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ARTICLE

The Effect of ENSO on Hydrological Structure and Environment in the South Central Coast – Vietnam

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ABSTRACT

ENSO (El Niño-Southern Oscillation) phenomena have impacted on the hydrodynamic regime and environmental factors of the tropical ocean in general. In case of Vietnamese South-Central Waters, impacts of ENSO only focused on issues of changing seasonal wind, seawater temperature anomalies, changing of water masses as the air-sea interaction. Based on several data sets collecting in the period of 2003-2017, new finding of seawater temperature, salinity and environmental factors was identified in the water masses of Vietnamese South-Central Waters. The highest salinity was 35.4 ‰. During the El Nino event, increasing water temperature and salinity caused to move the deeper water masses to be closer to the sea surface than that initial depth in the neutral period. During the La Nina event, the temperature of most water masses reduced by 0.1-3.0 ℃ , and then these water masses could be affected to the deeper layer. During the phase from strong ENSO event towards the neutral time, nutrient salts of the 4 water masses were lower concentration in the neutral year, causing the lack of phosphorus in sea surface water masses.

1. Introduction

The El Niño–Southern Oscillation (ENSO) called a climate phenomenon that varies between Neutral, La Niña or El Niño phases, including changes of sea surface temperature over the tropical central and eastern Pacific Ocean [1-4]. The temperature changes significantly linked to major climate fluctuations around the world and caused the extremely weather. The pattern of El Niño has changed dramatically with the first El Niño events recorded over the last 400 years and El Niño events become more intense in last few decade [5]. Three strongest El Niño events were recorded as 1982-82, 1997-98 and 2015-16 (https://ggweather.com/enso/oni.htm), in which the 2015-16 El Niño events was the longest one . The 2015-16 El Niño events caused seri-

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ous disasters on the global [6]. During this event, coastal provinces in the South-Central Vietnam had to declare natural disasters due to insufficient rainfall, high temperature causing drought –stricken areas. Especially, in November, 2017, typhoon Damrey with winds of up to 12 levels (Bopho Scale) destroyed both land–based source and ocean.

The ENSO events were influenced to the hydrological structure and marine environment in the South-Central Waters of Vietnam. Results focused the features of wind during the monsoon season, as well as the abnormal periods of climate. Chung and Long [7] reported the temperature anomalies and the mechanism of water level changed by the effect of ENSO, the abnormal increases of temperature and the abnormal decreases of wind speed, which cause the weakness of upwelling in the South-Central Region. Dipper [8] revealed that water bodies was influenced by seasonal variations. Xuan [9] reported that based on the collection of large data on temperature and salinity and T-S curve analysis determined the relations between the surface water mass and seasonal air temperature in the Southeast sea of Vietnam. Anomalous surface water temperature and salinity during the period of ENSO were as -4°C and +1.2 ‰, respectively [10,11]. Water mass with temperature anomalies affected the aquatic trophic structure [12,13]. During the uptake phase, the nutrient-enriched layers were concentrated in a clearly and relatively broad mass, with high nutrient content of the watershed [13]. ENSO also affected nutrient structures through effects on the phytoplankton community [14], food webs [15] and the elements of wind, rain, storms, temperature [16,17]. Upwelling phenomena declined sharply in the El Nino years [8]. The on/offshore of Ninh Thuan - Binh Thuan are quite affected by ENSO phenomena [13].

The paper found new score of hydrological structure and the environment during the phases of the ENSO phenomenon in the marine of South Central region of Vietnam.

2. Methodology

2.1 Data Set

Data sources were collected from Vietnam-USA joined project (2013-2016) (Figure 1), International Project Cooperation under the Vietnam-Germany protocols from 2003-2007 (Figure 2) and project "Changes of wind characteristics, air temperature and hydrological structure in Ninh Thuan - Binh Thuan Waters in ENSO years" (2016-2017) (Figure 3).

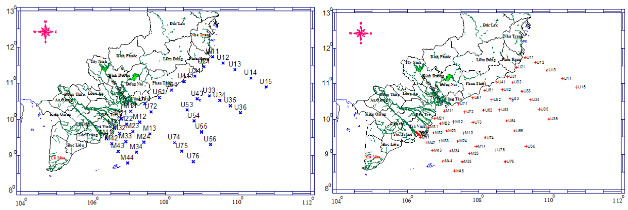

Figure 1. Sampling stations under Vietnam-USA joined project (left: in Northeast monsoon; right: Southwest Monsoon)

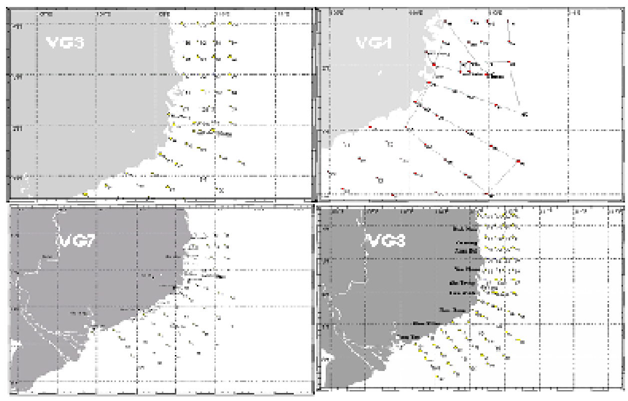

Figure 2. Sampling stations under Vietnam-Germany Cooperation projects: (a): VG3; (b): VG4; (c): VG7; and (d): VG8

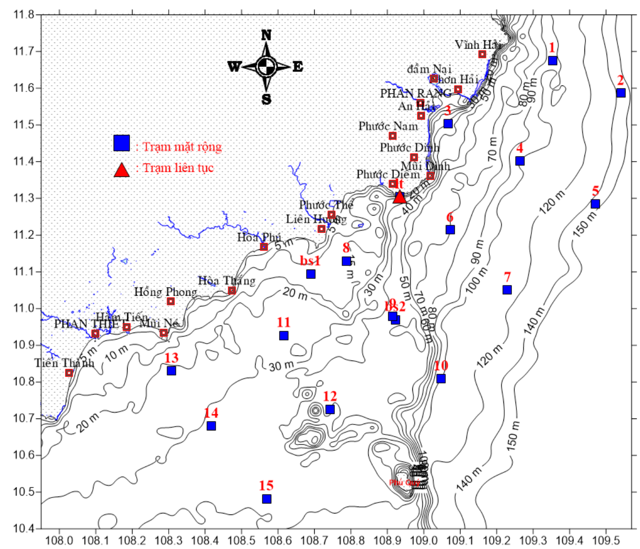

Figure 3. The map of sampling station in 2016 and 2017

In addition, data from the HYCOM + NCODA Global Reanalysis database, with high resolution 0.08° from 2002 - 2012 (11-year period) and from Aug. 2016 – Aug. 2017 were used for corrected with two surveys during ENSO years. The aggregate data on the vertical distribution of temperature - salinity structure (Wang *et al.*, 2016) with average values of several months from 1919 to 2014 in the South China Sea was combined in this analysis. Monthly

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average Nino index was collected from https://ggweather.com/enso/oni.htm.

2.2 Data Analysis

Temperature and Salinity profile and T-S diagram were analyzed with Mamayev [18] by using Matlab R2013a software. Using the statistical method to study the average fluctuation in the South Central Marine of Vietnam through the extreme analysis of standard deviation and specific time of extreme occurrence, average of the whole process.

3. Results and Discussion

3.1 The Influence of ENSO Phenomenon on Hydrological Structure in Water Masses in South Central Marine of Vietnam (SCMV)

Base on the TS-diagram and physical characteristics of the water layers, we identified the 10 water masses in SCMV from different origins (Table 1 and Figure 4). DW water had salinity of 34.4 psu and temperature of less than 04 °C and relatively stable with a water density of about 1027.6 kg/m^3. PTW water which exist in the depth of 400-700m had a temperature range of about 7-10°C, salinity of 34.2-35.0 psu. Between two these water masses, WM1 water had the characteristics of both DW and PTW water with temperatures in the range 4-7°C, salinity of 34.3-35.8 psu. MSW water found in the SCCV had a salinity of not less than 34.1 psu. This water layer was relatively close to the surface of the sea with a temperature of 16.5-20°C. This water mass interacts with PTW water in the deeper water to create a WM2 disturbance in the depth range of 100-450m with a temperature of 10-16.5°C and salinity ranging from 34.1-35 psu. The OSW water has a functional activity from the surface down to 90m with a salinity of 33.7-34.8 psu and a temperature of 25-30.5 °C. This OSW water also interacts with maximum salinity water to create WM3 water, which is mixed between MSW and OSW water. This mixing water was found from the surface layer down to a 180 meters and the temperature range was about 19-28°C and the salinity was in the range of 33.9-34.8 psu. As the water masses depend mainly on the current regime, so in the southwest monsoon season it cannot exclude the effects of water from the Mekong River and the Gulf of Thailand (MKGTW) in the study area, especially from south Binh Thuan to Vung Tau province. This water mass had a range of activity from the surface down to 60m in depth and has a salinity of no more than 32.9 psu. The temperature of this water was quite high from 27-31.5°C. EJW mainly occurs during the southwest monsoon season from the Karimata strait, which has a high temperature of 25.5-31°C and a salinity of 32.5-33.7 psu. The last ECSW water origined from the East China Sea appears to be predominantly in the northeast monsoon with relatively low temperatures of 21-25° C, salinity of 33.2-33.9 psu.

Table 1. Characteristics of water mass in South Central Marine of Vietnam [19]

No.	Watermasses	Temperature (°C)	Salinity (psu)	Layer depth (m)
1	Deep Water (DW)	<4	>34.4	>1,200
2	Permanent Thermocline Water (PTW)	7-10	34.2-35.0	400-700
3	Mixing of DW and PTW (WM1)	4-7	34.3-35.8	700-1200
4	Maximum Salinity Water (MSW)	16.5-20	>34.1	50-250
5	Mixing of PTW and MSW (WM2)	10-16.5	34.1-35.0	100-450
6	Offshore Water (OSW)	25-30.5	33.7-34.5	0-90
7	Mixing of MSW and OSW (WM3)	19-28	33.9-34.8	0-180
8	Mekong River and Gulf of Thailand Water (MKGTW)	27-31.5	<32.9	0-60
9	Equator and Java Sea Water (EJW)	25.5-31	32.5-33.7	0-80
10	East China Sea Water (ECSW)	21-25	33.2-33.9	0-80

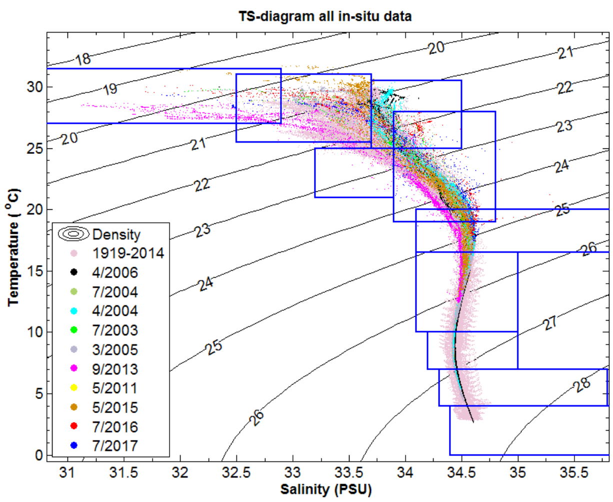

Figure 4. TS-diagram and typical distribution of water masses [19]

The influence of ENSO phenomenon on hydrological structure can be seen in all temperature profiles (Figure 5). The temperature was reached the highest value in May 2015 (brown line) at about 30-31.5 °C. In Vietnam records after two period of heat due to the influence of El Nino showed that average temperature in May 2015 is higher than average of several years about 2-3°C. Moreover, the salinity profile in 2016 at the Station 1 (located at longitude 109.3540°E, latitude 11.6707°N, Figure 5) revealed that salinity reached the value up to 35.4 psu. That salinity is the highest in the historical data series.

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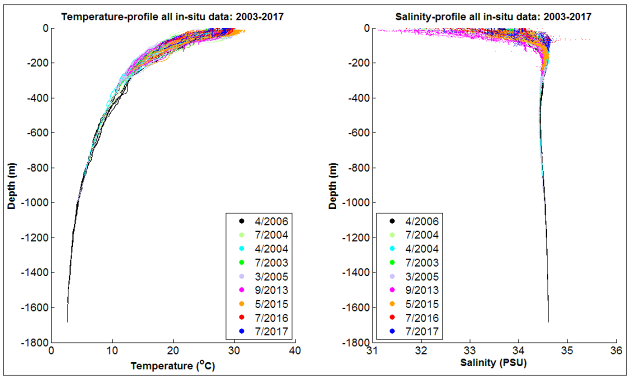


Figure 5. Vertical distribution of temperature and salinity from in-situ data in the South Central Marine of Vietnam [19]

Through the indicators of water body characteristics, the results of the variation of water masses over time and the depth distribution showed that in 2004 the presence of all water bodies was found in the South Central region, and in 2006 the presence of DW had a temperature in the range 2.7-4.0°C, and high salt content in the range 34.5-34.6 psu. In 2015 MKGTW had not much impact to the South-Central region because of the hot and dry weather last year in the South China Sea. In 2016 – 2017. Results of the six water bodies in the South-Central Coast indicated that surface water masses of OSW, EJW, ECSW and MKGTW had lower temperatures than that of basins in 2015 by around 0.5° C, but some salinity values are high up to 35.4 psu.

Influence of El Nino: The most obvious impact on surface water mass, such as the MKGTW, increases the water temperature by 0.4-0.7 ° C. Besides, offshore water mass, which is from the Western Pacific, are also affected by El Nino warmer 0.6°C while salinity also increases by 0.2psu. Under the impact of El Nino, salinity increased and water masses were pushed upward the surface about 80m to versus position depth in neutral phases. However, the blocks of deep water, PTW and DW were less influenced by El Nino. On the other hand, the impact of El Nino depends on their strength which is reflected in the variation of the water mass. Obtained data in July 2003 (moderate El Nino) and July (very strong El Nino) showed large fluctuations of the water depth (Table 3.2). Almost all of the waters distributed in the deeper layers tend to be pushed closer to the surface than in the strong El Nino period (2016) from a few meters up to tens of meters.

The influence of La Nina: The indicator of the effect of La Nina is water temperature. Almost all of the water masses in a strong La Nina period decreased temperature quickly from 0.1°C (WM2 water) to 3.0°C (WM3 water). Surface water masses as the MKGTW water decreased temperature by 1.4°C. However, there are some anomalies in that La Nina increased the temperature in water mass of ECSW, OSW, WM2 to 0.1 - 0.2°C. This confused result needs further study. Similar to El Nino's impact, La Nina also pushed PTW and WM1 to deeper water but raised MSW and WM3 to the surface of the sea by 40-50m. The remaining water masses have a small variation in the depth stratification with only a few meters in the sea.

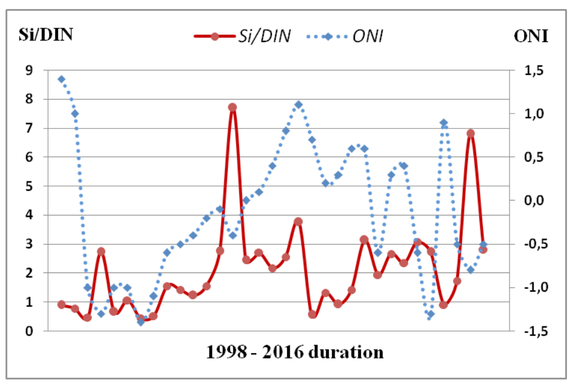
Table 2. The influence of ENSO on hydrological structure in each water mass [19]

No.	Water mass	El Niño			La Niña		
		Temperature (°C)	Salinity (psu)	Layer depth (m)	Temperature (°C)	Salinity (psu)	Layer depth (m)
1	DW	#	#	#	#	#	#
2	WM1	-1.0	0	+(30-50)	-1.4	+0.1	+(30-50)
3	PTW	0	0	+(30-50)	0	0	+(30-50)
4	WM2	+0.4	0	-75	-0.1	+0.1	#
5	MSW	+1.2	+(0.2-0.6)	-80	+1.0	-(0.1-0.2)	-(40-50)
6	WM3	0	+0.2	-70	-3.0	-0.2	-(30-50)
7	OSW	+0.6	+0.2	-30	-2.0	+0.2	-3
8	EJW	-0.4	0	-14	-0.5	0	-6
9	ECSW	-(0.4-0.6)	-0.1	-30	-2.5	+0.1	+20
10	MK-GTW	+(0.4-0.7)	-0.3	-15	-0.4	-0.2	-2

Note: + increasing - decreasing (+ depth) means deeper; (- depth) means shallower

3.2 Influences of ENSO on the Nutrient Structure in Water Masses

The Ocean Nino Index (ONI) indicator shows that during the period 1998 - 2016, the nutrients in the water bodies were not variable (Figure 6). All of the highest and lowest values of the DIN / DIP ratios (96.4 in 2000 and 6.5 in 2011), Si / DIN (7.7 in 2011 and 0.4 in 2000), Si / DIP (253.1 in 1998 and 11.2 in 2011) were recorded at the time of the La Nina phenomenon (02/2000 and 11/1998, ONI = -1.4 and - 1,3).



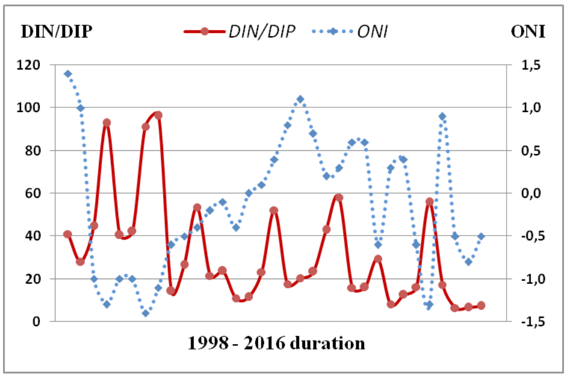


Figure 6. Si/DIN (left) and DIN/DIP (right) ratios to ONI over time

The results also showed that at the South Central the decline or accumulation of Si in sediments was not observed to change predominant species from diatoms to green algae or cyanobacteria (Figures 7, 8).

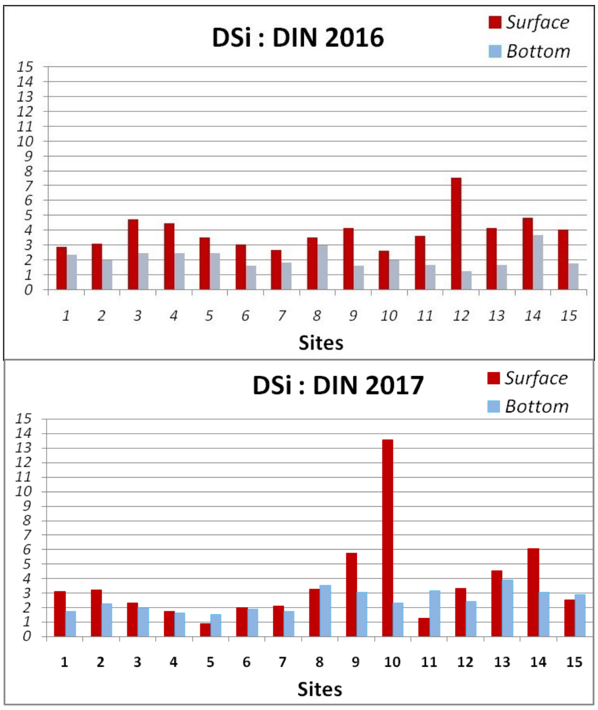
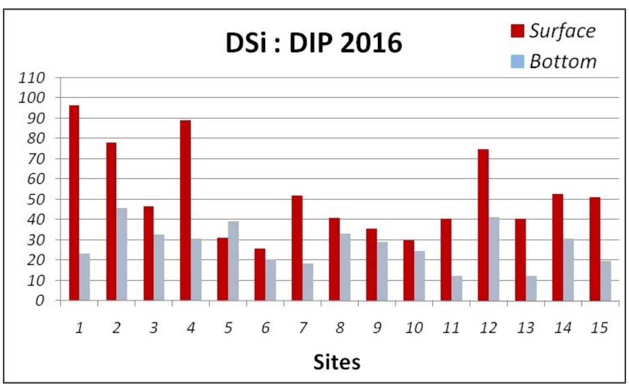


Figure 7. Chart of DSi/DIN ratio with stations in Figure 3



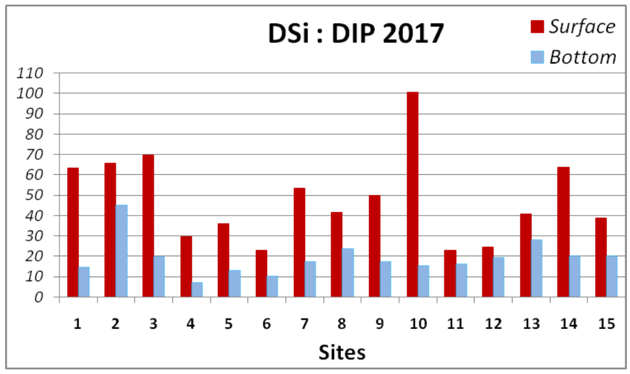


Figure 8. Chart of DSi/DIP ratio with stations in Figure 3

In the strong El Nino year (2016), there was a shortage of P in the surface with very low DIP concentrations and the DIP and DSi/DIP ratios were always more than 22. However, the mean values of molar ratios showed that there was a shortage of N at the bottom (Figure 9). In neutral year (2017), there was a shortage of P, N in some surface layers.

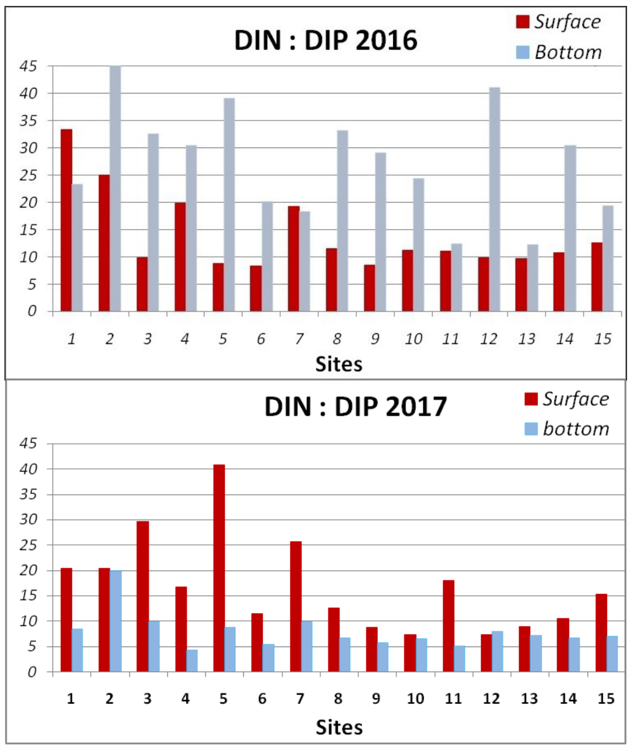


Figure 9. Chart of DIN/DIP ratio with stations in Figure 3

Nutrient characteristics in water masses: In general, the concentration of nutrient salts in most of the water bodies recorded in the neutral year is higher than in the active year of El Nino. Chart of distributed by depth showed that in El Nino years the water mass was pushed upward, but nutrient concentrations were lower than in neutral year (Figure 10-12). In MKGTW, the El Nino year was higher (9.78 µM) and the DSi / DIN, DSi /DIP ratios were both

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higher than those in the neutral year; but the DIN / DIP ratio was lower (12.46). In the remaining water bodies, although the levels of nutrient salts in El Nino year are lower than the neutral year, the molar ratios are not in the similar variation.

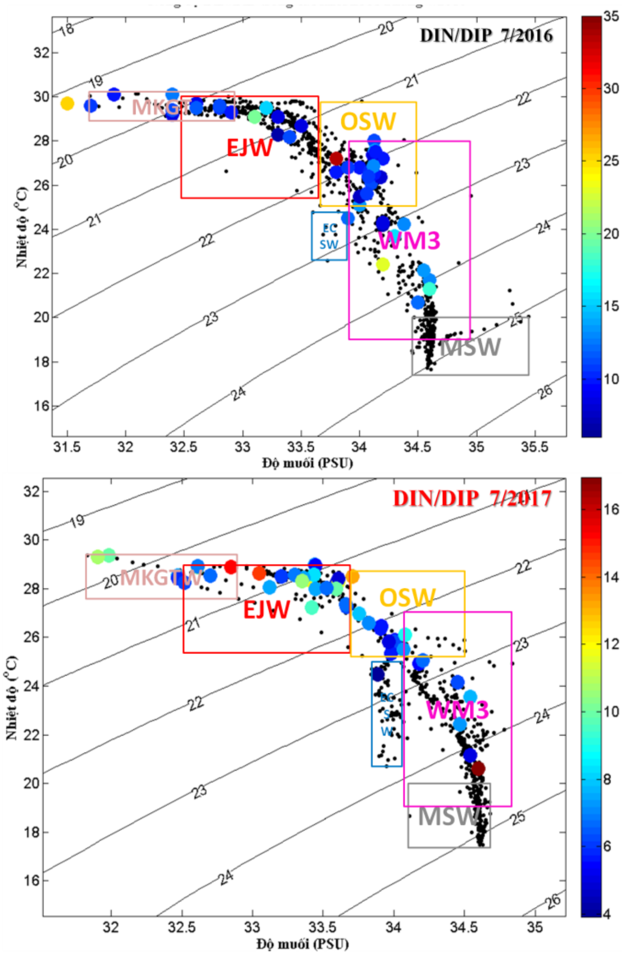
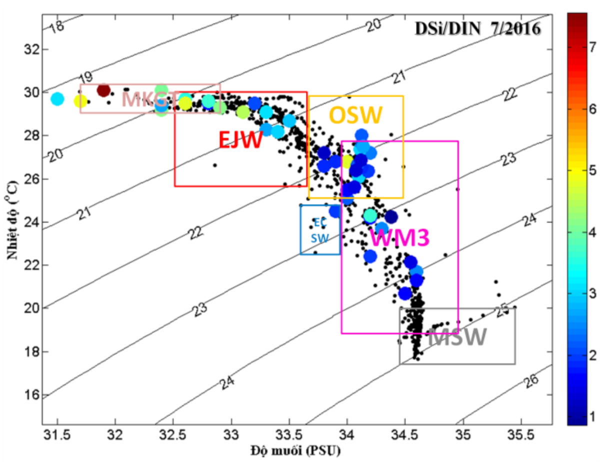


Figure 10. DIN/DIP ratio of water the masses recorded through the two surveys



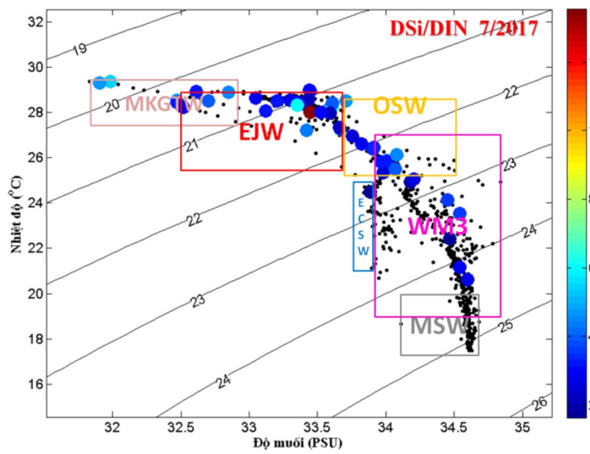


Figure 11. DSi/DIN ratio of water the masses recorded through the two surveys

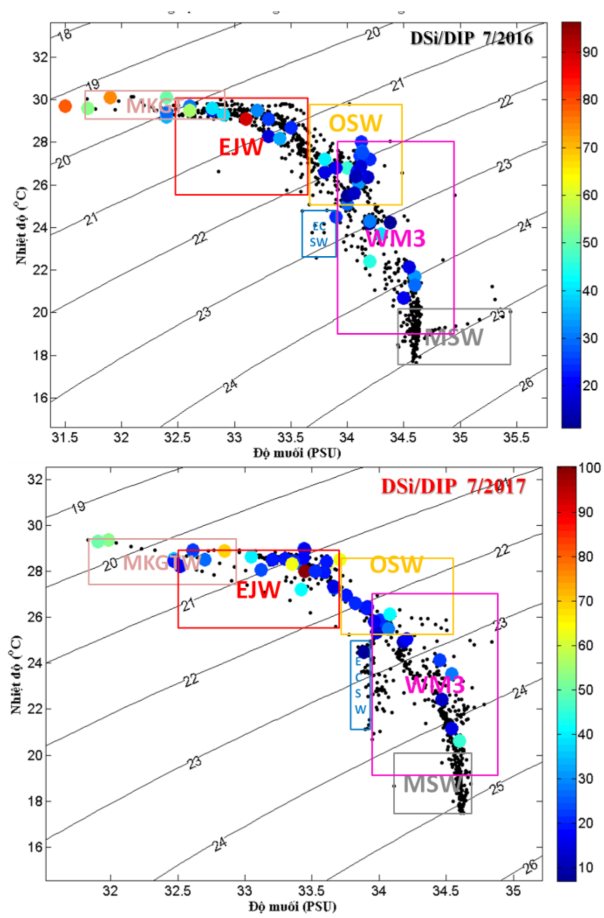


Figure 12. DSi/DIP ratio of water the masses recorded through the two surveys

4. Conclusion

Based on the results of analysis collected in the period of 2003-2017, the paper found (1) Highest salinity 35.4 psu in 10 water masses in the south central marine in strong

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El Nino year; (2) El Nino increased the salinity and temperature of water masses and pushed the upper masses closer to the surface from a few meters to 10 of meters; (3) La Nina decreased temperature and salinity from 0.1^0C to 3.0^0C and increased water exchange by ECSW anomalies, OSW, WM2 and increased temperature of 0.1 - 0.2^oC over the period of La Nina; (4) All of the highest value and lowest ratio of the DIN / DIP, Si / DIN, Si / DIP were recorded aduring the La Nina period; and (5) The nutrient concentrations in the water masses in neutral years were higher than those in strong El Niño year.

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