

East India Coastal Current induced eddies and their interaction with tropical storms over Bay of Bengal

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ABSTRACT

Eddies of about 10 to 500 km in diameter, persisting for periods of days to months are commonly referred to as meso-scale eddies in oceanography. Energetic eddies are frequently found in the vicinity of faster flowing currents like the Gulf Stream and the Kuroshio. The present study deals with the role of eddies, occurring in the vicinity of East India Coastal Current (EICC), particularly in the months of Apr- May and October- November, in the intensification of tropical cyclones in Bay of Bengal. Though the Bay of Bengal is well known for meso-scale eddies, the role of these in the intensification/weakening of the storms is not known quantitatively. In this study, an attempt has been made on the quantitative analysis of the role of these eddies (warm/cold) in the intensification of the storms over Bay of Bengal. It is found that in case of a severe cyclone during 16-19 October, 1999 the intensity of the storm was enhanced by 260% due to its interaction with a warm eddy. This is much higher than that reported in case of *Opal* (119%) and *Maemi* (138%) in the north Atlantic. The enthalpy fluxes (latent+sensible) are much higher (lower) over warm (cold) eddies. The warm eddy opposes the cooling induced by the storm and helps the intensification through the supply of large amount of enthalpy flux. This emphasizes the importance of eddies in the intensification of storms over Bay of Bengal, which is totally ignored by the meteorologists in forecasting the intensification of storms.

Keywords:

Upper Ocean, Coastal Currents; Eddy Conduction; Hurricanes; Heat content

1. Introduction:

The western boundary coastal current in the Bay of Bengal, known as the East India Coastal Current (EICC) has been extensively studied (Legeckies, 1987; Shetye et al., 1991&1996 and Shankar et al., 2002). Like the Somali Current in the Arabian Sea, EICC reverses direction twice a year, flowing northeastward from February to September with a strong peak in March-April; and southwestward from October to January with strongest flow in November (Legeckis, 1987). It extends to a depth of 200m and has a transport of ~10 Sv. A change in the direction of EICC is observed just south of 18⁰N in the peak southwest monsoon period. Sea surface height and wind stress observations indicate that the strength and direction of EICC follows closely the alongshore wind stress (Pratap et al., 2005). During summer monsoon season (May-August), the EICC flows northward along the southern part of the Indian coast and equator-ward along the northern part (Shetye et al., 1991) whereas, during October–December, the EICC flows equator-ward along the entire Indian coast (Shetye et al., 1996) carrying low salinity water from the Bay of Bengal enroute.

It was reasoned that the flow instabilities in the EICC lead to the formation of eddies in the vicinity of the EICC. It is worth noting that energetic rings and eddies are commonly found in the vicinity of faster flowing currents including the Gulf Stream and its North Pacific counterpart off Japan called the Kuroshio (Shenoi, 2010). In their mature phase the eddies may have meso scale dimensions of about 100 - 200 km in diameter and persist for periods of days to months. Though the EICC is not as strong as the Gulf Stream, it is also found to produce several cold and warm core eddies on both sides of the current during certain months (April & May, October & November) particularly when the EICC is very strong (Vinayachandran, 2008).

Over the north Indian Ocean, Bay of Bengal accounts for the majority (about 87%) of total pre and post monsoon tropical cyclones. Most of the severe cyclones in Bay of Bengal during pre-monsoon (April-May) and post-monsoon seasons (October-November) in Bay of Bengal hit east coast of India and cause colossal loss of life and property. The super cyclone which is the severe most during the last 110 years hit Paradeep, Orissa, on 29th October 1999. The lowest central pressure was 926 hPa and wind speed > 200 kmph. The storm surge of about 8m height traveled 30 km inland. More than 10,000 people were killed and the total loss due to damages was estimated as 4.5 billion US dollars (Sadhuram et.al, 2004). Hence advance and accurate prediction of the intensity and the track prediction of storm is very important to minimize the loss of life.

The interaction between tropical cyclones and the ocean eddies has been identified as an important area of research in the tropical cyclone intensity change (Hong et al., 2000, Shay et al.,

2000; Goni and Trinanes 2003; Kaplan and DeMaria 2003 and Emanuel et al., 2004). From the observational studies of various hurricanes like “*Opal*”, “*Mitch*”, and “*Bret*” in the Atlantic, it has been generally found that rapid intensification (typically from Saffir–Simpson category 1 to 4 within 24–36 hrs) was observed when these hurricanes passed over warm ocean features (Shay et al., 2000; Goni and Trinanes, 2003). The intensification of a cyclone depends on a number of meteorological and oceanographic parameters. Leipper and Volgenau (1972) first recognized the importance of ocean thermal structure in the tropical cyclone (TC) intensification. Goni et al., (2009) stressed the role of upper ocean thermal structure, since in most of the cases it is the upper ocean that supplies fuel for the movement and intensification of a cyclone. It has been generally established that tropical cyclones originate and intensify only in the oceanic regions where the Sea Surface Temperature (SST) is above 26°C (Palmen, 1948). Although sea surface temperature (SST) plays a role in TC genesis, the upper ocean heat content (UOHC) appears to play a vital role in the intensification of storms (Shay et al., 2000; Lin et al., 2008; Sadhuram et al., 2010). In Bay of Bengal, the average value of UOHC and the depth of 26°C isotherm (D26) is 3-4 times higher in a warm eddy compared with that in a cold eddy (Sadhuram et al., 2011). It is found that the intensity of storms is underestimated by 26-30% if the eddies are not considered (Lin et al., 2005).

Sudden and unexpected intensification of tropical cyclones often occurred within 24–48 hr before striking the coast upon passing over warm oceanic regimes such as the Gulf Stream or large warm core rings (WCRs) in the western North Atlantic Ocean and Gulf of Mexico. Although SST exceeding 26°C is a necessary condition for intensification of a cyclone, the Ocean Planetary Boundary Layer (OPBL) and the depth of the warm isotherm (D26) are equally important and represent regions of positive feedback to the atmosphere (Namias and Canyan, 1981). For example the hurricane “*Opal*” that occurred in 1995 intensified rapidly from Category 1 to Category 4 status within 14 hours as it passed over a warm core eddy and encountered a deeper and warmer oceanic regime in the Gulf of Mexico (Shay et al., 2000). Lin et al. (2005) have included the satellite altimetry data into a very simple coupled model to show that the presence of the warm ocean eddy can serve as an efficient insulator against the ocean’s negative feedback, helps to maintain and even boost the TC intensity.

Though Bay of Bengal is well known for eddies, quantitative analysis on the role of these eddies in the intensification of storms is still lacking. Ali et al. (2007) discussed the importance of eddies in case of May 2003 cyclone qualitatively. Lin et al. (2009b) reported sudden intensification of *Nargis* over a warm oceanic region, just before landfall. Sadhuram et al. (2011) showed that the intensity of *Aila* (24-26 May 2009) was enhanced by 43% when the storm encountered with a warm

eddy. Although these studies suggest the role of warm core eddies a systematic quantitative assessment has not been done so far for Bay of Bengal cyclones. In the present study, the generation of eddies due to EICC and their affect on the intensification/weakening of storms over Bay of Bengal is addressed using remote sensing data.

3. Material and Methods:

The merged products of altimeter data on Dynamic heights, geostrophic currents and surface height anomaly (SHA) for Bay of Bengal (78-99°E and 5-22°N) have been obtained for the period 1993-2009 from the NASA's AOML database in the netcdf format. After converting the netcdf data to ASCII, we used surfer software to plot the geostrophic currents overlying the sea surface height anomalies taken from the AVISO live access server.

Data on cyclone tracks and central pressure of the storms have been taken from the India Meteorological Department (IMD) and the Cyclone E- Atlas of IMD (2008). Argo data for locations (12.8°N, 81.1°E), (14.5°N, 85.7°E), (8.3°N, 84.2°E), (14.2°N, 82.21°E) and (8.59°N, 84.84°E) were taken from the INCOIS (Indian National Centre for Ocean Information services). To compute different oceanographic parameters that are necessary for this study, we interpolated the Argo data for every 1m depth interval using spline interpolation technique.

3.1 UOHC from Argo data

UOHC is computed using the following equation

$$UOHC = \rho C_p \int_0^{D_{26}} T dz$$

In which ρ is the density of water column above 26°C isotherm, C_p is the specific heat of seawater at constant pressure; T is the temperature in excess of 26°C for a layer of depth increment dz and D_{26} is the depth of the 26°C isotherm.

3.2 A new method to compute UOHC from SSHA

Using RAMA buoy data and satellite SSHA from 2007-2009 in pre and post monsoon months at three locations (8°N,90°E ; 12°N,90°E; 15°N,90°E) following equations were developed to compute UOHC and D26 from SSHA (Fig. 1).

Preferred position of Fig. - 1

SSHA is positively and significantly (>99% level) correlated with UOHC and D26. The regression equations are shown below:

Pre monsoon months (April-May):

$$\text{UOHC} = 2.55 * \text{SSHA} + 75.58 \text{-----}(1)$$

$$\text{D26} = 1.74 * \text{SSHA} + 71.89 \text{-----}(2)$$

Post monsoon months (October- November) :

$$\text{UOHC} = 2.09 * \text{SSHA} + 75.03 \text{-----}(3)$$

$$\text{D26} = 1.31 * \text{SSHA} + 70.67 \text{-----}(4)$$

3.3 Eddy feed back factor for few cyclones

To quantify the contribution of any eddy, a parameter called eddy feedback factor has been introduced by Wu et al., (2007) which is defined as follows

$$F_{\text{Eddy-T}} = (\Delta p_{\text{out}} - \Delta p_{\text{in}}) / \Delta p_{\text{in}}$$

Where, Δp_{in} is the amount of the sea-level central pressure deepening when the storm encounters the ocean eddy and Δp_{out} is that when the storm leaves the eddy.

Sensible and latent heat fluxes and all the meteorological parameters (zonal wind, RH, Air temperature) have been taken from the NCEP reanalysis. TMI SST has been taken from INCOIS.

4. Results and discussion:

4.1. EICC and eddies:

Fig. 2 shows the monthly climatology of geostrophic currents and associated sea level anomalies (1993- 2009) during pre and post monsoon seasons in the Bay of Bengal. In the mean monthly pictures, EICC appears to be a discontinuous flow with a few circulating loops along its path. The loops or meso-scale eddies are highly variable in direction at all time scales from intra-seasonal to inter-annual. EICC is quite strong in the months of April-May and October-November leading to the formation of several eddies (cold and warm core) all along its path. These meso-scale features associated with the EICC were studied earlier (Durand et al., 2009).

Preferred position of Fig. – 2

Preferred position of Fig. - 3

Typical temperature and salinity profiles of warm and cold core eddies compared to that of normal conditions (without eddies) are shown in Fig. 3. A deeper mixed layer and higher SST values are clearly seen in the warm core eddy compared to cold core eddy or to that during normal conditions. In the warm eddies the warm waters are found to stretch significantly to deeper depths

(>200m). Low Salinity was observed inside the warm core eddies. The positions of a few selected eddies and the dates of their occurrence along with the other computed oceanographic parameters like UOHC and D26 are presented in Table 1. All these parameters are generally higher in the warm core eddy compared to the other two cases. UOHC in the warm core eddy (156 kJ/cm^2) is almost 3 times higher to that of the normal condition (51 kJ/cm^2) and 4 times to that of cold core eddy (35 kJ/cm^2).

4.2. Eddies and the intensification of cyclones

The upper surface layer heat potential of the warm core eddy acts as a fuel for the intensification of a cyclone by giving a positive feedback to the cyclone. Where as in the case of cold core eddy the heat potential is comparatively less and gives negative feedback to the cyclone. Cyclones entering the warm core eddies are usually intensified depending on the strength and size of the eddy while those passing through cold core eddies are generally weakened. The rate of intensification of a cyclone also depends on the translation speed (U_h) of the cyclone. Because of the inverse relationship between the UOHC and U_h developed for west north Pacific Ocean (Lin et al., 2009b) and Bay of Bengal (Sadharam et al., 2010) suggests that a slow (fast) moving cyclone can intensify over the region where UOHC is high (low). Eddy feed back factor ($F_{\text{EDDY-T}}$) could be positive (warm eddy) or negative (cold eddy). If $F_{\text{Eddy-T}}$ is 0.6 it means that the cyclone is intensified by 60% on passing through the eddy. We have computed $F_{\text{EDDY-T}}$ for eight cyclones and the results are shown in the Table 2. The tracks of eight selected cyclones which passed through warm/cold core eddies are shown in Fig. 4. The pictures on the left hand side show the dynamic heights and the geostrophic currents of the sea surface in which the eddies could be clearly seen.

Preferred position of Fig. – 4

Similarly the pictures on the right hand side of the Fig. 4 show the sea surface height anomalies from which again the eddies could be identified. The severe cyclone during 16-19 October, 1999 formed at 13.5°N , 92.5°E , intensified to category 5 and crossed the Orissa coast near Gopalpur on 18th Oct 1999. On 17th Oct the cyclone passed through the warm core eddy of size more than 200 km as category-1 and became a very severe cyclonic storm of category-5 (IMD best track data). The geostrophic currents (left panel) and the Surface height anomaly (right panel) in Fig. 4 show that the ocean eddy is very strong and considerably warm with a maximum SSHA of about +35 cm. The eddy feedback factor ($F_{\text{EDDY-T}}$) as calculated from the central pressure variations of the cyclone is 2.6, which means that the intensity of the cyclone increased by 260% on passing through this warm core eddy on 17th October, 1999 (Fig. 4). On 26th Nov 2000 a tropical depression that

formed at 8.5°N, 91.5°E moved westward, strengthening to become a tropical storm later that day. It intensified into a cyclone on 28th November by passing through a warm eddy and made landfall on 29th November. From Fig. 4 it can be seen that the system belonged to category-1 on 26th November and was relatively weak before entering the warm eddy. But on 28th November after passing through the eddy the cyclone intensified to category-4. Although the eddy was only moderately warm with SSHA of about 10 cm the cyclone intensified significantly because it moved slowly and remained in the eddy for a longer time. The eddy feedback factor for the cyclone is 160%. The cyclone which formed in southern Bay of Bengal during 10-19 May 2003, entered an eddy with SSHA of 15 cm, made re-curved and intensified into category-4 cyclone. The eddy feedback factor for the cyclone is 75%. Later it changed direction and crossed the Myanmar coast on 19th May. The severe cyclone “ *Mala* “ (24 April – 2nd May, 2006) intensified into a severe cyclonic storm on Apr 27 and transformed into a very severe cyclonic storm (Category 4) on 28th April; but it weakened quickly after passing through a cold core eddy, made landfall on 29th April and quickly dissipated over Myanmar. Throughout Burma, the cyclone killed 22 people and caused damage to over 6,000 houses, of which 351 were completely destroyed. The cyclone ‘*Aila*’ formed on 23rd May 2009 and crossed west Bengal on 25th May. It started as a deep depression and intensified into category-2 cyclone as it passed through a warm eddy with SSHA of about 15 cm. The eddy feedback factor for the cyclone has been calculated as 0.43. Although ‘*Aila*’ was not a strong storm, it caused heavy rains and storm surges swamped the Mouths of the Ganges River in Bangladesh and India and caused extensive damage. At least 50,000 hectares of agricultural land was lost during the storm, costing an estimated loss of about US\$ 26.3 million. Cyclone *Laila* formed on 17th May 2010 at 11.6°N, 87°E and made land fall near Bapatla (15.8°N, 80.47°E). On May 17 it was located as depression at about 780 km east-southeast of Chennai (13.08°N, 80.27°E). On May 18 it passed through a warm core eddy with SSHA of about 20 cm and intensified into a cyclone, the eddy feedback factor is 100%. On 20th May, it moved slowly and intensified further to a severe cyclonic storm of category-3 and made landfall near Bapatla, Andhra Pradesh. The cyclone caused heavy destruction in Prakasam, Krishna and Guntur districts and preliminary reports prepared by the State government estimated the loss more than US\$ 105.2 million.

In addition to the above, two more case studies of cyclones that passed through cold core eddies (Fig. 5) are presented below. On 29th Nov 2005, a tropical cyclone ‘*Baaz*’ brewed in the Bay of Bengal off the southern coast of India near the Island of Sri Lanka. It was predicted that the storm would move towards east coast of India within the next 48 hours and thousands of people were

evacuated from the low-lying coastal strips of Tamil Nadu and Andhra Pradesh. But later it passed through a cold core eddy of SSHA -25 cm and had weakened considerably.

Preferred position of Fig. - 5

The eddy feedback factor is calculated as -0.60, meaning that the cyclone had weakened by 60% on passing through the eddy. By Nov 30, it turned into a depression and made slow progress toward land and dissipated. This emphasizes the importance of eddies in forecasting the intensity and the track. If the meteorologists considered the location and impact of this cold core eddy, the efforts put up by the government to evacuate people, would have been avoided. In 2008, a low pressure area was identified over southeast Bay of Bengal on 13th November which concentrated into a depression east-southeast of Chennai. A few hours later IMD upgraded the system to a deep depression. Intensified into a cyclonic storm '*Khai-Muk*' after passing through a warm core eddy. Later on 14th Nov as the cyclone passed through a cold core eddy of SHA -15cm, the system became sheared to the western periphery and the IMD downgraded it back into a deep depression and the corresponding eddy feedback is -40% (Table 2).

What could be the reason for the intensification /weakening of storms due to these eddies? It is a known fact that normally a cyclone will intensify if the conditions from both atmosphere and ocean are favorable. If the conditions from the ocean are not favorable, the storm may not intensify even if the atmospheric conditions are favorable. The main requirements are the enthalpy flux (latent+sensible) and the ocean with warm and deep thermal structure. The cyclone *Nargis* (27 April -2 May 2008) suddenly intensified over a warm ocean where the UOHC is 77-105 kJ/m^2 and the enthalpy flux was 900 w/m^2 (300% higher than climatological value) (Lin et al, 2009b). Similarly, *Aila* (24-26 May 2009) intensified over the warm eddy where UOHC and D26 were 146 kJ/m^2 and 126 m respectively (Sadharam et al., 2011). In case of *Sidr* cyclone, the pre-storm UOHC and D26 were 84 kJ/m^2 and 78 m respectively (Sadharam et al., 2010). For the present 8 cases (Table 2) in which the cyclones passed through the eddies, we computed the UOHC, D26 in the eddies using the equations 1-4. High UOHC of 194 kJ/m^2 , 139 kJ/m^2 and 127 kJ/m^2 were found in the warm core eddies during October 1999, *Aila* and *Laila* cyclones respectively. D26 observed in the above warm eddies was high and varied between 100-150m. Enthalpy fluxes are also high in the warm core eddies with a maximum of 214 w/m^2 which is double to the climatological value. In all the warm core eddies the enthalpy flux is 2-3 times higher than the climatological enthalpy flux. In cold core eddies, UOHC was < 60 kJ/m^2 (1/3rd of warm core eddy), D26 was < 65m and the enthalpy flux was 50% less than the climatological where the Nov 2005 cyclone and *Khaimuk* (November 2008) weakened. Maximum drop of 26 mb in the cyclone central pressure during the October 1999

cyclone was due to the presence of warm core eddy. There is a drop of 10-16 mb in the remaining cyclones due to the presence of warm core eddies. There is a rise in the central pressure by 4-6mb due to the cold core eddies. The UOHC and enthalpy fluxes are much higher over warm eddies compared with the cold eddies. Hence, the storms over warm (cold) eddy intensify (weaken) if the atmospheric conditions are also favorable. These results further support our earlier study (Sadhuram et al., 2011) and emphasize the role of eddies and UOHC in the intensification of storms over Bay of Bengal. We also examined the meteorological parameters known to be important for the intensification or weakening of tropical storms and these are shown in Table 3. The difference between the SST and Air temperature in all the cases is positive before the cyclone which is favorable for the formation of cyclones except during *Khaimuk* and negative after the cyclone, which is not favorable for cyclone intensification. Highest of 3.49° was observed in case of November 2000 cyclone. Relative humidity (RH) at 600 hPa is higher during all the cyclones compared to the climatological values. Kikuchi and Wang (2010) showed the importance of RH at 600 hPa for the intensification of tropical storms. Highest (82%) was observed during May 2003 cyclone. Vertical wind shear between the 200 and 850 hPa in all the 8 cases is also less compared to the climatological values which is the favorable condition for the formation and intensification of cyclones (Gray, 1968). Less shear was observed in the case of *Laila* cyclone (2010). Zonal wind at the 1000 hPa pressure level is less compared to the climatological zonal wind except in case of two cold core eddy cases. In case of *Aila* cyclone less zonal wind of 0.16 m/s was observed. The higher SST compared to the atmosphere at the surface and low wind seems to be favorable for the storm vortex growth via Wind induced surface heat exchange (Emmanuel, 1987a). The contribution of different parameters for the intensification will vary from cyclone to cyclone. So, both the atmospheric and oceanographic conditions are equally important for the cyclone intensification studies. But, without the supply of sufficient enthalpy flux from the ocean, storms may not intensify even though the atmospheric conditions are favorable.

5. Conclusions:

Meso-scale eddies (warm core and cold core eddies) occur in the neighborhood of EICC in Bay of Bengal, particularly in the months of April-May and October-November when the EICC is strong. The intensification/weakening of cyclones due to their interaction with warm/cold eddies is possible in the Bay of Bengal, which is totally ignored in the storm intensification forecasting models. From the few cases studied, it is observed that the eddy feed back factor ranges from -60% to 260%. It is found that in case of a severe cyclone during 16-19 October 1999, the eddy feed factor is 260% much higher than reported (Wu et al., 2007) for *Opal* (1995) and *Maemi* (2003) (119% and 138%

respectively). The high UOHC ($>120\text{kJ/m}^2$) and enthalpy fluxes ($>400\text{ w/m}^2$) in the warm eddies are perhaps responsible for the intensification of storms over warm eddies. It is suggested that the modelers have to pay attention towards the role of these meso scale eddies in the intensification/weakening of storms over Bay of Bengal.

6. Acknowledgements:

The authors are thankful to Dr. SWA Naqvi, Director, NIO and Dr. V.S.N.Murty, Scientist-in-charge, NIO Regional centre, Visakhapatnam for their support and encouragement. Thanks to NOAA for making the data sets on SSHA & geostrophic currents and IMD, New Delhi for the data on cyclone tracks available on their websites. Also thankful to Prof. B.S.R.Reddy for his critical review of this paper. Mrs. Maneesha is thankful to CSIR, New Delhi for providing the Senior Research Fellowship. This has the NIO contribution No XXXX.

Figure captions:

Fig. 1. Scatter plot between SSHA and UOHC, D26 for pre(a,b) and post (c,d) monsoon months.

Fig. 2. Climatology of geostrophic currents and sea level anomaly since 1993-2009 in (a) April (b) May (c) October and (d) November.

Fig. 3. Variation of temperature and salinity profiles in warm core eddy, cold core eddy and under normal conditions.

Fig. 4. Tracks of cyclones passed through warm core eddies in Bay of Bengal during (a,b) 16-19 October 1999 (c,d) 25-29 Nov 2000 (e,f) 10-19 May 2003 (g,h) 25-29 April 2006 (*Mala*) (i,j) 23-25 May 2009 (*Aila*) (k,l) 17-19 May 2010 (*Laila*).Geostrophic currents (left panel) and SSHA (cm) (right panel) were overlaid.

Fig. 5. Tracks of cyclones passed through cold core eddies in Bay of Bengal during (a,b) 28 Nov- 2 Dec 2005 (*Baaz*) and (c,d) 13-16 November 2008 (*Khaimuk*).Geostrophic currents (left panel) and SSHA (cm) (right panel) were overlaid.

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Table 1

Comparison of oceanographic parameters for typical cold core and warm core eddies

Eddy location and date	SST(°C)	MLD (m)	D26(m)	UOHC(kj/cm²)
Cold eddy (8.3N,84.2E) (29/05/2009)				
Float ID 2900106	29.24	34	31	35
Warm eddy (13.9N,82.0E) (13/05/2009)				
Float ID 2901073	30.3	50	135	156
Normal condition (without eddy) (8.6N,84.8E) (28/05/2009)				
Float ID 4900670	29.43	28	49	51

Table 2

Oceanographic parameters and Enthalpy fluxes in eddies through which the cyclones passed

S.No	Period/name of the cyclone	Central pressure before entering the eddy (hPa)	Central pressure after coming out of the eddy (hPa)	Eddy feed back factor $F_{\text{eddy-T}}$	UOHC (kj/cm ²)	D26(m)	Enthalpy Fluxes(kj/cm ²)	
							Climatology	Observed (NCEP Reanalysis data)
1	15 th to 19 th oct							
	1999	994	968	260%	194	165	85	211
2	25 th to 29 th Nov				110			
	2000	992	976	160%		97	132	214
3	10 th to 19 th May				114	98		
	2003	998	982	75%			92	197
4	28 th Nov to 2 nd Dec							
	2005	998	1002	-60%	46	52	131	65
5	25 th to 29 th April							
	2006 (Mala)	964	954	30%	97	87	120	204
6	13 th to 16 th Nov							
	2008 (Khaimuk)	998	1004	-40%	58	60	149	70.5
7	23 rd to 25 th May							
	2009 (Aila)	984	974	43%	127	107	111	122
8	17 th to 19 th May							
	2010 (Laila)	993	978	100%	139	115	92	169
9	Opal (1995)			119%				
10	Maemi (2003)			138%				

Table 3

Meteorological parameters in eddies through which the cyclones passed.

	SST-Air temperature (⁰ C)			RH at 600 hPa			zonal wind difference (200-850 hPa) (m/s)			Zonal wind at 1000hPa (m/s)		
	Before	After	Climatology	Before	After	Climatology	Before	After	Climatology	Before	After	Climatology
15 th to 19 th oct 1999	2.91	-1.57	2.37	54	66	48	-1.02	-5.2	-1.32	-1.3	-2.74	-1.37
25 th to 29 th Nov 2000	3.49	-0.08	2.42	70	51	48	-4.45	-2.29	6.88	-2.76	-5.33	-4.30
10 th to 19 th May 2003	1.08	-0.3	1.08	82	68	32	-1.66	-1.86	6.29	4.79	4.45	3.5
28 th Nov to 2 nd Dec 2005	1.22	-0.13	2.76	27	74	48	6.75	-3.58	2.76	-5.92	-5.09	-4.30
25 th to 29 th April 2006 (Mala)	1.41	-0.55	0.52	32	44	25	2.22	-3.02	10.47	2.63	4	2.8
13 th to 16 th Nov 2008 (Khaimuk)	0.72	1.21	2.42	34	65	48	3.95	4.92	2.76	-4.92	-5.89	-4.30
23 rd to 25 th May 2009 (Aila)	1.02	-2.96	-1.57	78	66	50	-4.15	-4.03	9.68	0.16	0.03	1.8
17 th to 19 th May 2010 (Laila)	1.22	-1.93	0.05	25	56	38	-0.04	-12	-4.95	-0.67	0.47	1.13

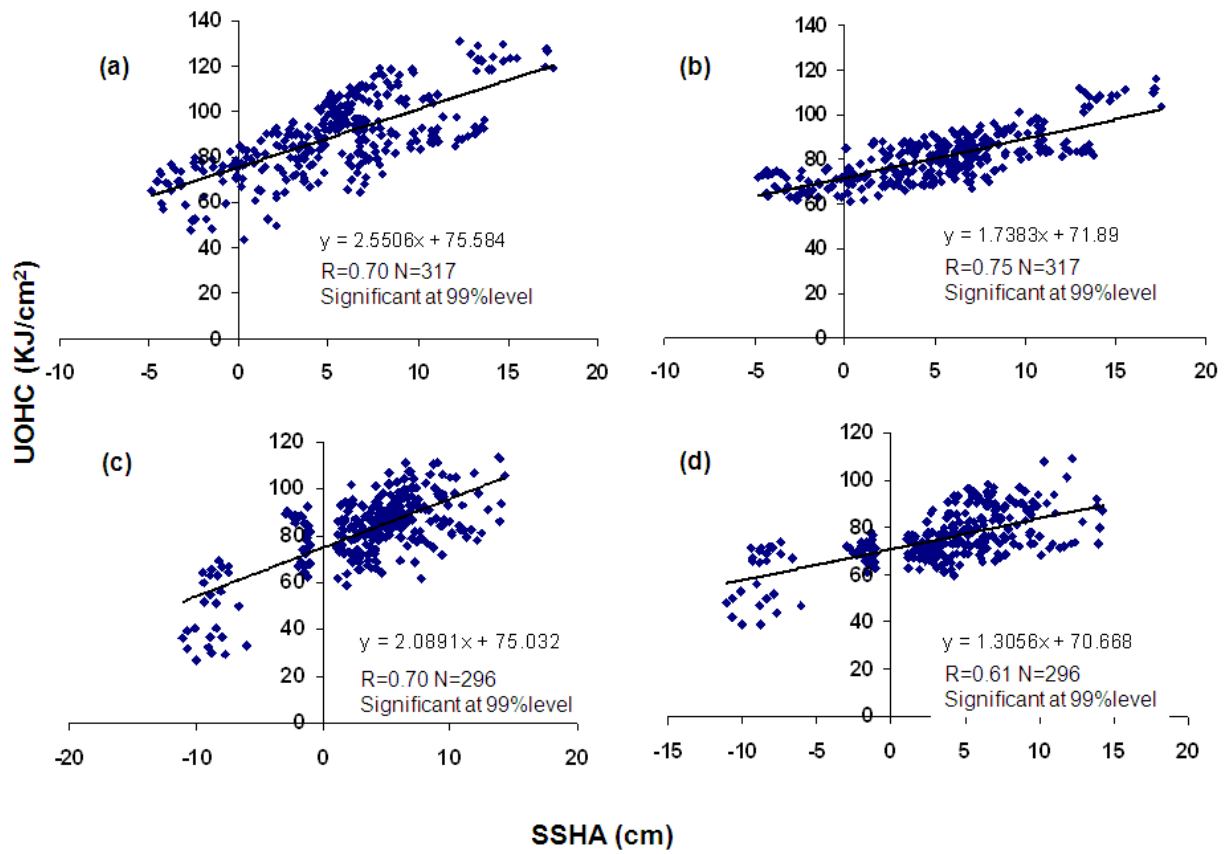


Figure 1

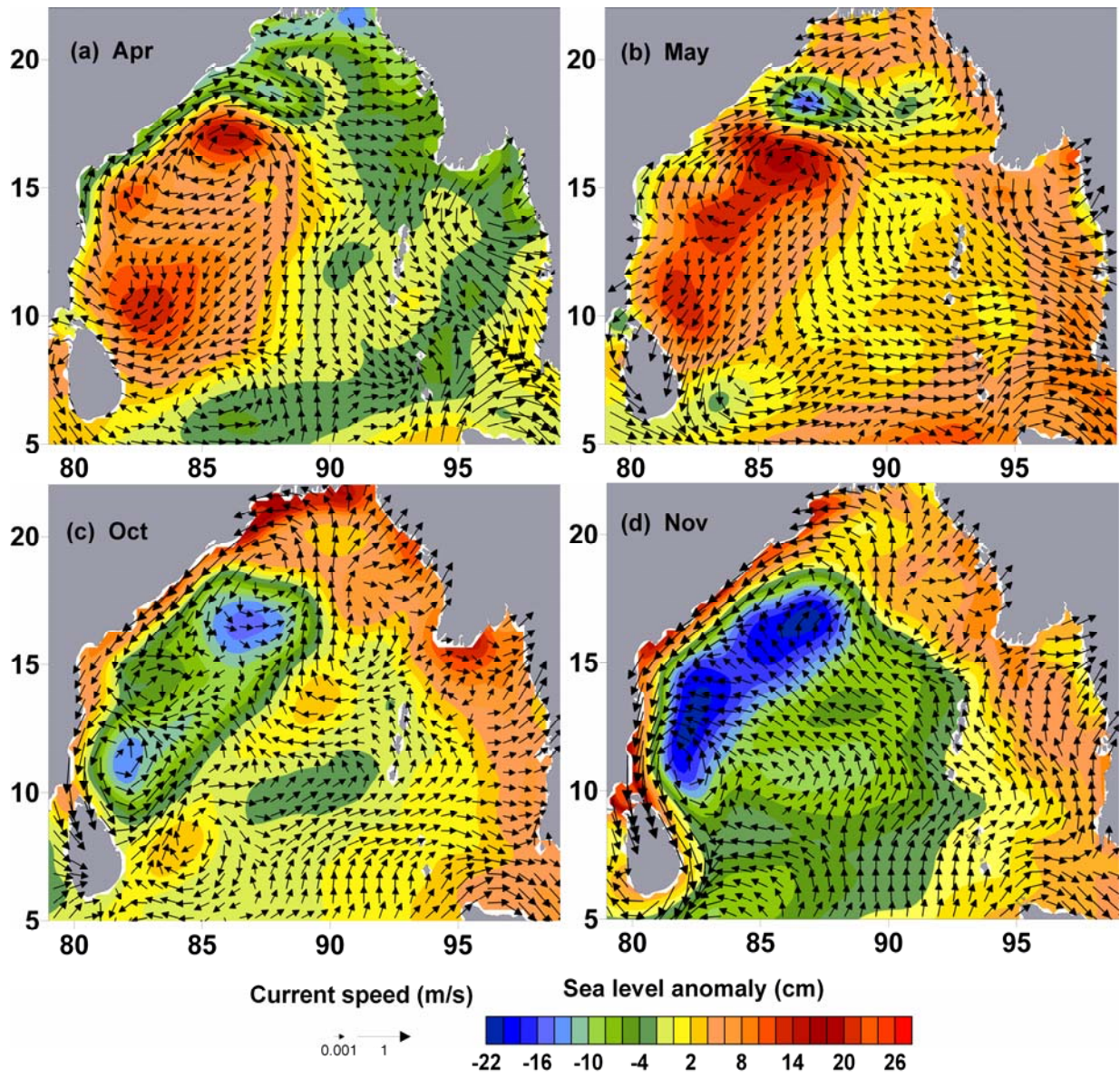


Figure 2

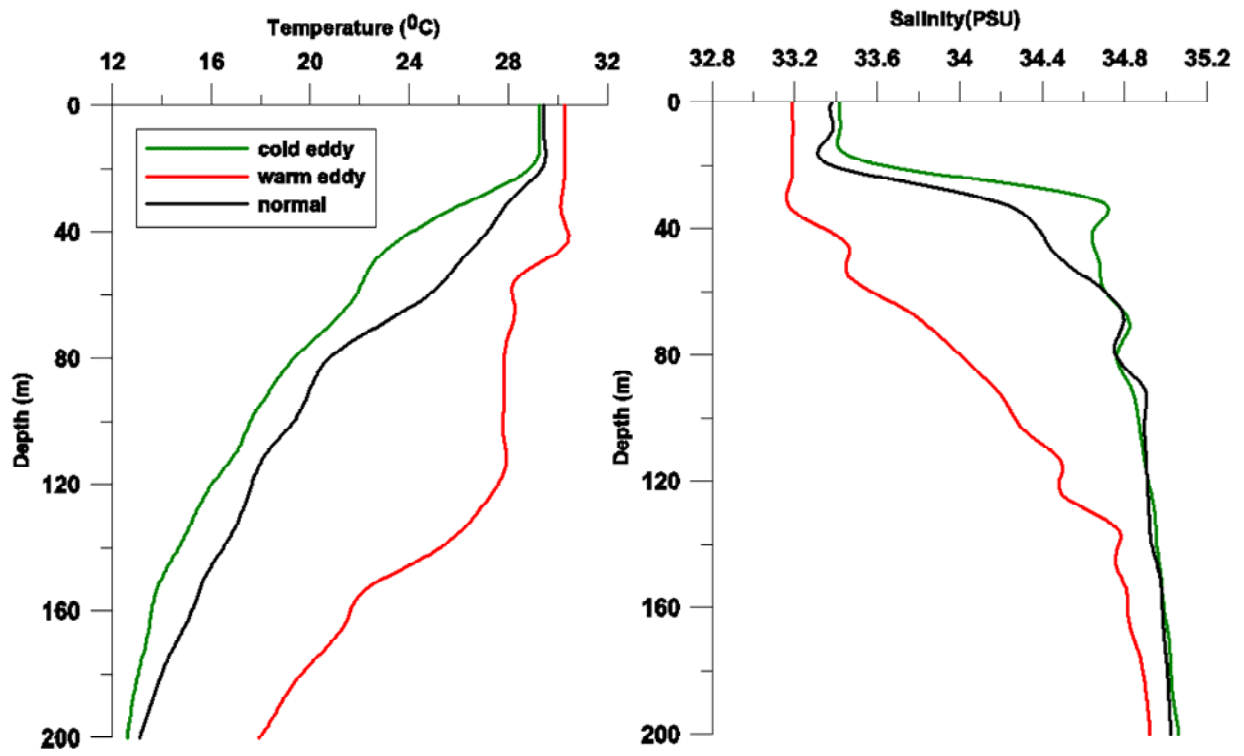


Figure 3

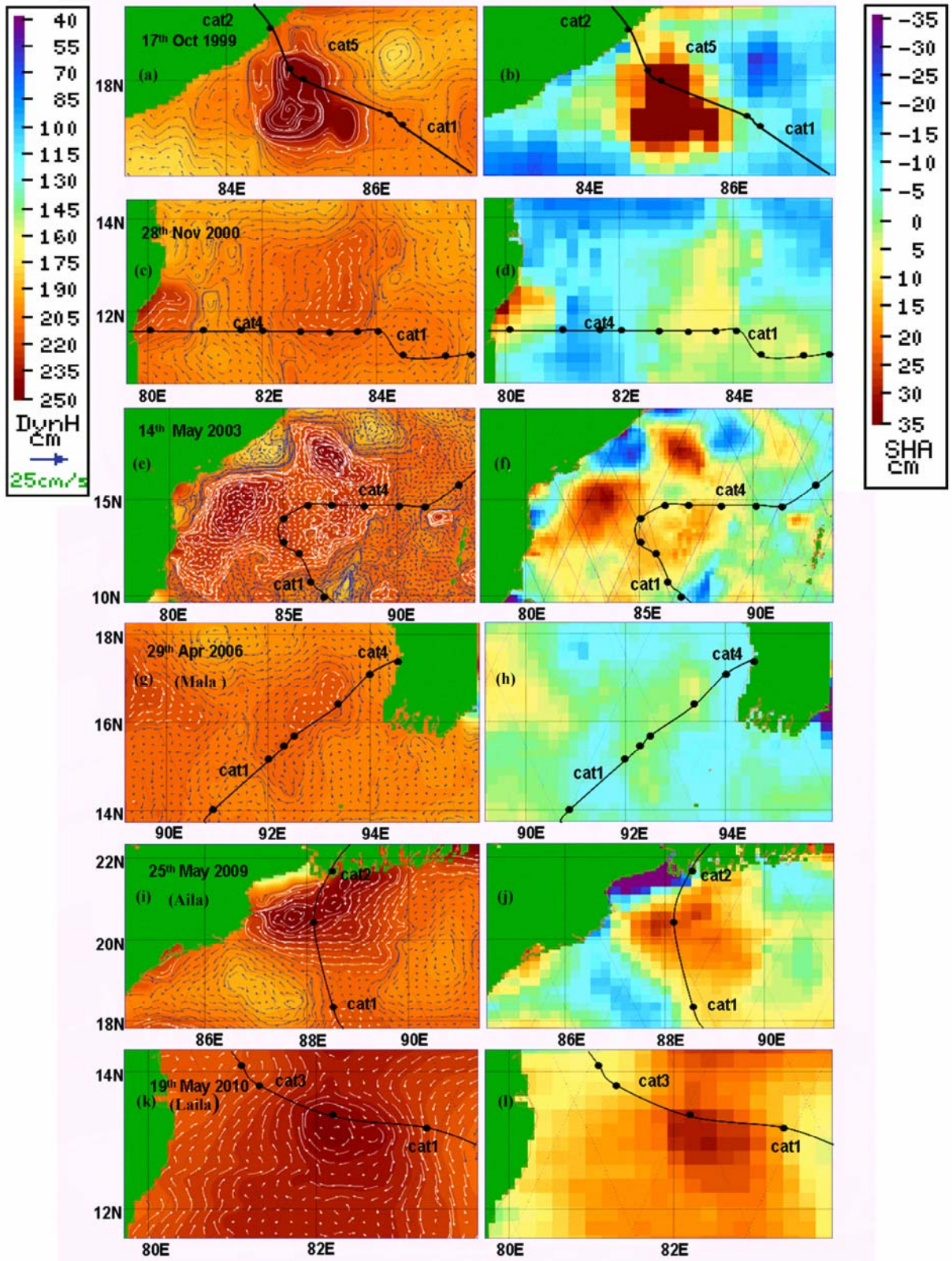


Figure 4

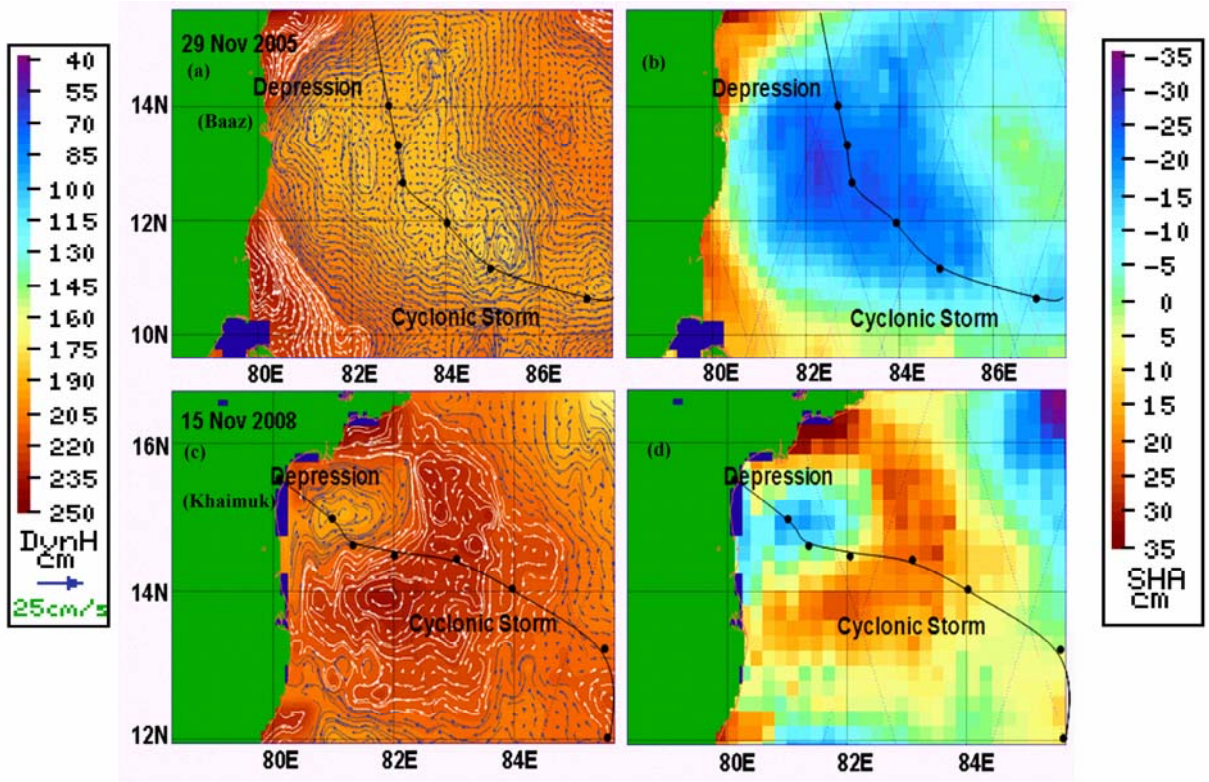


Figure 5