POSITIVE IMPACTS OF TYPHOON [CASE STUDY ON TYPHOON *KETSANA* IN THE SOUTH CHINA SEA: SEPTEMBER 2009]

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ABSTRACT. *This brief study depicts the changes of water properties (temperature and salinity profile) after Typhoon Ketsana passed over the South China Sea and the benefits contributed to marine life as well as human being. Argo float data near the typhoon track before and after Typhoon Ketsana, available from GODAE website was analyzed in this project. Cooling of sea surface temperature (SST) about 1 to 3 ˚C was recorded in the study area. Typhoon Ketsana had removed about 250 to 380 MJ of heat from a surface area of 1 m^2. Sea surface salinity was observed to be increased about 0.2 to 0.4 pss after the typhoon. In addition, thermocline and halocline depths have deepened about 7.8 to 12.6 m and 10.3 to 12.9 m respectively due to the increase of surface layer depth. Even though the lifespan of Typhoon Ketsana was short, it brought several positive impacts: removed heat from the tropic regions in order to maintain moderate temperature, increased the concentration of nutrients due to the increases of salinity thus enhancing phytoplankton bloom in the ocean. Furthermore, the typhoon changed the ocean structure by deepening the thermocline and halocline depths. This affects the behavior of marine organisms that perform vertical migration. From the rough estimation, if the heat energy removed by Ketsana could be harnessed and converted into electricity, it would support the electrical usage in Malaysia for many years. Therefore, this study may cause some people to change their perspective on typhoons. In fact typhoons causes not just destruction and tragedy they also bring positive benefits to human kind and marine environment.*

KEYWORDS. Halocline, SST, SSS, thermocline, typhoon

INTRODUCTION

Typhoons, also known as tropical cyclones or hurricanes, are storm systems with closed circulation around the center of low pressure, fueled by the heat released when moist air arises and condenses. To form a typhoon, the sea surface temperature is required to be above 26 ˚C and down to a depth over 50 m, together with pre-existing system of disturbed weather, low wind shear and Coriolis effect. Typhoons normally happen in tropics to the mid-latitude regions and form between May to November particularly in Western Pacific Ocean for the northern hemisphere.

In the normal perspective, human always have negative judgment on typhoon that typhoon only brings damages and losses of properties as well as human life. However, on the bright side, typhoon also brings several benefits to both human being and marine environment. Typhoon is a natural heat removing mechanism as it transfers heat from tropic to mid latitude region by reducing the sea surface temperature (SST) after typhoon passed. This phenomena relieves heat stress and promote healthy environment for human being as well as marine life. Besides, strong turbulent mixing induced by the typhoon increases sea surface salinity (SSS) and this somehow will enhance the primary production (phytoplankton) in the ocean.

In addition, typhoon modifies the structure of the ocean, which are the thermocline and halocline depth. This uncertain shift of thermocline and halocline depths will affect the vertical motion of marine organism, create stress on prey and predator relationship as well as affect the food source for marine organisms.

Typhoon Ketsana

On 23rd September 2009, a Tropical Depression had been reported at about 860 km to the northwest of Palau and had given the name of *Ondoy*. On 25th September, the Tropical Depression was found at the east of Manila in the Philippines. It was then upgraded to a Tropical Storm on 26th September and had given the name of *Ketsana*. After the storm passed the Philippines, it moved into the South China Sea (Figure 1) and upgraded into a Severe Tropical Storm on 27th September 2009. During 27th September 2009, *Ketsana* developed further and was upgraded to a Typhoon. Typhoon *Ketsana* was then intensified quickly during the same day and reached the peak wind speed of 165 km/h and 140 km/h which made it as Category 2 Typhoon on the Saffir-Simpson Hurricane Scale. On 29th September, *Ketsana* caused severe landfall on Quang Nam in Vietnam at 0600 UTC (Coordinated Universal Time). *Ketsana* was then rapidly weakened as a Severe Tropical Storm until later that day when it was downgraded into a Tropical Storm. Early of the next day, it was downgraded as a Tropical Depression as the depression centre was located at Laos (JTWC, 2009).

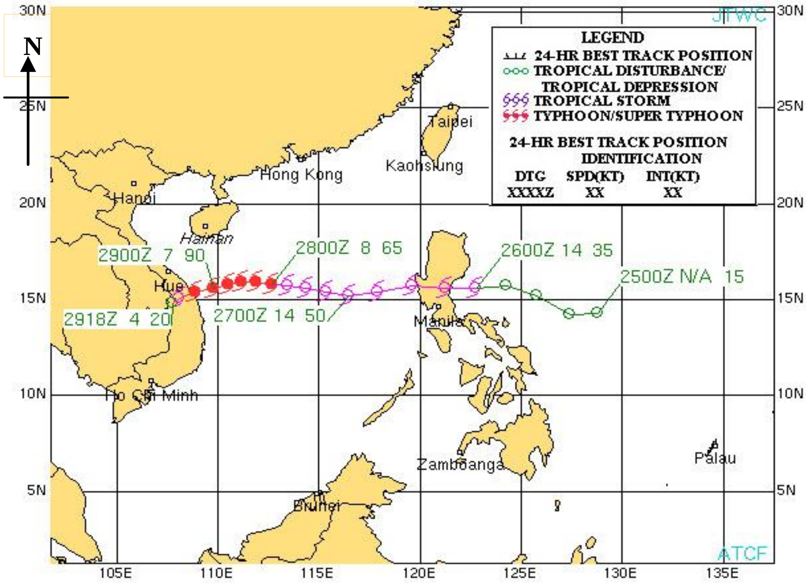


Figure 1. Track of Typhoon Ketsana (Source: Modified from JTWC, 2009).

MATERIALS AND METHODS

First, the track of Typhoon *Ketsana* was observed. The dates and the latitudes and longitudes of typhoon were identified. Next, the Argo float data (temperature and salinity profile) required for the analysis before and after the typhoon are obtained via Global Ocean Data Assimilation Experiment (GODAE) website (http://www.usgodae.org). Argo float is a part real time Global Ocean Observing system. It is a drifting oceanic robotic probe with function to collect temperature and salinity profiles down to a depth of 1000 m or 2000 m of the ocean for every ten days per cycle (Argo, 2010). The data was obtained from three different Argo floats which are near to the track of typhoon *Ketsana* (Figure 2) located at the South China Sea between latitudes of 10 ˚N to 20 ˚N and longitudes of 110 ˚E to 120 ˚E, which is situated between Vietnam and Philippines.

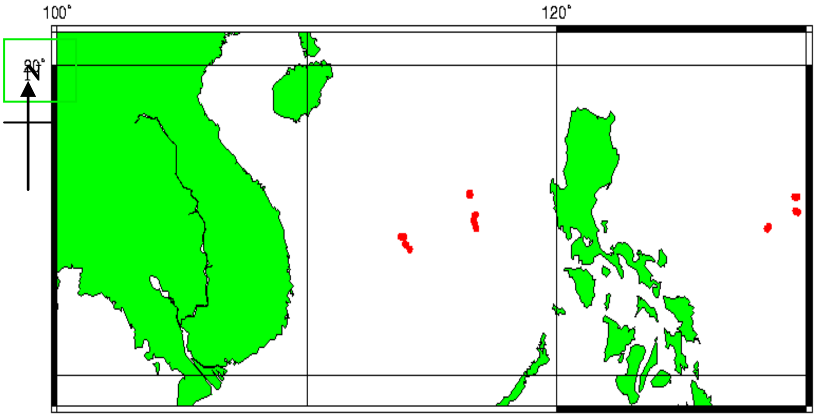


Figure 2. Argo floats used in this study and their locations (Source: Modified from GODAE, 2010).

Calculation of Heat Removed

Typhoon passes from the tropics toward mid latitude regions. At the same time, it carries heat away from tropic toward mid latitude regions. The amount of heat can be calculated by using the Equation (1):

$$\frac{\Delta Q}{A} = \rho h c \Delta T \qquad (1)$$

Where:

$\frac{\Delta Q}{A}$ = Changes of heat energy per unit area of sea surface after typhoon passages (J m^{-2})

ρ = Average density of seawater in the area (1022 kg m^{-3})

h = Depth of the mixed layer (m) [where temperature change takes place]

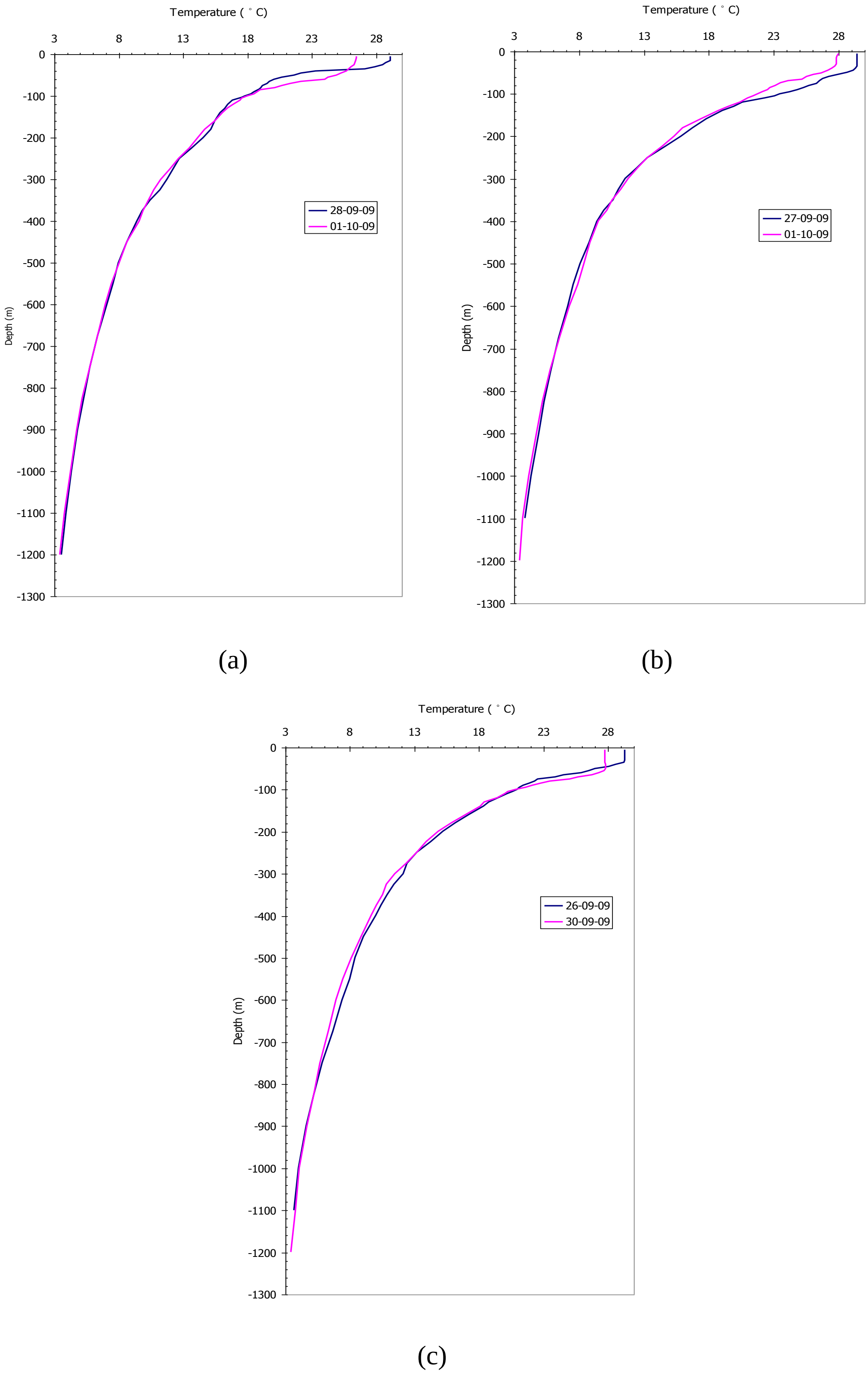
c = Specific heat capacity of seawater (3983 J˚$C^{-1}kg^{-1}$)

ΔT = Changes in temperature (˚C) before and after a typhoon

RESULTS AND DISCUSSION

Temperature Profiles

Temperature profile before and after *Ketsana* passed South China Sea (SCS) were plotted using the temperature data collected by the Argo float in Figure 3. The temperature data is available down to the depth of 1200 m. Generally the sea surface temperature (SST) experiences more changes than the deeper layer below 700 m.



(a) (b)

(c)

Figure 3. Temperature profile of Argo float: (a) Float 1, (b) Float 2 and (c) Float 3.

It is obvious that the SST recorded by each float in this study has decreased after Typhoon *Ketsana* passed the area. SST cooling of about 1 to 3 ˚C has been recorded after

Ketsana and change of surface layer depth (SLD) are shown in Table 1.

Table 1. The changes of sea surface temperature and surface layer depth. ('+' sign represents increase; '-' represents decrease).

Float	Date	SST (ºC)	Changes of SST (ºC)	SLD (m)	Changes of SLD(m)
1	28-09-2009	29.08	- 2.64	15.1	+ 15.2
	01-10-2009	26.44		30.3	
2	27-09-2009	29.42	- 1.43	44.8	- 0.50
	01-10-2009	27.99		44.3	
3	26-09-2009	29.31	- 1.54	34.6	+ 24.8
	30-09-2009	27.77		59.4	

This result is consistent with the previous studies whereby passage of typhoon have been proven to cause SST cooling of, about 3 to 7 ˚C by Hurricane Ivan (Walker *et al*., 2005), about 1.3 to 10 ˚C by Hurricane Fabian (Son *et al*., 2007), about 3 ˚C by TC Gene (Prasad *et al.*, 2009) and there are some simulated typhoon showed SST decrease after passage of typhoon (Mao *et al.*, 2000; Rao *et al*., 2010). The decrease of SST depends on the locality and the strength of typhoon.

SST decreases dramatically after typhoon passage is caused by the strong turbulent mixing induced by typhoon and evaporation due to heat removed. High wind stress generated by typhoon causes the surface water to diverge and this causes the cold water from the thermocline layer to mix with the surface water and thus results in SST cooling (Pollard *et al.*, 1972; Price, 1981; Walker *et al*., 2005). It is also to be noted that the surface layer depth of study area increases about 15 to 25 m after the passage of typhoon across South China Sea. Cold water from deeper layer mixes with the warmer water in surface layer causes structural changes in the ocean whereby the surface layer deepens after typhoon passed (Zenghong *et al*., 2006).

Calculation of Heat Removed

Typhoon is known as the natural heat removing mechanism, it transports heat energy away from tropic region to subtropic region (Prasad *et al.*, 2009), hence SST decrease dramatically. The amount of heat energy removed by Typhoon *Ketsana* can be calculated using Equation 1.

For float 1,

$$\frac{\Delta Q}{A} = 1022 \times 30 \times (29.08-26.44) \times 3983$$

$$= 322{,}393{,}579.2 \text{ J m}^{-2}$$

$$\approx 322 \text{ MJ m}^{-2}$$

It also means that from an area of 1 m^2, approximately 322 MJ of energy was removed by *Ketsana*. If we look at the electrical energy point of view:

$$\text{Energy} \approx 322 \times 10^6 \times \frac{1\,\text{h}}{3600\,\text{s}} \approx 89444.44 \text{ Wh}$$

$$\approx 89.44 \text{ kWh}$$

Ketsana can provide 89.44 kWh of energy from 1 m^2 area. If the sea surface near the typhoon track is considered, the total energy removed is extremely huge. Table 2 shows the amount heat removed and estimation of electrical energy.

Table 2. Amount heat removed and estimation of electrical energy.

Float	Amount heat removed (MJm^{-2})	Estimation of electrical energy (kWh)
1	322	89.44
2	262	72.78
3	377	104.72

From the calculation above, it is proven that Typhoon *Ketsana* is able to remove huge amount of heat energy from the area where it passed. By the estimation the sea surface area near the typhoon track is about 2.03×10^5 km^2, so the estimation of the heat loss for the area is about 6.51×10^{13} MJ. This can prove that typhoon is capable to reduce the heat stress on human and marine environment.

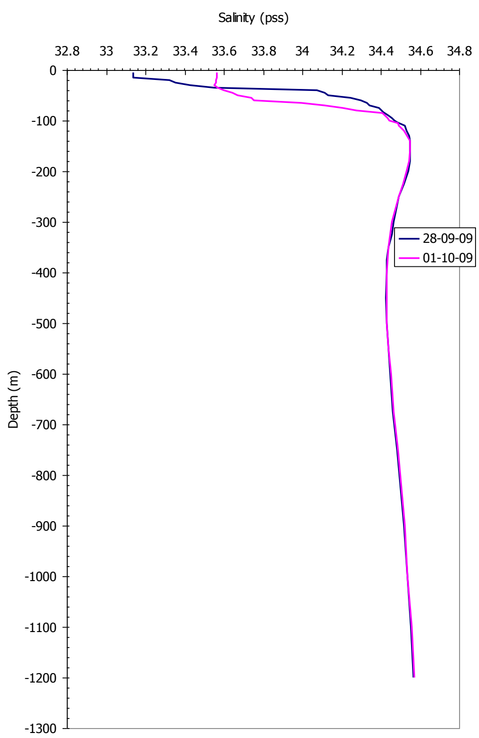
If the ambient temperature increases drastically, human are at the risk of heat stress or overheating. Heat stress may result in hallucination, confusion, slurred speech, muscle cramp or even death (CDC, 2010). Heat stress also affects the marine ecosystem especially coral reefs. Corals are very sensitive to the changes of water temperature. They are vulnerable to heat stress if water temperature increases and experience coral bleaching with reduced population density of zooxanthellae (Hoegh-Guldberg, 1999). Typhoon is then becoming a necessity in the tropic region as it transports heat away and reduces the problem of over heating on human being and promotes a healthier environment for the growth of coral reef.

As a wishful thinking, it could even provide energy supply to the area if the energy were to be harnessed. From the estimation of heat loss, it is equivalent to 1.81×10^7 million kWh. So, compare to Malaysia's electrical usage is about 1.07×10^5 million kWh for year 2009 (Department of Statistic, 2010), if the heat energy can be harness and convert to electrical power, it can support the electrical power in Malaysia for many years.

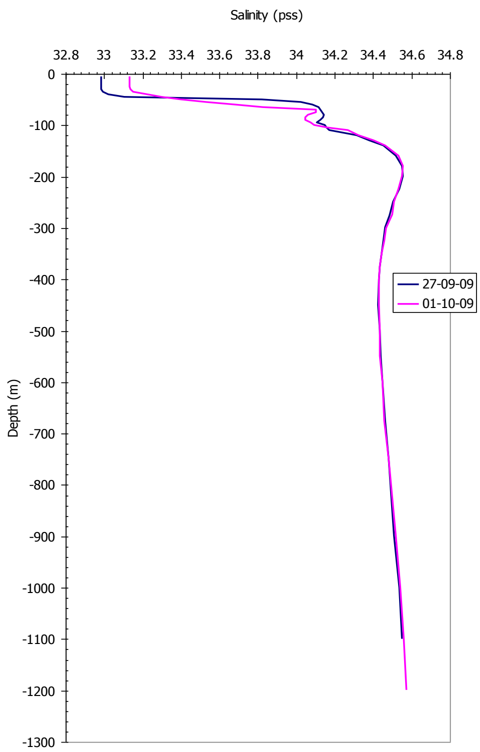
Salinity Profiles

Salinity profile before and after *Ketsana* passed South China Sea (SCS) were plotted using the salinity data collected by the same Argo floats as temperature profiles. Figure 4 shows sea surface salinity (SSS) increase after Typhoon *Ketsana*.

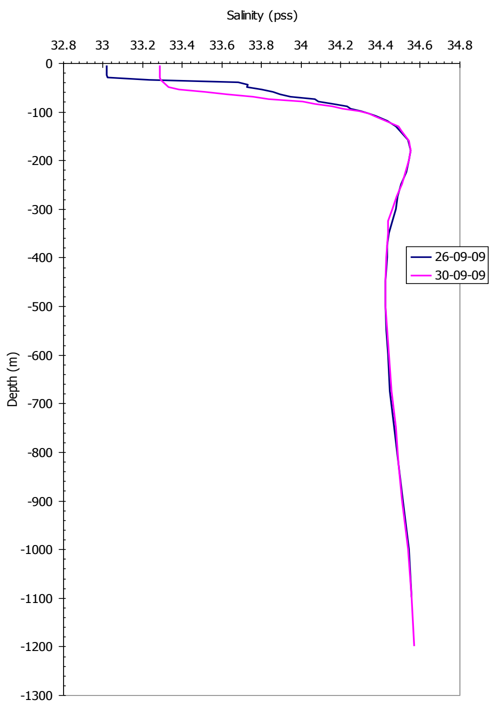
SSS has increased about 0.1 to 0.4 pss as shown in Table 3 after the passage of Typhoon *Ketsana*. This result is consistent to the simulation experiment carried out by Robertson & Ginis (1998) on the ocean response to Tropical Cyclone without the rain flux where it is proven that SSS has increased about 0.2 pss correspond to the passage of typhoon. There are several simulation models by Jacob & Koblinsky (2007) and Hu & Meehl (2009) also supported the study by Robertson and Ginis whereby it is proven that SSS increases after the passage of simulation typhoon.



(a)



(b)



(c)

Figure 4. Salinity profile of Argo float: (a) Float 1, (b) Float 2 and (c) Float 3.

Table 3. The changes of sea surface salinity. ('+' sign represents increase of SSS).

Float	Date	SSS (pss)	Changes of SSS (pss)
1	28-09-2009	33.14	+ 0.43
	01-10-2009	33.57	
2	27-09-2009	32.99	+ 0.14
	01-10-2009	33.13	
3	26-09-2009	33.02	+ 0.27
	30-09-2009	33.29	

SSS increase or decrease is due to the phenomena of evaporation and precipitation. During the formation of typhoon, warm surface water being evaporated as warm moist air and rises to atmosphere. It results in the formation of clouds. Only the sea water can be evaporated as water vapor where particles in seawater will remain. These particles are responsible in increasing the salinity as most of the water has been evaporated. Hence, the evaporation of surface water causes the increasing of SSS. However, there is also other reason causing the salinity to be changed, that it is the turbulent mixing induced by typhoon. This causes the saltier water from halocline enter surface layer by mixing each other (Robertson and Ginis, 1998).

The increasing of surface salinity is beneficial to the ocean because it promotes phytoplankton blooms. Phytoplankton in the euphotic zone is the key element in the ocean food chain. It serves as the primary producer in undergoing photosynthesis and also main food source for other marine organisms in higher trophic level. Phytoplankton requires a range of nutrients and adequate sunlight as well as carbon dioxide to carry out photosynthesis, grow and survive. During the process of photosynthesis, phytoplankton consumes carbon dioxide and releases oxygen into the atmosphere. When phytoplankton blooms, the amount of carbon dioxide in the atmosphere can be reduced by the uptake of large number of phytoplankton in the ocean. Consequently, carbon dioxide as one of the greenhouse gases can be controlled and reduced (Lin *et al*., 2003; Babin *et al*., 2004; Zimmerman & Emanuel, 2010).

Phytoplankton bloom is also known as Chlorophyll-a (Chl-a) enhancement. The concentration of Chl-a is typically used in most studies as to indicate the amount of phytoplankton induced by typhoon. In the studies by Lin *et al*. (2003), Walker (2005), Son *et al*. (2007); Wu *et al*. (2007) and Liang *et al*. (2008), the concentration of Chl-a has increased significantly after typhoon passed due to the mixing of nutrients and phytoplankton from the deeper layer to the surface ocean.

Changes of Thermocline and Halocline Depths

Typhoon *Ketsana* has modified the structure of the ocean, which are the thermocline and halocline depths. Based on Tables 4 and 5, the changes of thermocline and halocline are shown.

Table 4. Changes of thermocline depth ('+' sign represents increase; '-' represents decrease).

Float	Date	Thermocline depth (m)	Changes of thermocline depth (m)
1	28-09-2009	87.30	+ 7.8
	01-10-2009	95.10	
2	27-09-2009	101.90	- 0.2
	01-10-2009	101.70	
3	26-09-2009	96.85	+ 12.6
	30-09-2009	109.45	

Table 5. Changes of halocline depth ('+' sign represents increase; '-' represents decrease).

Float	Date	Halocline depth (m)	Changes of halocline depth (m)
1	28-09-2009	87.30	+ 12.9
	01-10-2009	100.20	
2	27-09-2009	99.35	- 2.45
	01-10-2009	96.90	
3	26-09-2009	94.35	+ 10.25
	30-09-2009	104.60	

For Float 1 and Float 3, the thermocline and halocline depths have deepened. However, for Float 2, the thermocline and halocline depths have shallowed. The structure of the ocean – thermocline and halocline depths are able to change and this is due to the changes of the surface layer. When the surface layer has been deepened, it pushes down the underlying thermocline and halocline layers, and vice versa.

The changes of thermocline and halocline depth induced by typhoon affect the behavior of marine organisms that perform vertical migration in the ocean. As thermocline depth changes, marine organism may move to find the optimum temperature and suitable food source to live that they have different requirement for thermal adaptation and food ability (Hamrin, 1986; Neilson & Perry, 1990; Olla & Davis, 1990). When halocline depth changes, salinity that is associated to density and viscosity causes zooplankton to remain suspended in more saline water as they require less energy to move. In the study by Harder (1968) and Lougee *et al.* (2002), marine organisms need to swim harder in less saline water and easy sink out. Slight aggregations of organisms are found in or below the halocline layer.

Based on the analysis carried out in this study, Typhoon *Ketsana* has significantly cooled the sea surface temperature (SST) of about 1 to 3 ˚C. This shows that typhoon has induced the decrease of SST. Typhoon generates high wind stress causing the surface water to be diverged. Thus, the cold water from the thermocline layer mixes with the surface water and reduces SST.

Typhoon has been clarified as natural heat removing mechanism as it transports heat energy away from the tropic regions to sub-tropic regions. The amount of heat loss from the sea surface area (2.03×10^5 km^2) near the typhoon track has been estimated about 6.5×10^{13} MJ, which equivalent to 1.81×10^7 million kWh from the electrical point of view. Moreover, by transporting heat energy away, typhoon provides a healthy environment for human as well as marine ecosystem as it reduces the heat stress.

The sea surface salinity (SSS) has significantly increased right after the passages of

Typhoon *Ketsana* of about 0.1 to 0.4 pss. It is to be noted that salinity does not changes as easily and quickly as temperature does in the ocean water. The increase of salinity is associated with the evaporation of surface water induced by typhoon. As a result, it causes more saline water from the halocline layer to be mixed with the surface water. Increase of salinity induces phytoplankton blooms where phytoplanktons are the primary producers in the marine food chain as well as the oxygen producers to the atmosphere.

Furthermore, typhoon has modified the structure of the ocean that includes the changes of thermocline and halocline depths. From the analysis in this study, thermocline and halocline depths have changed after Typhoon *Ketsana* passed South China Sea (SCS) for the areas of ARGO floats considered. The modification of the ocean layers influences the behavior of marine organisms that perform vertical motion in the ocean due to changes of food source and predator stress.

From this case study, human should change their mind-set and have balanced point of view on typhoon as if typhoon only bring tragedies to human kind. In fact, the presence of typhoon should somehow be appreciated as it is responsible to cooling the tropics regions to maintain the moderate temperature for life, creating a healthy marine environment. Without these regular occurrences of typhoons in the tropic regions, our lives together with the marine ecosystem would have been rather miserable with unbearable heat stress. Due to the destructive power of typhoon, it is also quite important to implement the strategies of preparation, adaptation and mitigation for forth coming typhoon in the next seasons.

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