WATER MASS ANALYSIS OF THE INDONESIAN THROUGHFLOW BY MEANS OF PRINCIPLE COMPONENT ANALYSIS

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Abstract

The water masses in both routes of Indonesian Throughflow (ITF) from historical hydrographic data are examined by means of the Principal Component Analysis (PCA), a multivariate statistical technique, during the southeast monsoon and northwest monsoon, and compared with the TS diagrams. The temperature and dissolved oxygen always play in the same PC, which describes a variability contribution of the water mass characters, while salinity in a different PC. The relationship of the water masses parameters may indicate the character of dissolved oxygen as a non-conservative tracer. The Principle Component Analysis may also be used to follow the trends of core layer attenuation as verified by the salinity corresponds at the PC. It will be higher with S-max and S-min and more closely resemble the sources. This condition is shown in the waters close to the main sources in the Pacific, like Sulawesi, Maluku and Halmahera Sea, where both the salinity extrema can still be observed. Conversely, in the Banda and Timor Sea, where S-max and S-min are greatly attenuated even completely removed, the correspondence of salinity in the water mass character variability becomes smaller.

As seen on TS and TO diagrams, PCA graphics are also showed the dominant of the North Pacific water in the western route seas, the Sulawesi, Makassar Strait and the Flores Sea, but relatively salty water of South Pacific origin is observed in the Halmahera Sea, particularly in the northwest monsoon. The strong seasonal variability of surface water in the Indonesian can also be observed in the PCA graphics.

Keywords: Water Mass, Indonesian Throughflow, PCA

I. Introduction

The Indonesian Throughflow (ITF) is an interocean flow of the tropical thermocline water from the Pacific Ocean to the Indian Ocean through the eastern Indonesian seas. The through flow plays an important role in a global thermohaline circulation as a part of a surface water flow to complete the ocean circulation, which begins in the Northern Atlantic Ocean and also influences the global climate.

There is much attention in recent literature to this throughflow, for instance the relative contribution from the direct North Pacific and South Pacific water into the archipelago and on into the Indian Ocean. Most the oceanographers use the water mass property curves to analyze the characteristic of the water mass, but in this study we try to use the Principal Component Analysis (PCA) to follow the trend of the core layer attenuation and evolution of the shape of potential temperature, salinity and dissolved oxygen relationship.

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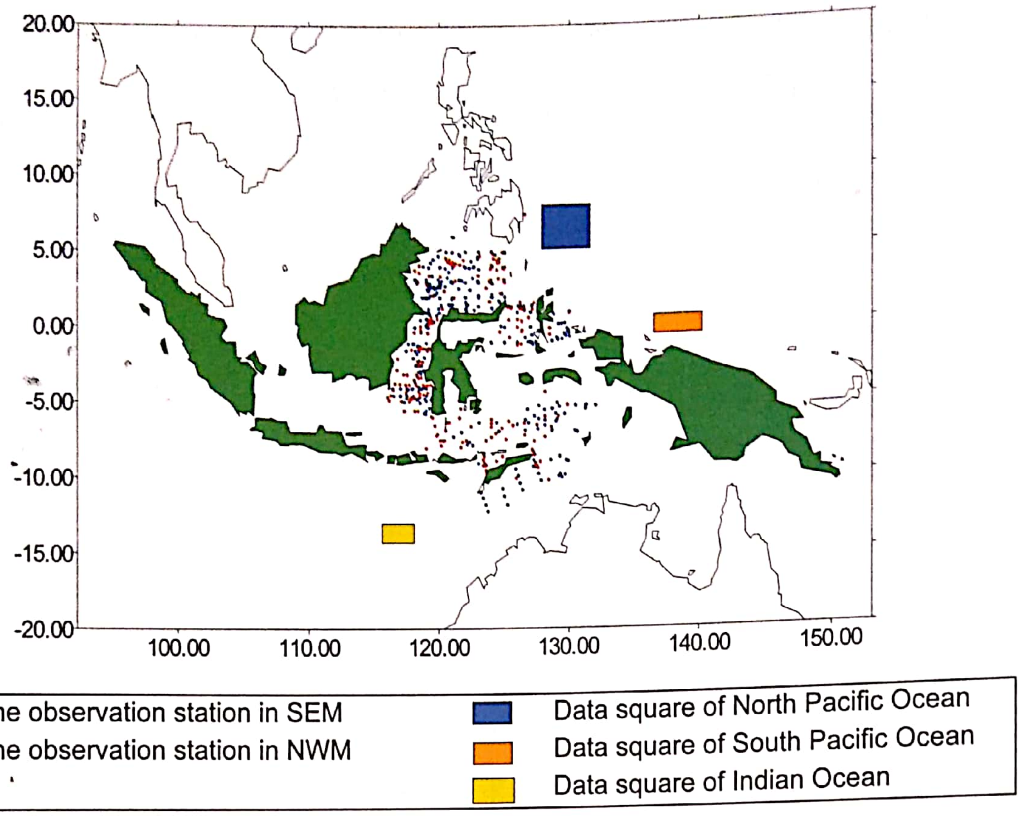

Fig. 1. The Position of observation station of the Indonesian Throughflow research

PCA is a useful technique for compressing the variability in time series data, that is also commonly known as Empirical Orthogonal Function (EOF) analysis (Emery and Thompson, 1998[1]). Basically, PCA is a multivariate statistical technique that deals with the internal structure of matrices (Ludwig and Reynolds, 1988[2]), which measures an Euclidean distances, i.e. the sum of the square difference of two stations of the parameter that correspond to the data. More closely, the Euclidean distance of the two stations have more resemblance to both character masses and vice versa (Dillon and Golstein, 1984[3]). This condition might be allowing the possibility of PCA as one of the water mass analysis.

II. Materials and Methods

This study examines the water masses characteristics in both routes of ITF, the western seas i.e. Sulawesi Sea, Makassar Strait and Flores Sea, and the eastern seas i.e. Halmahera, Maluku Sea. From both routes, the ITF flows to Banda Sea and the major flow out toward the Indian Ocean is through the Timor Sea. The historical data used in this study were drawn largely from the NODC archive data and a variety of the Indonesian expedition until 1995.

In comparison with the source waters, we selected 3 positions of the source water mass that are the North Pacific source drawn from 6 – 9 °N, 127 – 131 °E, the South Pacific source from 1°S – 1 °N, 134° – 140°E (Ffield and Gordon, 1992 [4]) and the Indian Ocean source from 13 – 14°S, 115 – 117 °E. The last one was examined only in the Banda Sea and Timor Sea where some of the deep water originates from the Indian Ocean (Wyrtki, 1961 [5]). These three sources are used as the supplementary variables that are not involved in the calculation process. The position of observation stations and sources are shown in Figure 1.

We were examined the water mass characteristics based on monsoon time, which are the Northwest Monsoon (NWM), December, January and February, and the Southeast Monsoon (SEM), June, July and August (Wyrkti, 1961). A data subset for PCA was selected by requiring that each retained station have temperature, salinity and oxygen data. These input variables are used to describe the water mass characteristic. We first present the TS and TO diagrams and then compare it with the PCA graphic.

III. Results and Discussion

a. The parameter of the water masses characteristic

The covariance matrix (Table 1), a matrix of parameter of the water masses character after the data centering and reduction, shows a high value of the temperature and oxygen correlation, in all the seas during both seasons (0.821-0.982 in SEM and 0.856-0.973 in NWM) These parameters are independent variables so that there is an external correlation where it occurs between the parameters caused by an external factor or a mechanism from out of the parameters. This external factor triggers apparently have a correlation pattern between temperature and oxygen eventhough actually there is no relationship between them. The positive value of the temperature and oxygen correlation means that it is connected to a phenomenon in the sea in each season. In the NWM season, the wind blows higher than that in SEM so that a mixing process in the surface layer makes a diffusion of the oxygen more effective. This condition may result in a higher correlation value in NWM season than that in SEM. Besides the other possibility from a biologic process also influences the oxygen concentration in the water column.

Table 1. Covariance matrix of water mass parameter in the ITF seas in the southeast monsoon (SEM) and Northwest Monsoon (NWM)

Seas	Parameters	Temperature		Salinity		Dissolved Oxygen	
		SEM	NWM	SEM	NWM	SEM	NWM
Sulawesi Sea	Temperature Salinity Dissolved Oxygen	1 -0.236 0.949	1 -0.603 0.968	1 0.025	1 -0.562	1	1
Makassar Strait	Temperature Salinity Dissolved Oxygen	1 0.033 0.982	1 -0.641 0.973	1 0.119	1 -0.669	1	1
Flores Sea	Temperature Salinity Dissolved Oxygen	1 -0.644 0.945	1 -0.656 0.936	1 -0.558	1 -0.671	1	1
Banda Sea	Temperature Salinity Dissolved Oxygen	1 -0.687 0.870	1 -0.003 0.874	1 -0.753	1 -0.024	1	1
Maluku Sea	Temperature Salinity Dissolved Oxygen	1 -0.080 0.894	1 -0.187 0.916	1 -0.084	1 -0.219	1	1
Halmahera Sea	Temperature Salinity Dissolved Oxygen	1 -0164 0.891	1 -0.320 0.929	1 -0331	1 -0.477	1	1
Timor Sea	Temperature Salinity Dissolved Oxygen	1 -0.796 0.821	1 -0.011 0.856	1 -0.727	1 0.029	1	1

Table 2. Eigenvalues and variance percentages in PCs

Seas	Principle Component (PC)											
	PC1				PC2				PC3			
	SEM		NWM		SEM		NWM		SEM		NWM	
	α	%	α	%	α	%	α	%	α	%	α	%
Sulawesi Sea	1.9724	65.70	1.8567	61.90	1.0116	33.70	1.0008	33.40	0.0160	0.50	0.1450	4.80
Makassar Strait	1.9936	66.50	1.9990	66.60	0.9922	33.10	0.9178	30.60	0.0142	0.50	0.0832	2.80
Flores Sea	2.4453	81.50	2.5173	83.90	0.5058	16.90	0.4193	14.0	00498	1.60	00635	2.10
Banda Sea	2.5433	84.80	0.8740	62.50	0.3348	11.20	0.9998	33.30	0.1222	4.10	01261	4.20
Maluku Sea	1.9091	63.60	1.9091	63.60	0.9853	32.80	0.9853	32.80	0.1055	3.50	0.1055	3.50
Halmahera Sea	2.0131	67.10	2.5326	84.40	0.8949	29.80	0.4407	14.70	0.0920	3.10	0.0267	0.90
Timor Sea	2.5637	84.50	1.8567	61.90	0.2750	9.20	1.0008	33.40	0.1613	5.40	0.1425	4.80

Note: α = *Eigenvalue*
% = *Variance*

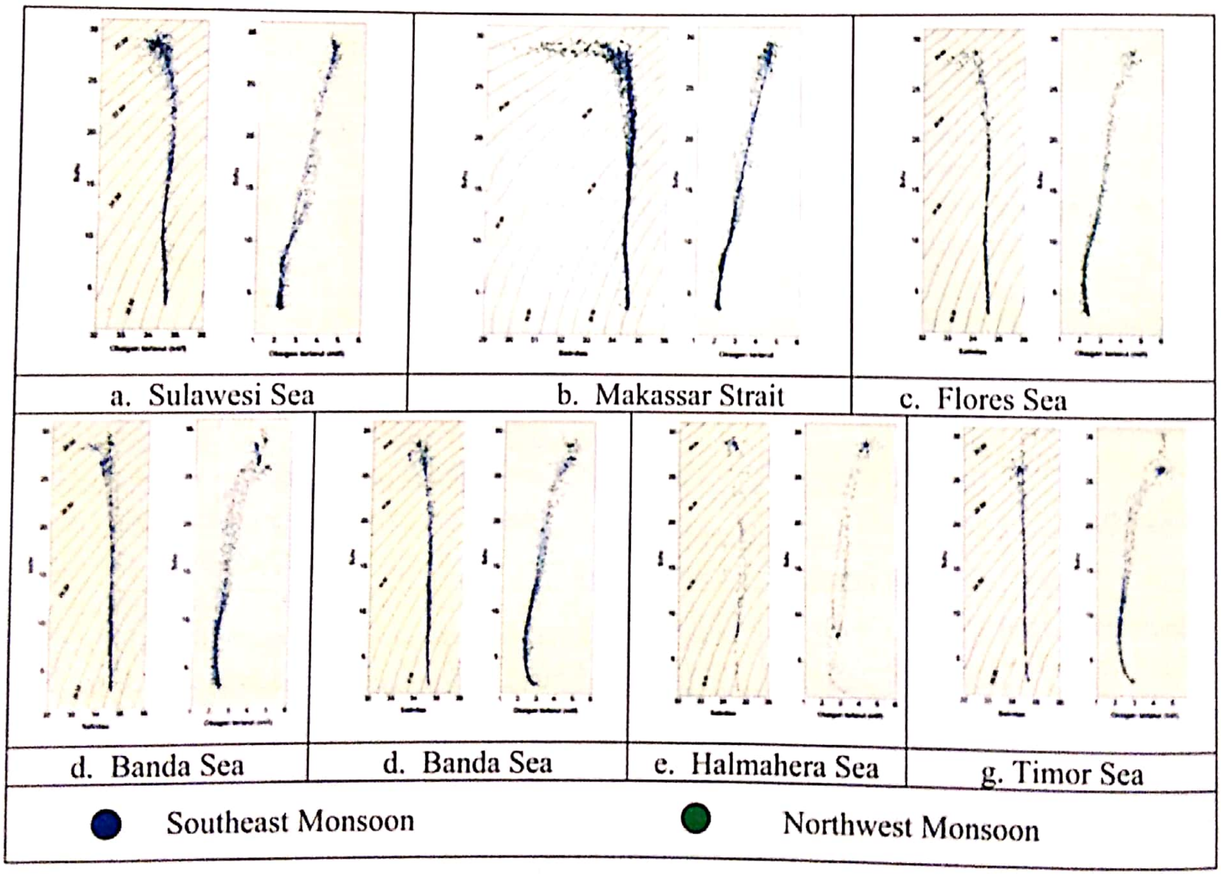

Fig. 2. TS and TO diagrams of Indonesia seas throughflow during the southeast and northwest monsoon

We know from the eigenvalues that the biggest information in all the observed seas are focusing on the first two principle components (Table 2). The first principle component (PC1) corresponds to temperature and oxygen and the second PC (PC2) corresponds to salinity. The temperature and oxygen always play in the same PC, so it may indicate that oxygen is a non-conservative tracer as usually shown in other water mass analysis. This is one of the advantages if using PCA method in water mass analyses so that we can use correlation values in each PCs to know the conservative propert of the water mass parameter. Conservative property of parameter is an important thing in the water mass analyses, because it needs parameter that only influenced by physical processes. In this case, oxygen is not good enough as a tracer in water mass analyses.

PCA also shows the role of parameters in determining of variability water mass character through the correlation of the parameters in the PCs. For example, in the seas where the S-max and S-min are greatly attenuated like in the Banda Sea, even completely removed like in the Timor Sea, the salinity does no longer play a significant role as a character of the water mass. This condition is clearly seen in the PCA graphics that reveal the correspondence of salinity in both PCs. The salinity plays as a negative value in the first PC, but as a positive value in the second PC.

The PCA analysis may also be used to follow the trends of the core layer attenuation as verified by the correspondence of the parameter of the water mass character at the PC. There is a decreasing of the correspondence of temperature and oxygen at the first PC and salinity at the second PC, in both routes of the passage of ITF. The presentation of the salinity extrema in an area will be determining the variability of the water mass character. It will be higher with S-max and S-min and more closely resemble the sources. This condition is shown in the waters close to the main sources in the Pacific, like Sulawesi, Maluku and Halmahera Sea, where both the salinity extrema can still be observed. In these seas, the salinity plays an important role in the variability of the water mass character.

From the result above, we find that the advantage of using PCA in the water mass analysis is determining the conservative properties of water mass, determining parameter that plays an important role in water mass character, and attenuation value of water mass.

b. Water Mass Characteristic of the Passage of Indonesian Throughflow

The examining of the resemblance of the water mass characteristic can be conducted by the trend of a grouping of the observation station to the supplementary station, North Pacific water (yellow), South Pacific water (red) and, especially in the Banda Sea and Timor Timor, it is added by the Indian Ocean water (light blue) (Fig. 3 and 4). The correspondence of every point in the observed sea at PCs is determined by the angle of square cosinus that determines the goodness of fit. Almost all of the points in PCA graphic are the overlapping points of several stations where the water character is the same. The points of the same depth will be mapped in a close position.

As seen on the TS and TO diagrams (Fig. 2), the PCA graphics were show the dominance of the North Pacific water in the western route of Indonesian Throughflow, in the Sulawesi Sea, Makassar Strait and the Flores Sea (Fig. 3 and 4). The station of the South Pacific water that is indicated by more saline water is never grouped with these seas. This condition is used as one base to justify that the observed seas closely resemble the North Pacific water.

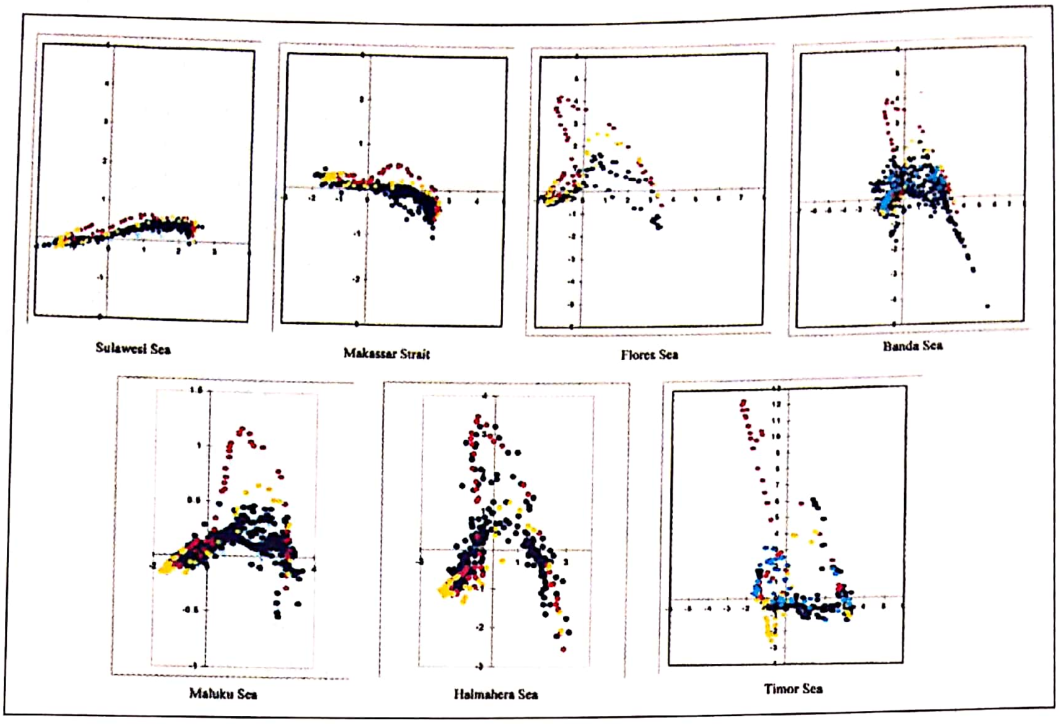

Fig. 3. PCA graphic of the Indonesia seas throughflow during the southeast monsoon

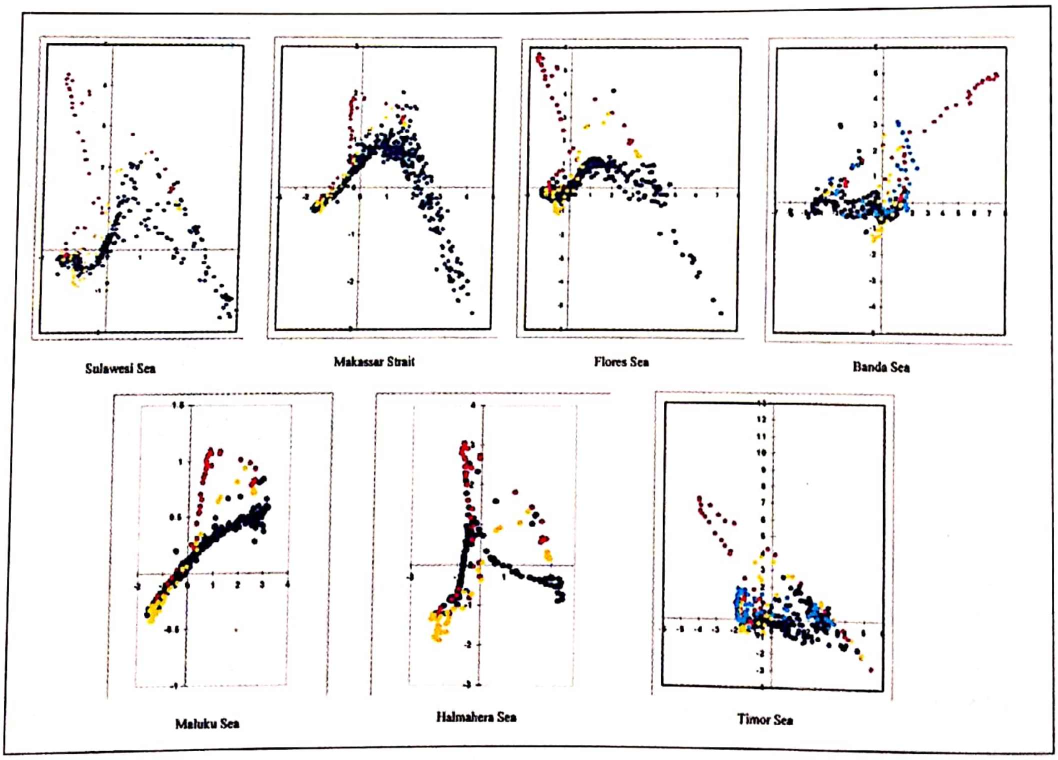

Fig. 4. PCA graphic of the Indonesia seas throughflow during the northwest monsoon

The TS and TO diagrams also display that the surface water character changes with the season. These differences are indicated in the PCA graphic by many observation points in the quadrant IV that shows relatively low salinity water and is influenced by temperature and oxygen. This character is found only in the NWM (Figure 3 and 4).

The water mass characteristic of the Sulawesi Sea in the NWM is different from it in SEM. The position of the observation point extents in the first PC and a small range in the second PC, meanwhile, the other figure shows that especially in quadrant I, the observation points are close to the second PC. These conditions show that in SEM, the Sulawesi Sea water has a limited salinity range with a higher temperature and oxygen than that of the NWM.

During both seasons, the resemblance of the Makassar Strait with the North Pacific water is shown well. The water with a low salinity character but high in temperature and oxygen in SEM becomes stronger in NWM. It is indicated by large numbers of stations in the quadrant IV of the PCA graphic. During the NWM, there is also found a water mass characterized by high salinity, temperature and oxygen.

The water mass of the Flores Sea does not completely overlap with the North Pacific water but the trend is following the water source pattern. This condition shows that in the qualitative sense, we can see the change of the water mass characteristic in the passage of Indonesian Throughflow. The graphic of the Flores Sea is close to the Sulawesi and Makassar graphics in NWM. The surface water salinity of the Flores Sea in SEM is higher than that in NWM. During the NWM season, it is characterized by high temperature and oxygen with restricted variability.

During the SEM, the variability of temperature, salinity and oxygen in the Banda Sea tends to be of a limited range. It is indicated by grouping of the observation points in the central point of the axes. During this season, it is also found a water mass characterized by low salinity, but high in temperature and oxygen, as seen in the Sulawesi Sea and the Makassar Strait in the same season. The Banda Sea graphic in both seasons is different from each other. During the NWM, the Banda water has a high temperature and oxygen with a restricted variability but a low salinity value.

The presence of NPSW and SPSW influence the resemblance of the Banda Sea to the Pacific Ocean thermocline water mainly during the SEM. In the NWM, the characteristic of the Banda water is closer to the North Pacific water with a smaller change of salinity than that of the South Pacific water. The difference is pointed by decreasing value of S-max of NPSW and SPSW in the Banda Sea. The PCA graphic of the Banda Sea shows a grouping to the Indian Ocean water particularly in the SEM with a difference in low salinity water, but high in temperature and oxygen.

TS and TO diagram display some kind of the Pacific thermocline water in the Maluku Sea, NPSW, SPSW and NPIW. In PCA graphic it is indicated by a grouping of the Maluku Sea station to the North and South Pacific station near the central point of the PCs and in the quadrant II and III. This grouping trend is always seen in both seasons. Eventhough the temperature and oxygen values in both seasons are always high, the salinity of the Maluku water is relatively higher than that during SEM.

The graphic of the Halmahera Sea is different from the previous observed seas. It is clearly seen in a grouping of observation points that the high salinity of South Pacific station which reveals the Halmahera water is derived from the South Pacific water. The same result is pointed by the TS and TO diagrams that show a relatively high salinity of the Halmahera Sea water that is impossible coming from the North Pacific. The TS and TO diagrams of the Halmahera Sea also show the dominance of the South Pacific water during the NWM than that of the SEM. It is showed by the PCA graphic during the NWM with a lower salinity of the North Pacific water which is completely separated from the Halmahera Sea water.

The difference from the source comes from the reason that, there is a water mass characterized by high temperature and oxygen during the NWM. In the SEM, there is also found a water mass with a low salinity but high in temperature and oxygen.

As already explained in the TS and TO diagrams, the Timor Sea water has a new character which the Smax and Smin of the Pacific water are completely removed. In this sea, the observation points are not grouped to the pacific station, but even closely resemble the Indian Ocean water.

IV. Conclusion

PCA shows the resemblance of the water masses characteristics in the western route of the Indonesian Throughflow to the Pacific thermocline water. However, a relatively high salinity of South Pacific water is found in Halmahera Sea that indicated by the grouping of observation points to the South Pacific station. The PCA graphic also can show the trends of the core layer attenuation as verified by the correspondence of the parameter of the water mass character at the PCs and reveals the character of dissolved oxygen as a non-conservative tracer by the correspondence of temperature and dissolved oxygen in the same PC.

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