POST-EL-NIÑO WEAKENING OF COASTAL UPWELLING AND ITS ECOLOGICAL IMPACTS IN THE SOUTH-CENTRAL VIET NAM REGION

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Abstract: *Upwelling that occurs in the summer offshore of South-Central Viet Nam in the South China Sea (SCS) also known as the East Viet Nam Sea (EVS), is one of the region's key dynamic processes. The weakening of upwelling phenomena during post-El-Niño events and their ecological responses were studied based on a reanalysis dataset derived from the HYCOM/NCODA system, coupled with a local Finite Element Model (FEM) and observed data. Long-term warming, along with orographic and wind factors, play significant roles in the formation and weakening of upwelling phenomena during normal and post-El-Niño episodes, respectively. The weakening of upwelling during post-El-Niño periods is reflected by: Extreme weakening of wind forcing and Ekman pumping; a northward shift of the cold-saline tongue and current dipole, with a limited eastward extent; dominance of northward circulation in the surface layer and westward circulation in deeper layers; and the formation of a homogeneous surface thermohaline layer of about 50 meters thick, with a thermo-halocline layer at 50-60 meters depth. These abrupt changes strongly influenced the ecological characteristics of the upwelling area. Coral bleaching during the summers of 2010 and 2016, as well as anomalous distributions of chlorophyll-a (Chl-a) in the surface layer in 1998, 2003, 2010, and 2016, were concrete indicators of the ecological responses of Viet Nam's coastal upwelling waters in post-El-Niño years. Detailed intra-seasonal variations of temperature during the summer showed a warming of the waters, leading to coral bleaching and abnormal Chl-a levels during post-El-Niño years. Organisms in this region struggled to adapt to these rapid environmental changes, leading to a potential reduction in living resources.*

Keywords: *Weakening of upwelling, post El-Niño period, Viet Nam coastal upwelling, coral bleaching, South China Sea/East Viet Nam Sea.*

1. Introduction

Coastal upwelling, which moves up cold and nutrient-rich water towards surface, is one of the most important physical processes involved in ocean primary production as well as in self-purification of marine waters. The coastal upwelling of the South Viet Nam Sea (SVS) is one of the major hydrographic features of the SCS. Locating in the western side of the SCS, Central Viet Nam upwelling is influenced by the monsoon regime [1]. In summer, the coastal current system is characterized by the cold water tongue which extends offshore as a cold jet stretching Eastward along 11°N - 12°N, and this is influenced by the Southwest monsoon [2], [3]. This circulation results from an upwelling which causes a decline of the sea surface temperature (SST) by more than 1^{o}C [1], [2], [4], [5]. The Eastward extension of the cold surface water from the Vietnamese southern coast creates a cold filament with minimum SST below 26^{o}C [2], [6], ... While the crosswise extent at the coast is less than 100 km, the cold filament transports cold waters up to 800 km offshore.

Observational and numerical studies suggested that strong El-Niño-Southern Oscillation (ENSO) events influence the SCS circulation, in particular contributing to the

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weakening of the Central Viet Nam upwelling [7], [8], [9]. For post El-Niño years, Sea Surface Height (SSH) anomalies in the Southern basin represent a marked weakening of the climatological anti-cyclonic circulation there, acting to inhibit the eastward advection of coastal water that is critical to develop the cold filament in a normal year. This configuration with the Northward shift of the anticyclonic eddy was observed during 1998 summer [10] when the SCS was anomalously warm, making it the warmest summer on record in this region [11]. From observational data, Ose et al. (1997) showed that, SST anomaly in this region is recognized as an index for the Asian monsoon and ENSO system because of its special geographical location, with positive anomalies associated with above the average El-Niño indexes [12]. In a recent study, Tran and Bui (2015) also showed anomalous oceanographic patterns in summers of 1998 and 2010, the two hottest years of SCS during the period of 1997-2015 [13]. During these two summers, the cold filament disappeared and SSH dipole offshore the southern Viet Nam shifted Northward. Those high SSH anomalies in the Vietnamese coastal upwelling in summers 1998 and 2010 coincided to with post-El-Niño years. Previous studies mostly focused on the upwelling phenomena and on its variability in surface water layer. The functioning and variation of oceanic structures in surface and deep layers in upwelling area during normal and anomalous periods of ENSO still need to be examined.

Therefore, a series of questions arise from the previous studies of the Central Viet Nam upwelling. Do the filament and the dipole structure off southern Viet Nam exist every summer and what are the key processes for their offshore development? What causes inter-annual variability of the cold filament and dipole structure? Is the disappearance of cold filament and dipole in summer related to ENSO events? What are the mechanisms of the water circulation patterns in surface and deep layers and how do they vary between normal and anomalous summers? Regarding these questions, scientists have found answers and interpretions based on several techniques [14], [15, [16],...]. The main objective of this paper is to examine the influence of ENSO events on the dynamics and ecosystems of South Central Viet Nam upwelling system using a combination of oceanographical in-situ and satellite data together with results from numerical simulations and the ecological evidents of the system.

2. Data and methods

The coupled reanalysis-assimilation datasets obtained from the Global Forecast Climate System were downscaled into regional and local scales in the studied area to find the weakening signals of upwelling phenomena during the post-El-Niño events in the SVS. Moreover, the phenomenon of coral bleaching; anomalous distribution of chll-a as evidential proofs in support of ecological responses resulted from the warming of the waters during the post-El-Niño.

The NCEP wind and sea surface temperature datasets: Ekman transport describes the wind-driven portion of circulation seen in the surface layer [17], [18]. Ekman transport can be assessed through the Wind Stress Curl (WSC). In the northern hemisphere, when WSC>0, Ekman pumping is strong and an upwelling can develop, whereas when WSC≤0, a downwelling may appear [19], [20], [21]. The wind dataset from 1979 to 2016 from the Climate Forecast System Reanalysis (CFSR) [22] of the National Centers for Environmental Prediction (NCEP), derived from the NCEP Climate Forecast System Version 2 (CFSv2), was used for assessing the WSC time series. Hourly time-series products (ds094.1) with spatial resolution of 0.2 degree and with temporal resolution of 4 data per day (0000, 0600, 1200, and 1800 UTC) were selected and integrated to daily, weekly, and monthly means.

The HYCOM/NCODA reanalysis/assimilation dataset: The analysis and reanalysis datasets obtained from the Global Climate Forecast System were downscaled into regional and local scales to study the weakening signals of upwelling phenomena during the post-El-Niño years in the SVS (Fig. 1). Observed data of T & S from Viet Nam Ocean Database Center (http://vodc.vnio.org.vn) were assimilated into HYCOM/NCODA and updated the system to help for calculation and forecast.

The FEM: The FEM (Finite Element Method) calculated for the upwelling region of SVS was applied and combined with HYCOM+NCODA [13]. The HYCOM-NCODA-FEM datasets include temperature (T), salinity (S), and current (in 26 layers with hourly time series) and were extracted and used for the analysis. The average and fluctuations of T, S, and current by spatial and temporal (layer, transect,... day, month, intra-season,...) ares calculated by traditional statistical methods.

The ETOPO1 was used for the bottom topography of the whole study area, and a 1 arc-minute global relief model of Earth's surface, combined with bathymetry maps in a big scale of 1/50,000. In coastal waters, the bathymetric map at a scale of 1/100,000 was used.

The Oceanic Niño Index (ONI): The Oceanic Niño Index, equal to the running mean 3-months SST anomaly for the Niño 3.4 region (5°N-5°S, 120°-170°W) is a standard index used for identifying El-Niño events (https://ggweather.com/enso/oni.htm).

In situ data: Coral bleaching and distributions of chl-a were obtained from field surveys in support of ecological responses during post-El-Niño years. The data and pictures of coral bleaching have been investigated by SCUBA diving in the coral bleaching monitoring program [23], [24].

Satellite ocean color data: Based on observed data of chl-a at the same times, satellite imageries including two SEAWIFS L2B imageries (July of 1997, 1998) and four MODIS imageries L2B (July of 2002, 2003, 2009, 2010) were used to determine the contents of chl-a for comparison of the typical features of chl-a distribution in upwelling region during El-Niño and post-El-Niño episodes (https://oceancolor.gsfc.nasa.gov/SeaWiFS/ and https://modis.gsfc.nasa.gov).

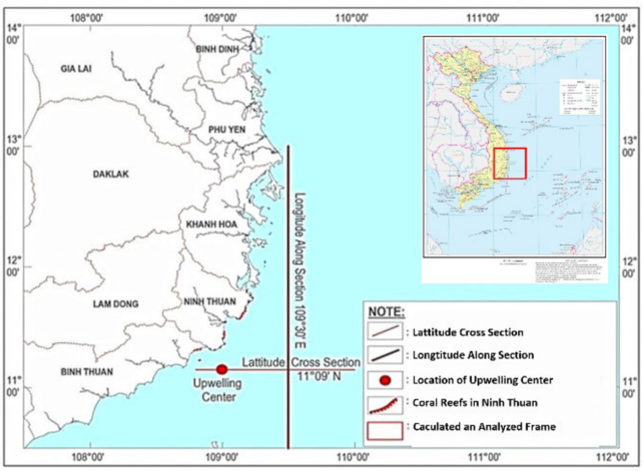

Fig. 1. The map of studied region

3. Results and discussions

3.1. ENSO events and oceanographic features of the surface layer

The ONI values of the 21-year period of 1996-2016 show strong El-Niño events in 1997-1998, 2002-2003, 2009-2010, and 2015-2016 (Table 1). While the ENSO event of 1997-1998 (from April 1997 to June 1998, i.e. 15 months, with an average ONI of 1.35) was a very strong El-Niño event, the ENSO events of 2002-2003 (from May 2002 to March 2003, 11 months, 0.74) and 2009-2010 (from June 2009 to May 2010, 12 months, 0.73) were medium.

The ENSO event of 2015-2016 (from October 2014 until June 2016, 21 months, 1.12) was one of the strongest and longest El-Niño events. The ENSO of 2004-2005 (June 2004 - May 2005, 12 months, 0.51) and 2006-2007 (August 2006-

February 2007, 7 months, 0.53) can be identified as weak El-Niño periods.

Spatial distributions of SST and Sea Surface Salinity (SSS) obtained from the FEM show that a cold, saline tongue extending Eastward between 11.00°N and 12.00°N is usually observed in July in neutral years (such as 2001, 2002, 2006, 2008, 2011), due to the upwelling. Such a zone with cold and saline surface waters almost disappeared in July 2010 or shifted Northward in July 1998, 2003, and 2005, the years after an El-Niño event (Figs. 2, 3). The Surface Water Circulation (SWC) showed a shift of the movement of the current dipole towards the North from 11°N to 13°N in July of 1998, 1999, 2003, 2005 and 2010 (Fig. 4).

Table 1. The ONI Index from 1996 - 2016 (NOAA's Climate Prediction Center)

Year	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ
1996	**-0.9**	**-0.7**	**-0.6**	-0.4	-0.2	-0.2	-0.2	-0.3	-0.3	-0.4	-0.4	-0.5
1997	-0.5	-0.4	-0.2	0.1	**0.6**	**1.0**	**1.4**	**1.7**	**2.0**	**2.2**	**2.3**	**2.3**
1998	**2.1**	**1.8**	**1.4**	**1.0**	**0.5**	-0.1	**-0.7**	**-1.0**	**-1.2**	**-1.2**	**-1.3**	**-1.4**
1999	**-1.4**	**-1.2**	**-1.0**	**-0.9**	**-0.9**	**-1.0**	**1.0**	**1.0**	**1.1**	**1.2**	**-1.4**	**-1.6**
2000	**-1.6**	**-1.4**	**-1.1**	**-0.9**	**-0.7**	**-0.7**	**-0.6**	**-0.5**	**-0.6**	**-0.7**	**-0.8**	**-0.8**
2001	**-0.7**	**-0.5**	-0.4	-0.3	-0.2	-0.1	-0.1	-0.1	-0.2	-0.3	-0.4	-0.3
2002	-0.2	0.0	0.1	0.2	0.4	**0.6**	**0.8**	**0.8**	**0.9**	**1.1**	**1.2**	**1.1**
2003	**0.9**	**0.7**	0.4	0	-0.2	-0.1	0.1	0.2	0.2	0.3	0.3	0.3
2004	0.3	0.3	0.2	0.1	0.2	0.3	**0.5**	**0.6**	**0.7**	**0.7**	**0.6**	**0.7**
2005	**0.7**	**0.6**	**0.5**	**0.5**	0.3	0.2	0	-0.1	0	-0.2	-0.5	-0.7
2006	-0.7	-0.6	-0.4	-0.2	0.0	0.0	0.1	0.3	**0.5**	**0.7**	**0.9**	**0.9**
2007	**0.7**	0.4	0.1	0.1	-0.2	-0.3	-0.4	**-0.6**	**- 0.9**	**-1.1**	**-1.3**	**-1.3**
2008	**-1.4**	**-1.3**	**-1.1**	**-0.9**	**-0.7**	**-0.5**	-0.4	-0.3	-0.3	-0.4	-0.6	-0.7
2009	-0.7	-0.6	-0.4	-0.1	0.2	0.4	**0.5**	**0.5**	**0.6**	**0.9**	**1.1**	**1.3**
2010	**1.3**	**1.2**	**0.9**	**0.5**	0.0	-0.4	**- 0.9**	**-1.2**	**-1.4**	**-1.5**	**-1.4**	**-1.4**
2011	**-1.3**	**-1.0**	**-0.7**	**-0.5**	-0.4	-0.3	-0.3	**-0.6**	**-0.8**	**-0.9**	**-1.0**	**-0.9**
2012	**-0.7**	**-0.5**	-0.4	-0.4	-0.3	-0.1	0.1	0.3	0.3	0.3	0.1	-0.2
2013	-0.4	-0.4	-0.3	-0.2	-0.2	-0.2	-0.3	-0.3	-0.2	-0.3	-0.3	-0.3
2014	-0.5	-0.5	-0.4	-0.2	-0.1	0.0	0.1	0.0	0.1	0.4	**0.5**	**0.6**
2015	**0.6**	**0.5**	**0.6**	**0.7**	**0.8**	**1.0**	**1.2**	**1.4**	**1.7**	**2.0**	**2.2**	**2.3**
2016	**2.2**	**2.0**	**1.6**	**1.1**	**0.6**	0.1	-0.3	**-0.6**	**-0.6**	**-0.7**	**-0.7**	**-0.6**

Note: Warm (red) and cold (blue) periods based on a threshold of +/- 0.5°C for ONI) (3 month running mean of ERSST.v4 SST anomalies in the Niño 3.4 region (5°N-5°S, 120°-170°W)), based on centered 30-year base periods updated every 5 years (https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php).

Those movements and disappearance have been confirmed in the discussions of previous authors [2], [6], [25] with a strong relationship between current structure and the presence or absence of cold filament in El-Niño or non-El-Niño years. Furthermore, while the WSC is usually maximum during El-Niño events (1997, 2002, 2004, 2006, 2009, 2015; Fig. 5), it seems to be the weakest in the following years in whole study area like in July 1998, 2003, 2005 and 2010.

Normally, a strong wind jet occurs at its Southern top to offshore of Southern Viet Nam (Fig. 5). It creates a current dipole at 11°N - 12°N latitude and results in a strong WSC that is of major importance for the upwelling development off the coast [10].

The dipole axis of this wind jet divides the SCS into two parts, namely Ekman upwelling and downwelling areas prevailing in the Northern and Southern parts, respectively. During post-El-Niño period, these dipole axis's move Northward, with their locations lying roughly around 13°N latitude in July 1998, 2003, and 2010, and the upwelling center also moves Northward. By observing of multi-sensor satellite imageries, Kuo et al. (2004) explained the weakening of Viet Nam coastal upwelling waters during 1997-1998 ENSO [9].

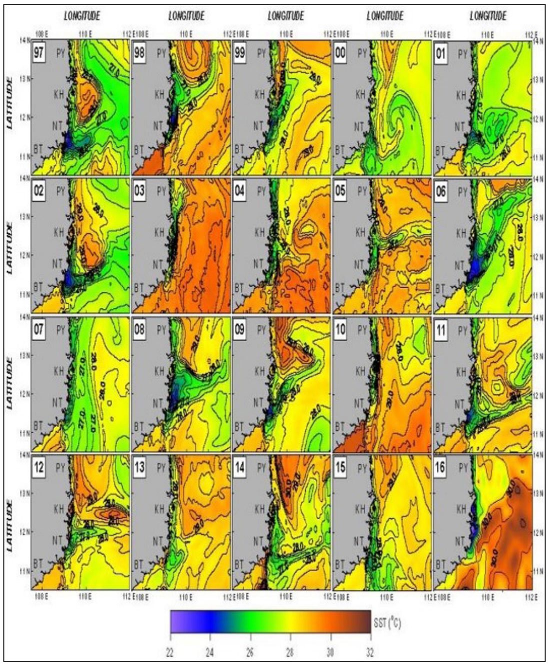

Fig. 2. Time series of SST dist. on July (1997-2016)

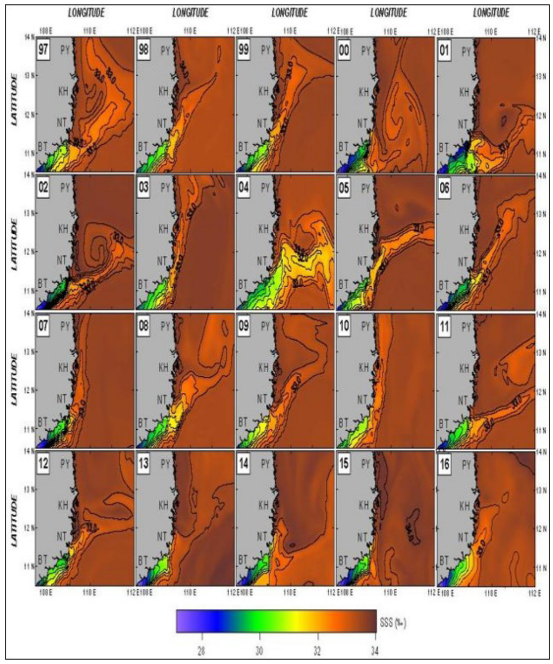

Fig. 3. Time series of SSS dist. on July (1997-2016)

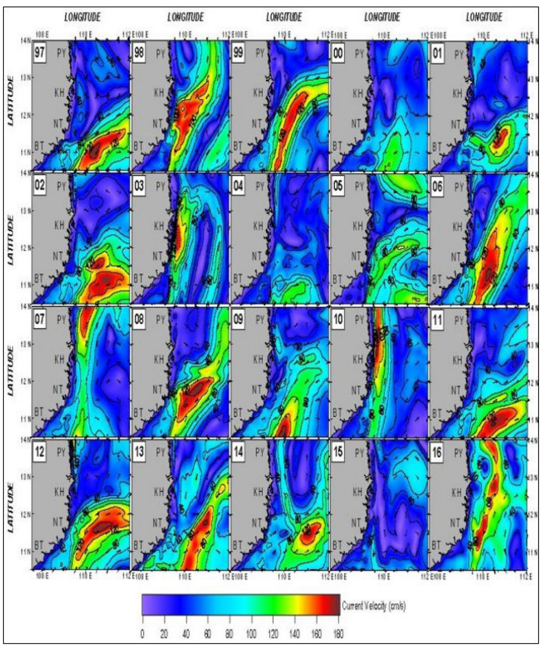

Fig. 4. Time series SWC dist.on July (1997-2016)

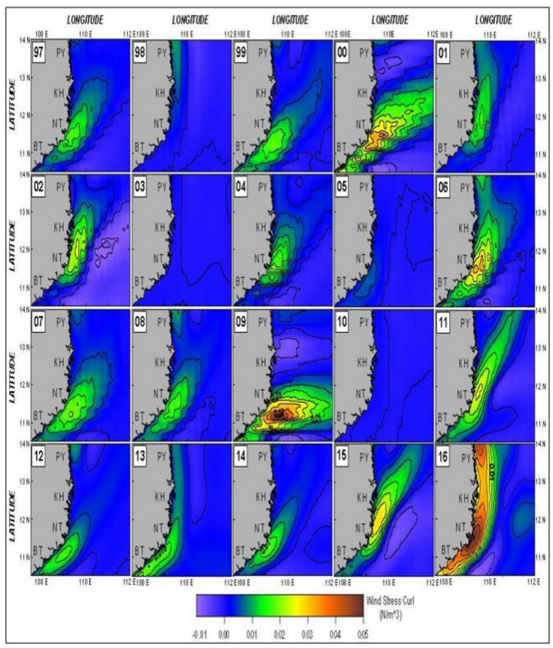

Fig. 5. Time series WSC dist. on July (1997-2016)

The rule of the weakening of upwelling phenomena in coastal waters in the SVS which happened during post-El-Niño event, resulted from seawater warming after a long time (about 10 to 12 months). The mechanism of this water warming will be explained in more detail in the next sections.

3.2. Vertical structures of T, S, and current

3.2.1. T & S vertical profiles in upwelling center during post-El-Niño

To complete the previous analysis of the oceanographic patterns at the surface in mid-summer in relation with the El-Niño event, a detailed analysis of the subsurface oceanographic parameters is necessary. While the depth-profiles of monthly July T & S in the central point of the upwelling region (109°00E; 11°15'N) of SVS (FEM data) can show a high variability from one year to another if we exclude the post-El-Niño years (Fig. 6, left panels), they show a remarkable similarity in 1998, 2003, 2010, 2015 & 2016 (Fig. 6, middle and right panels)

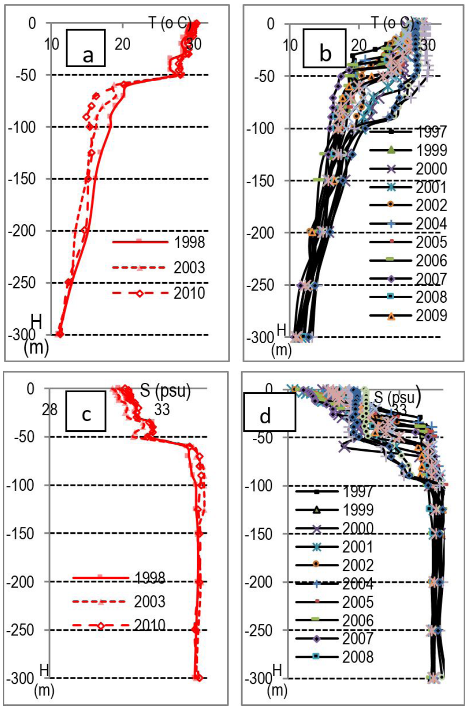

Fig. 6. Monthly July T &S vertical profiles in the central point of the upwelling region during the post El-Niño periods (a, c) and normal ones (b, d) from the FEM data

During a post-El-Niño year, the mixing is high in a homogeneous warm mixed surface layer of 50 m depth, and the thermocline and halocline were observed at between 50 and 60 m depth. In other periods, the homogenous layer was shallower, and the thermocline and halocline started at shallower depths (from 30 m up). Warming for a long time during El-Niño periods induced a warm, homogenous temperature layer to 50 m depth which increased the stratification of the water column. The intensification of the vertical stratification associated with this warm surface layer would contribute to preventing the upwelling from developing. This warm layer could be due to atmospheric forcing but also to a change in large scale oceanic circulation. This may explain why the upwelling had been disappearing or weakening during the year after an El-Niño event.

Based on the above anomalous characteristics, we computed indexes of T & S changes in the thermocline-halocline layers as follows:

$$Temp\ Grad_{50\text{-}60} = T_{50} - T_{60} \quad (1)$$

and $$SalGrad_{50-60} = S_{50} - S_{60} \quad (2)$$

Where T50, S50 & T60, S60 are respectively the monthly July T & S at 50 and 60 m depth in the central point of the upwelling region (from the FEM data). The temporal variation of $TempGrad_{50-60}$, $SalGrad_{50-60}$, as well as WSC at 10 m high from 1997 to 2016 are shown on Fig. 7.

The results showed that the anomalies of TempGrad>6°C and WSC<0.008 Nm^{-3} only happened and SalGrad <1.6 psu mostly happened during the post-El-Niño summers (in July 1998, 2003, 2010). A strong relationship between T & S gradient in thermocline and halocline with WSC during the post-El-Niño year allows to confirm the hypothesis of the weakening of the upwelling phenomena in typical years caused by less Ekman suction induced by a weaker WSC.

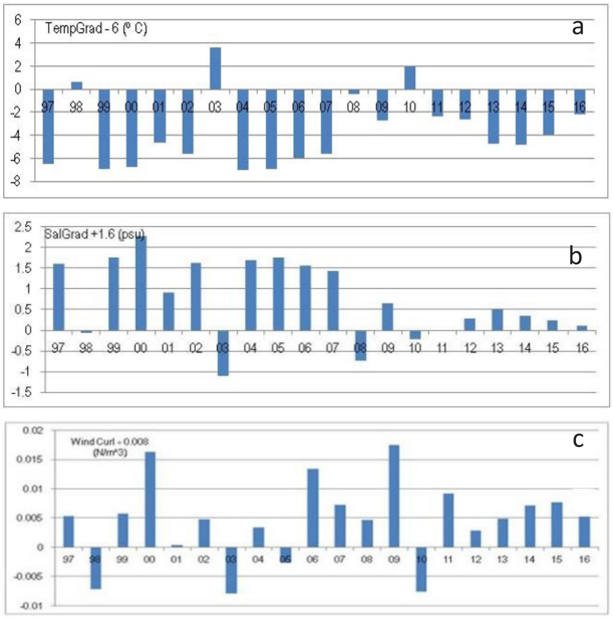

Fig. 7. Temporal variation of TempGrad (a), SalGrad (b) and WSC (c) in the central point of the upwelling region (109°00E; 11°15’N) of SVS

3.2.2. Longitude and latitude sections during El-Niño and the year after

During the early phase of El-Niño (1997, 2002, 2009), a filament of cold water (<26°C) is observed in a surface layer between 11.00°N and 12.00°N and accompanied by the rising of colder and saltier waters near the coast, typical of the upwelling (Fig. 8 & 9).

In the year after El-Niño (1998, 2003, 2010), this water mass moved further north like in 1998 & 2003, or was pinned down to a deeper water layer like in 2010, in every case around 13.00°N (Fig. 2 & 9). In the mid-summer of the early phase of El-Niño (1997, 2002, 2009), the meridian (V) current component was Southward near the shore and reversed offshore. The zonal (U) velocity component was eastward and relatively strong around 11.00º-12.00ºN, and developed from deeper layers to under surface layers, due to the upwelling phenomena. A coastward current was observed between 11.00°N and 12.50°N over most of the upper 150 m layer. During the mid-summer of post-El-Niño years (1998, 2003, 2010), the current of the upper 200 m layer showed a prevailing trend of moving northward (V>0) with a weaker eastward component near the surface (U>0) (Figs. 9 & 10). The coastward current (U<0) zone was reduced as compared to El-Niño years, restricted to deep waters further North. Clearly, there are remarkable changes of oceanographical characteristics in the upwelling water from the early to the post-El-Niño phases.

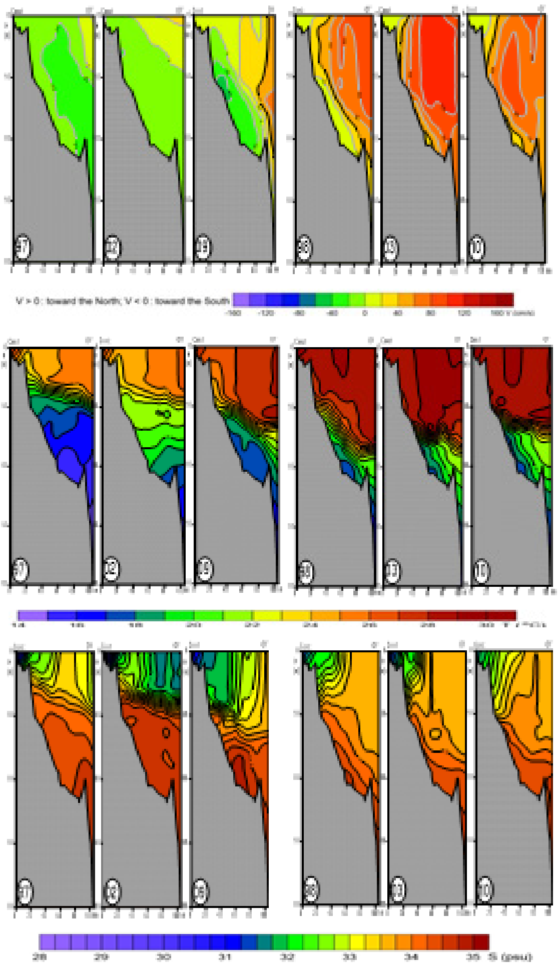

Fig. 8. Meridian (V) current velocity component (upper), T (middle), S (lower) along 11°15'N during El-Niño (July of 1997, 2002, 2009) and post-El-Niño (July of 1998, 2003, 2010) events

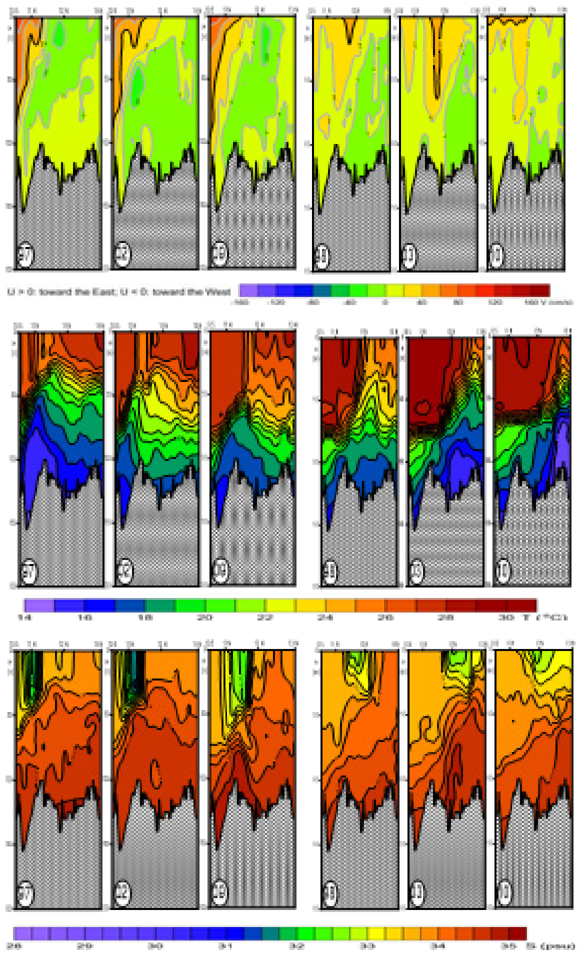

Fig. 9. Zonal (U) current velocity (upper), T (middle), S (lower) along 109°30'E during El-Niño (July of 1997, 2002, 2009) and post-El-Niño (July of 1998, 2003, 2010) events

3.3. Intra-seasonal variation of sea water temperature along time-longitude section and time-profile during the El-Niño and the year after

The analysis based on time-latitude sections of SST along 109°30'E, a longitude cutting across cold filaments (Fig. 10), showed that every summer from May to September, two to four cooling events occurred. Each one is associated with a decline of SST by at least 1-1.5°C during El-Niño events (1997, 2002, and 2009).

During the post-El-Niño years (1998, 2003, and 2010), fewer cooling centers were observable, and they were mostly further North around latitude 13°N. A precise comparison of 2009 and 2010 shows that, for example, a long cooling episode occurred from June to August 2009 around 11.5°N, followed by another cooling event in late September, while two short cooling episodes were observed in 2010, one in June around 12.7° and one smallest late August, in further South.

In the upwelling area (i.e. 11.00 - 12.00°N), hotter and colder SST values are observed alternatively in May-June because of secondary cooling rain events which happened early in June. Such events are not observed every year after El-Niño. In particular in 2010, no such event occurred. In summer 2010, strong drought occurred, and the accumulated heat made the water temperature greater than 30.0°C for 2 months. Warm surface waters (>29.0°C) South of 12.00°N are indeed observed for long periods during post-El-Niño years (Fig. 10).

The analysis of intra-seasonal variation (by biweekly period) of the sea water temperature time - profile nearby the coral reefs of the Ninh Thuan province gives additional important information (Fig. 11). The year after El-Niño, the seawater warming for a long time not only occurred in the surface layer but also influenced to the layer of 60 m deep. The water temperature was higher than the average (> 25.0°C) over the upper 60 m of the water column for a long time, reaching 28.0°C over the whole column in summer 2010, while for El-Niño years, upwelling events interrupted those warm periods.

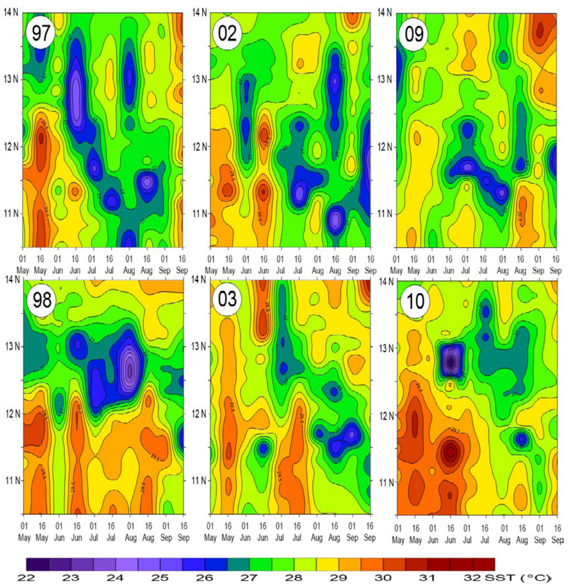

Fig. 10. Summer intra-seasonal pulses of SST in time-longitude sections along 109°30' E in the South of Viet Nam in 1997, 2002, 2009 (typical for in El-Niño) and 1998, 2003, 2010 (typical for post-El-Niño)

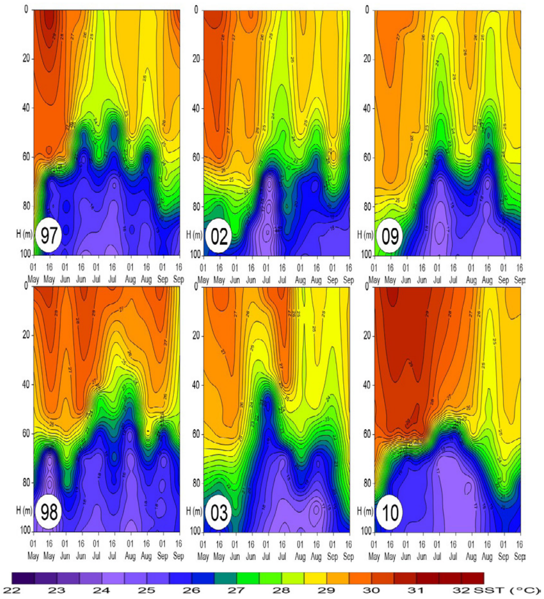

Fig. 11. Summer intra-seasonal time-profile evolution of SST (at 109°30'E; 11°20'N) in 1997, 2002, 2009 (typical El-Niño) and 1998, 2003, 2010 (post-El-Niño)

3.4. Ecological responses during the post-El-Niño

3.4.1. Occurrence of coral bleaching during post-El-Niño 2010 and 2016

The coral reef monitoring data of the Institute of Oceanography [20] in coastal waters of Ninh Thuan province (2005-2012) showed that coral bleaching happened during summer 2010 in this region, in My Hoa, Mui Thi, Bai Nho, Hang Rau and Mui Do (Fig. 12). The coral reef monitoring program between 2013 and 2016 evidenced another coral bleaching event in this region during the summer of 2016 (Fig. 13).

From the ONI index (Table 1), we can check that the summer of 2016 is coincident with a new post-El-Niño event. Those coral bleaching episodes in the coastal waters of Ninh Thuan province in June 2010 and at the end of May 2016 were induced by long periods of high water temperature evidenced in part 3.3: When the water temperature was high over the upper 60 m of the water column for a long time (like in summer 2010), the bleaching of the reefs in this area were induced. This demonstrates clearly the ecological impacts of seawater warming during post-El-Niño as massive coral bleaching in coastal waters of Ninh Thuan province.

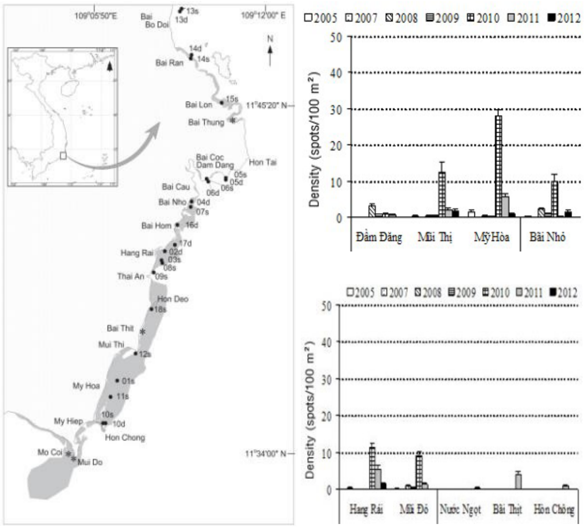

Fig. 12. Coral bleaching monitoring (2005-2012) in coastal waters of Ninh Thuan province [23, 24]. Left: Location of the stations; right: Density of bleached corals per area at different stations

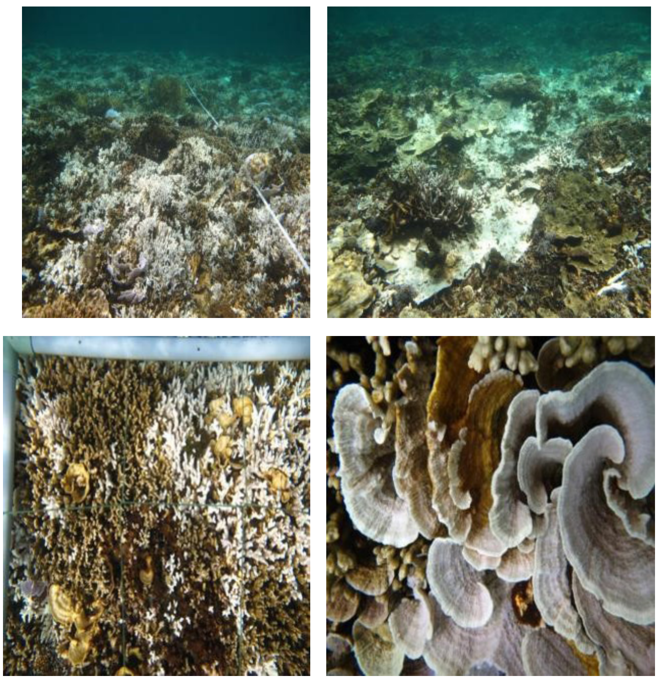

Fig. 13. Some scenes on massive coral bleaching in coastal waters of Ninh Hai commune-Ninh Thuan provinces in the end of May 2016 (photographs of Thai Minh Quang, Institute of Oceanography, VAST and Dr. Tkachenko Konstantin, Samara State University, Rusia)

3.4.2. Anomalies of chl-a features after the El-Niño events

As discussed in previous sections, such dynamics also have impacted on the primary production of phytoplankton and on the distribution of chl-a which can be derived under the sea surface from visible satellite imagery and/or from in situ monitoring. Distributions of chl-a contents from ocean color data (Fig. 14) have evidenced a clear difference between the El-Niño years with a developed upwelling (upper panel) and the year after with no upwelling, or with a reduced and further North short upwelling episode (lower panel).

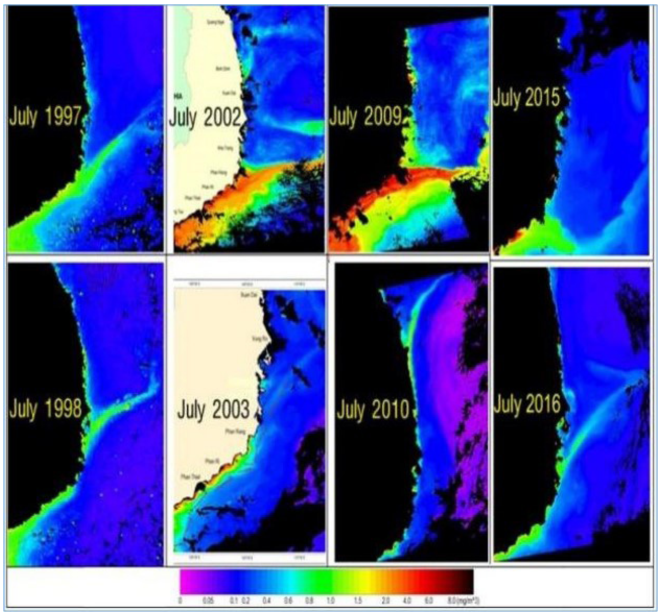

Fig. 14. Surface distribution of chl-a in early El-Niño episode of 1997, 2002, 2009 (upper panel) and post-El-Niño one of 1998, 2003, 2010 (lower panel) from multi sensor satellite imageries

Observed and satellite data therefore show that the Viet Nam central upwelling induces a cooling and saltening waters but also a nutrient enrichment of the surface waters resulting in high primary production. The weakening and/or displacement of the upwelling during post -El-Nino years have strongly reduced this strong biological activities.

5. Conclusions

Reanalysis data derived from HYCOM/NCODA model were coupled with FEM to examine the weakening of the upwelling phenomenon in the SCS that occurs the years after the El-Niño event. The upwelling's weakening after El-Niño is associated with the following signals: The wind force and Ekman pump are very weak; the cold-saline tongue and current dipole shift Northward and do not extend Eastward in the surface layer, while it is Westward deeper; a homogenous mixed surface layer of 50 m depth is observed with a thermo-halocline layer between 50 and 60 m depth with strong gradients (extreme values of the order of -6.00ºC and +1.60 psu, as compared to the other periods).

A more detailed analysis of intra-seasonal variations of sea water temperature before and during summers allowed to verify the effects of sea water warming that can induce coral bleaching which can be observed during the year after an El-Niño event. In the SCS, coral bleaching only happened when high sea water temperatures lasted for a long duration, i.e. during the spring and summer following El Niño episodes. Moreover, at this period, extended drought avoid usual secondary rainy events in June in this area, hence contributing further to the surface and subsurface water warming. Coral bleaching events only occurred during early phase of summer (i.e., May or June) of post-El-Niño years when upwelling had not developed yet.

Clearly, the changes described above happened abruptly and strongly influenced ecological characteristics in the "upwelling area" and were confirmed from field surveys and satellite imagery. Phenomena of coral bleaching during summer of 2010, and 2016; anomalies of thermohaline factors, anomalous distribution of chl-a content in surface water layer in 1998, 2003, 2010;... are concrete evidences on the responding of Viet Nam coastal upwelling during post-El-Niño. The organisms living in this area have difficulties adapting to the rapid changes in the environment, reduction of living resources may occur, and resilience of the reefs may be further studied in future studies.

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