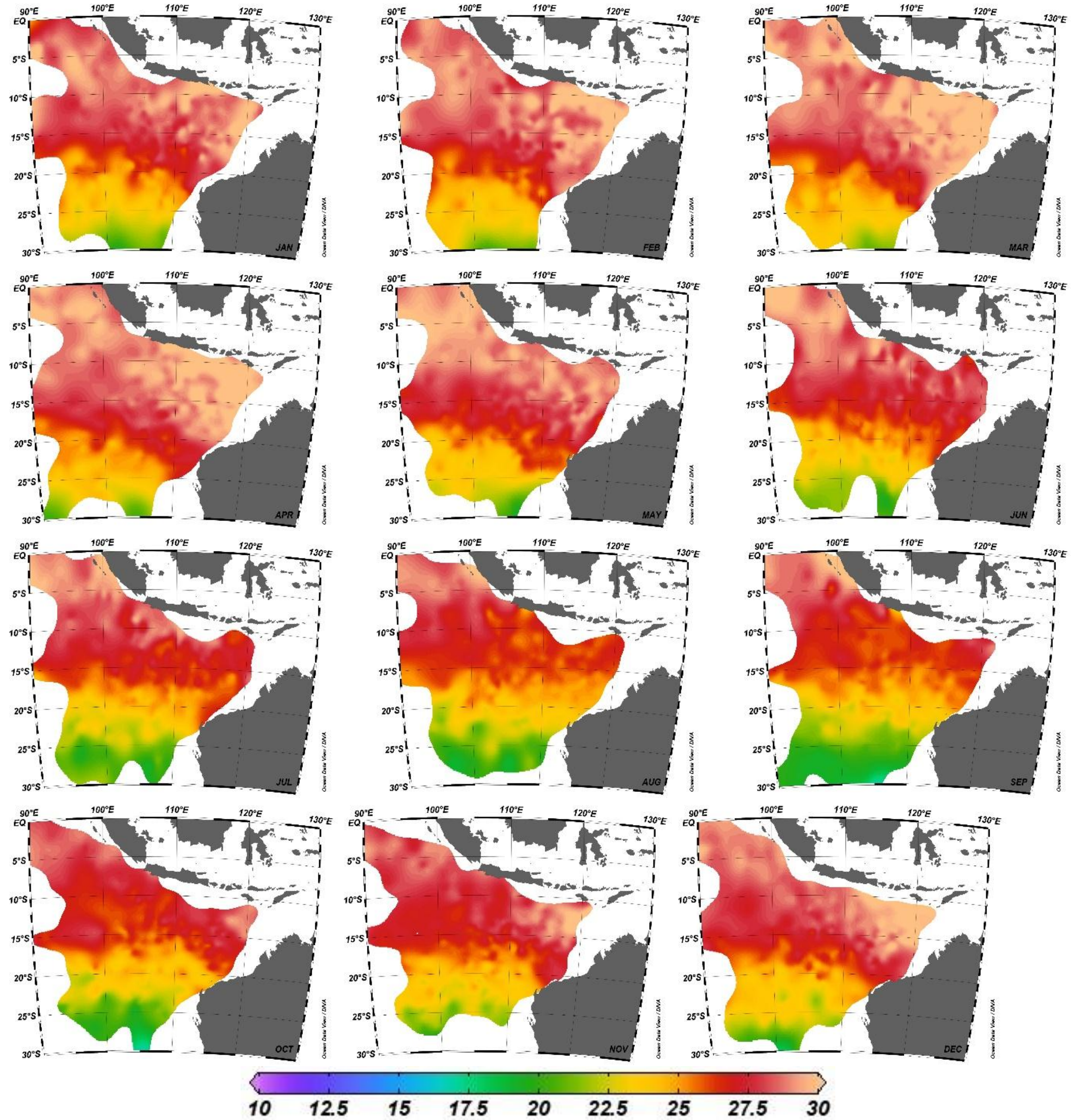

Figure 6. Monthly temperature profile in ~4 meter (4dbar)

The temperature of water mass coming from Pacific Ocean via Indonesia Troughflow (Bali Strait at 115^0 E and Savu at 121^0 E) as primary outflow expands to 20^oS and promotes a stronger LC. In summer months, added warm from tropical and salt from Western Australia Current. Thereafter, the cold temperature water from subtropical south expands northward in May to about 20°S with minimum temperature 17.5°C. Range temperature near 30°S is 23-32°C [5]. The flow starts in February and peak in June. In August and September, water from Antarctic penetrates as far to 20°S [21]. Variability in the SEC in EIO region is weak during Jan-May, but is strong during Jun-Oct. The strong SEC liner with strong flows of ITF to Indian Ocean [2].

3.4. Spatial variability of Salinity

The SJC reverses to southeastward flow semi-annually around May and November, SJC has been found to consist of narrow cores of accelerated flow extending to 150-250 m depth [10, 27]. Near NW Cape, salinity rises. The lower salinity around Sumatera and Java occurred monthly, with range about 33-35 PSU. Low salinity water is carried out southward in some area at Java strait and near Bali.

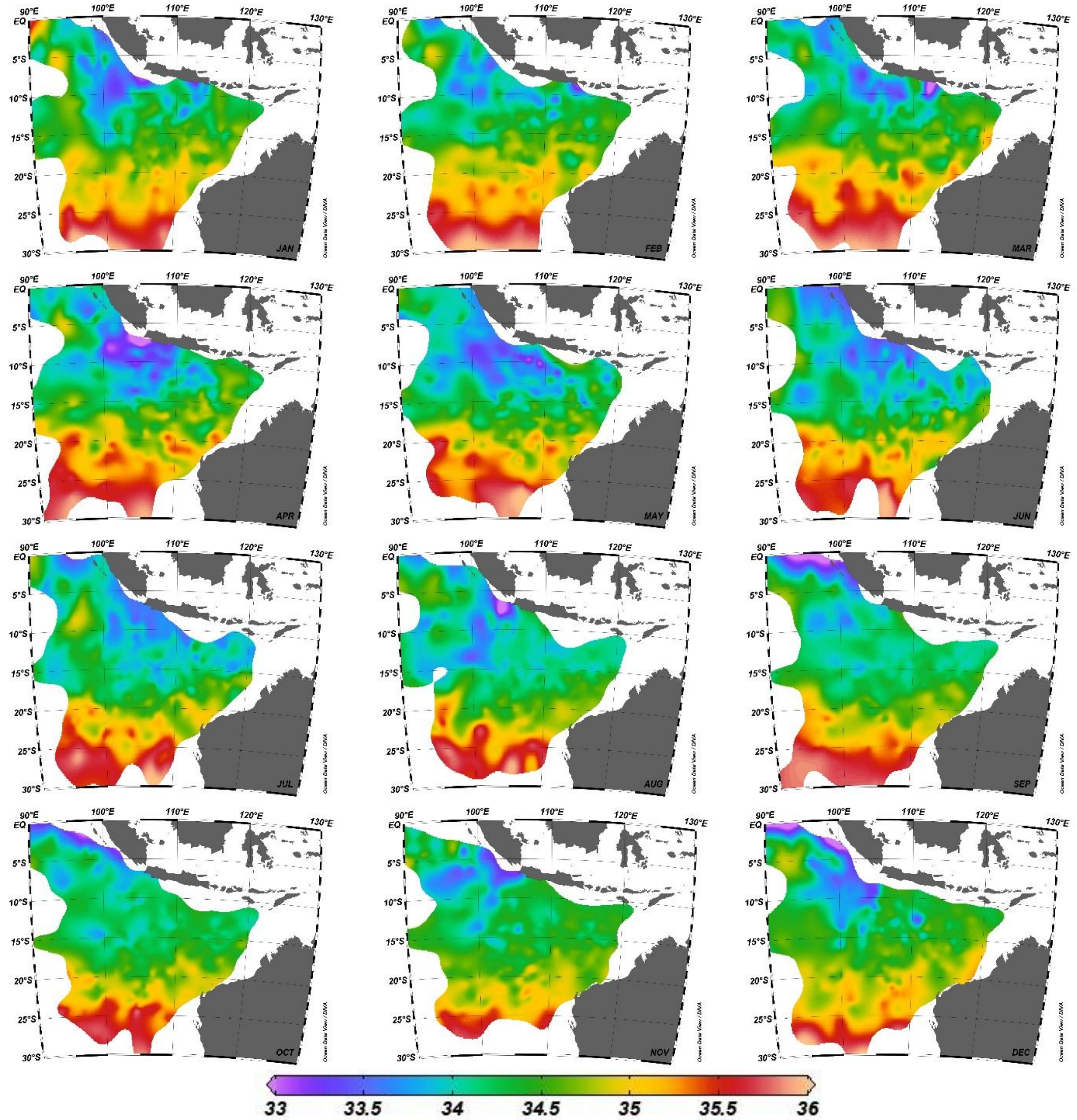

Figure 7. Monthly salinity profile in ~4 meter (4dbar)

The changing pattern near Indonesian Seas also followed by change pattern in the South Indian Ocean (20 °S -25°S). For the occasion of the decreasing salinity in the Indonesia Seas. It causes the high salinity moves southwardly. This probably caused by strengthen of SEC with salinity range 34.2-34.7 PSU and have been recognized [23]. Based on model [20] salinity in near 30°S with range 31.5-35.3 PSU. The eastern of Australia in May with strong salinity fronts [6].

4. Conclusion

We have described the characteristics and variability of temperature and salinity using Argo profiles in EIO between 1999-2016. This more precise description about using Argo's to assess the characteristics in Indonesia-Australia that linked to SEC. ITF contributes a huge impact on the changing of temperature and salinity in the EIO. The water mass profile on the seas close to Sumatera-Java-Bali tends to fluctuate highly, and there is a distinctive stratification in salinity and temperature profile. Salinity can play a strong role in the density stratification of EIO. Temperature and salinity varies in all seasons, and furthermore the temperature structure in the upper water column can vary depending on the season. SJC not able to be seen clearly from the temperature and salinity contour, this probably caused by the deficient resolution of Argo. But overall, AF defines temperature and salinity adequately in all sections. From all section, the description of SJC is not clear to define in the spatial contour. This is might be the position of Argos is not close to Java.

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