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Vertical diffusivity and water qualities in the upper Gulf of Thailand in March 2009

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Abstract — Field observation in the upper Gulf of Thailand (UGoT) in March 2009 was conducted to prove the relationship between vertical diffusivity (water turbulence) and chlorophyll-a (Chl-*a*), addressed by numerical model results of our previous study. Relationships between Chl-*a* and water properties, including salinity, temperature, density, dissolved oxygen (DO), dissolved inorganic nitrogen (DIN) and phosphorous (DIP), dissolved silicate (DSi) and turbulence, were investigated. Blooming areas did not exactly correspond to the area of freshwater influences and high nutrients, except DSi. Insignificant relationships between Chl-*a* and environmental parameters were found in the correlation analysis. The correlation line indicated that no relationship is evident in the case of Chl-*a* and DIN. Proportional relationships seem to happen for Chl-*a* and DIP, and Chl-*a* and DSi, while reverse relationships for Chl-*a* and K_z. Further investigations are required to clarify the occurrence mechanism of red tide in UGoT.

Key words: vertical diffusivity, chlorophyll, dissolved nutrient, water quality, Gulf of Thailand

Introduction

Red tide, a serious coastal environmental problem in the upper Gulf of Thailand (UGoT) (Figure 1) resulting from eutrophic condition, has long been scientifically interested (Rungsupa et al., 2003). This problem is more intense nowadays, related to increases in population and country development resulting in high waste water loads, some of which include those of nutrients and organic matters. Red tides were reported to occur year round but in different locations–along the western coast and the northeastern corner of UGoT during the northeast and the southwest monsoons, respectively (Lirdwitayaprasit et al., 1994; Buranapratheprat et al., 2009). Previous attempts, mostly focused on investigation of relationship between nutrients and phytoplankton blooms (e.g., NRCT-JSPS, 1998), were done to explain mechanism of red tide incidents. They, however, still cannot clarify why some blooms occurred in low nutrient water, and some others did not, in areas where nutrients were high. This suggests the need of alternative approaches to unlock the mechanism of such an environmental problem.

Princeton Ocean Model (POM) coupled with Nutrient-Phytoplankton-Zooplankton-Detritus ecosystem model (NPZD) was used to simulate seasonal variation in red tides in terms of chlorophyll-*a* (Chl-*a*) distribution in UGoT (Buranapratheprat et al., 2008). Calculated results suggested that nutrient loads from major rivers located in the north of UGoT are significant sources of nutrient supply to blooming. Movement of high Chl-*a* areas to the west and the east of UGoT corresponded to wind and current patterns during the northeast and the southwest monsoons, respectively. Water column condition, mostly influenced by wind variation, was found to affect spatial and temporal variations in plankton growth and cell accumulation near the sea surface. Plankton bloom was stimulated in the area where vertical diffusivity was low, and it was used to explain why sometimes there was no blooming in the area where high nutrient waters located or the condition of "high nutrient, low chlorophyll". These simulation outputs, however, strongly required verification from the data derived from the field observation. The objective of this study is therefore to investigate the relationship between phytoplankton blooming and water properties to confirm the reliability of the ecosystem model results.

Material and Methods

A field observation was carried out on March 20–21, 2009 using R/V Kasetsart, to assess vertical diffusivity, physical, biological and chemical properties of seawater at 14 stations covering the northern part of UGoT (Figure 1). A Turbulence Ocean Microstructure Acquisition Profiler (TurboMAP) (Wolk et al., 2002), developed by Alec Electronics Co., Ltd., was used for in-situ measurement of vertical diffusity. The TurboMAP is a tethered profiler that samples the

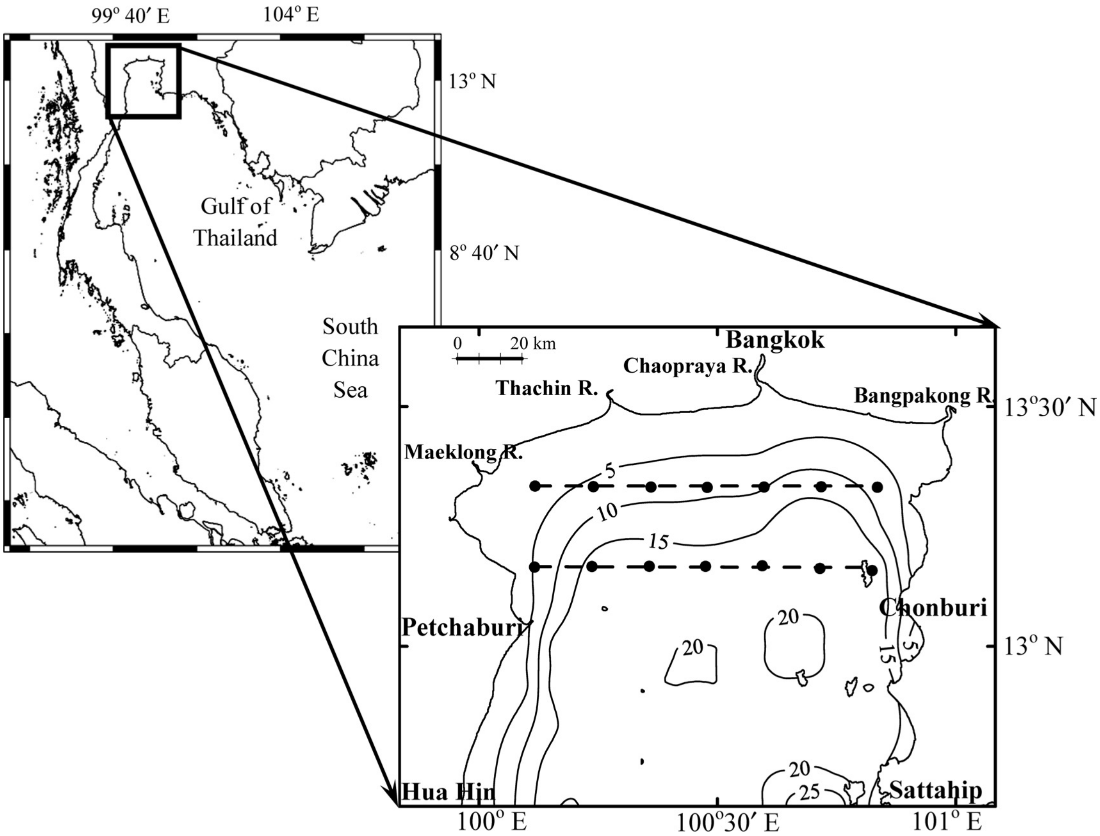

Fig. 1 The upper Gulf of Thailand (UGoT) showing depth contours (meter), dots representing observational stations and broken lines used for investigating vertical water properties.

micro-scale vertical shear of horizontal velocity, temperature, conductivity, and pressure. These probed data are then processed using an instrument's software to get vertical diffusivity output. A series of 3–6 descending profiles was taken at each sampling station.

Salinity and temperature were probed in-situ employing a conductivity-temperature-depth sensor (CTD) (SensorData Technologies Inc.), while dissolved oxygen (DO) was measured by using a DO sensor (YSI Incorporated). Water samples for dissolved inorganic nitrogen (DIN) and phosphorous (DIP), dissolved silicate (DSi), and Chl-*a* analyses were collected at the sea surface, middle and near the sea bottom levels using a Vandorn water sampler. Water samples, after immediately filtered through a GF/C filter onboard, were collected in 1 liter polyethylene bottles and then kept in a freezer for nutrient analyses in the laboratory. Colorimetric methods using a spectrophotometer were used for nutrient analyses following Strickland and Parson (1972). Part of water samples, used for Chl-*a* analysis, were also collected and filtered (GF/F) onboard. The filtered papers were stored in a freezer for Chl-*a* analysis in the laboratory using a method appearing in Strickland and Parson (1972). Chl-*a* was extracted from the filter remnant after adding 90% acetone, stirring vigorously, and centrifuging at 3,700 rpms for 5 mins. The clear supernatant solution was measured for Chl-*a* by using a spectrophotometer.

Results

Average and standard deviation of parameters used for this study is listed in Table 1. Average salinity (32.71 psu) and temperature (29.30°C) were high in March because of low river discharges and high air temperature during summertime (Buranapratheprat et al., 2003). DO (6.53 mg/l) was in a good condition for marine lives. DIN (1.42 μM) and DIP (1.10 μM) concentrations were relatively low when compared to those of Si (24.85 μM). Mean Logarithmic vertical diffusivity ($LogK_z$) was as high as $-4.19\pm1.04\,m^2/s$. Chl-*a* was very high with the averaged value of $54.26\pm40.52\,\mu g/l$ due to a strong phytoplankton bloom during the field observation.

Distributions of water properties are studied from their contour plots, processed using Ocean Data View software (ODV) (Schlitzer, 2007). Horizontal distributions of salinity, temperature, in situ density (sigma) and DO at the sea surface (0.5 m depth) are presented in Figure 2. Comparatively low salinity and high temperature occurred in the northwest corner of UGoT where their values were around 30 psu and 30°C, respectively. Sigma distribution also trended in the same way as salinity distribution. This evidence suggests the influence of freshwater discharge of the Maeklong River, which is located in the westernmost of the UGoT northern coast (Figure 1). Surface DO was as high as over 6 mg/l throughout the study area but having a gradient trend of high and low DO from offshore to near shore, respectively. Relatively low DO was found near the mouth of the Tha Chin River.

Vertical distributions of salinity, temperature, sigma and DO along the north and the south transects (Figure 1) are presented in Figure 3a and 3b, respectively. The distributions of parameters in both transects look similar that water stratification was dominant in the west of UGoT due to freshwater influence of the Maeklong River. A weak stratification in the easternmost is also observed, expected to come from the Bangpakong River discharge. Low DO water around 5–6 mg/l is located near the sea bottom. It shifted from the middle to the west areas while moving from the north to the south transects.

Table 1. Average and standard deviation of parameters measured from field observation.

Parameters	N	Mean±SD
Salinity (psu)	356	32.71±0.78
Temperature (°C)	356	29.30±0.32
Density (Sigma) (kg/m^3)	356	20.28±0.68
DO (mg/l)	356	6.53±0.80
DIN (μM)	42	1.42±0.64
DIP (μM)	42	1.10±0.58
DSi (μM)	42	24.85±11.65
Log K_z (m^2/s)	292	−4.19±1.04
Chl-*a* (μg/l)	42	54.26±40.52

Nutrient and Chl-*a* distributions at the sea surface (Figure 4) did not exactly correspond to the distributions of salinity and density (Figure 2). DIP along northern stations was high in the west where the Maeklong River locates, not in the east where the Bangpakong River locates although salinity was low, and DSi was high, in both areas. DIN has a trend to be high in offshore and low in near shore and not correspond to the distributions of physical water properties (Figure 2). Surface Chl-*a* was high in the east and in the west on the north and the south transects, respectively. Chl-*a* gradient trend, however, was not similar to those of physical properties and nutrients, except DSi.

Vertical diffusivity (K_z) or water column turbulence was rather high near the sea surface and low in the lower depth (Figure 5). It should be addressed here that measured K_z values just below 3.5 m depth are reliable due to technical limitation of a TurboMAP descending measurement. Horizontal distribution of vertical diffusivity at 3.5 m below the sea surface (Figure 6) indicates relatively low values on the order of 10^{-5} m^2/s in the west of the south transect. K_z along the north transect also has this trend, but there is a peak of lowest value on the order of 10^{-4} m^2/s at the station near the Chaopraya River mouth.

Discussions

Correlations of Chl-*a* and nutrient concentrations together with Chl-*a* and vertical diffusivity were carried out to investigate if Chl-*a* is influenced by these water parameters

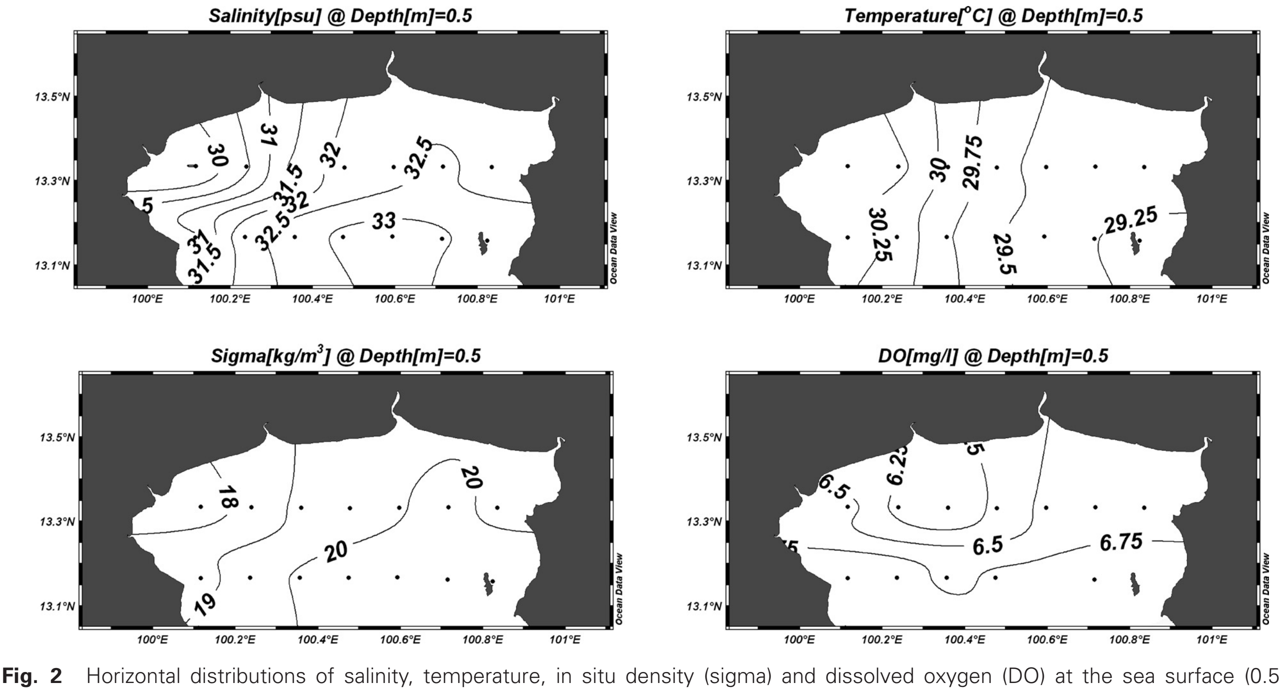

Fig. 2 Horizontal distributions of salinity, temperature, in situ density (sigma) and dissolved oxygen (DO) at the sea surface (0.5 m depth).

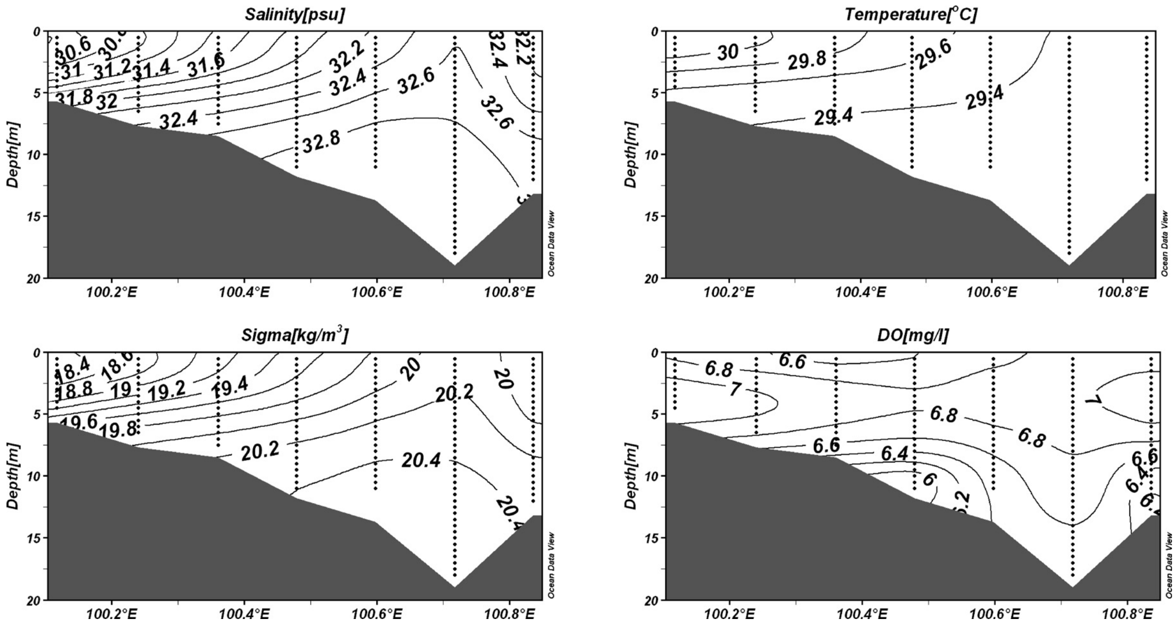

Fig. 3a Vertical distributions of salinity, temperature, density (sigma) and DO along the north transect.

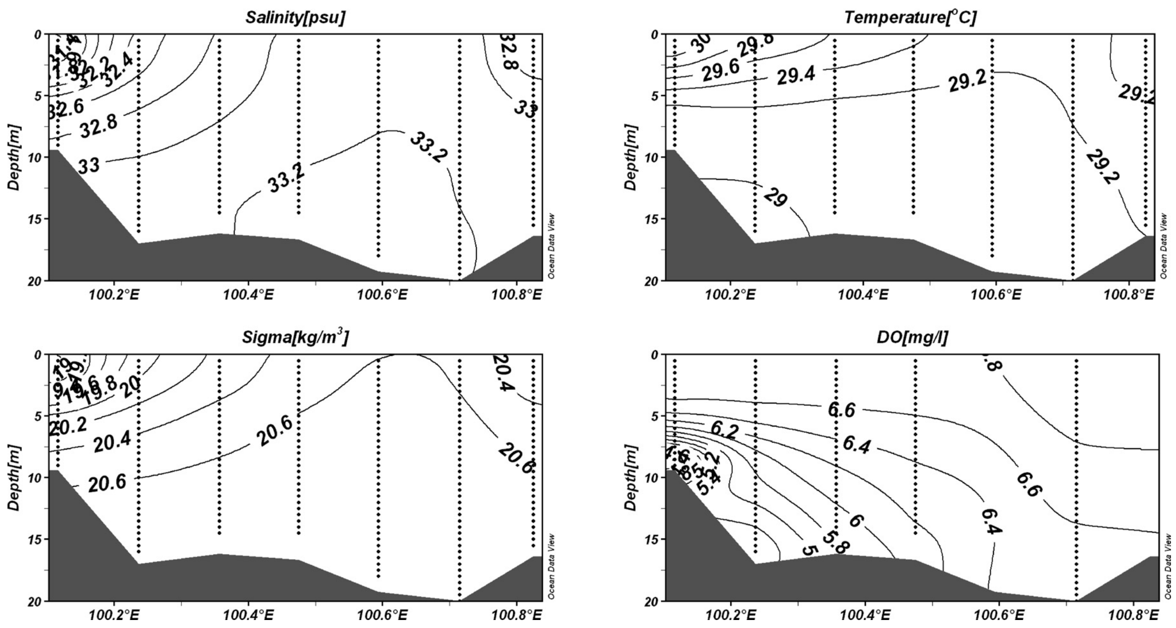

Fig. 3b Same as Fig. 3a but for the south transect.

(Figure 7). Data points in each correlation figure are scatter indicating the relationship between Chl-*a* and those parameters are not strongly significant. Coefficient of determination (R^2) is therefore not so high with the maximum R^2 of 0.1614 in the case of the relationship of Chl-*a* and DIP. Trends of regression slope, however, may be used to discuss their relationships instead. No relationship is evident in the case of Chl-*a* and DIN. Proportional relationships seem to happen for Chl-*a* and DIP, and Chl-*a* and Si, while reverse relationships for Chl-*a* and K_z.

It is uneasy to explain the relationship between phytoplankton bloom and nutrients because of variations in plankton species that favor different environmental conditions and phases of plankton growth or blooming stages. Many studies, such as Rungsupa et al. (2003) and Thongra-ar (1997), have been done to investigate the relationship of red tide and water properties. Their results cannot confirm on what really are the most significant factors to stimulate or control blooming due to the difficulties addressed above. There was a strong bloom of *Noctiluca scintillans* in green color during our field survey. This plankton species is a dinoflagellate that does not need DSi for their photosynthesis, but the correlation between Chl-*a* and DSi has a positive trend. This may be explained that high DSi in blooming areas occurred because

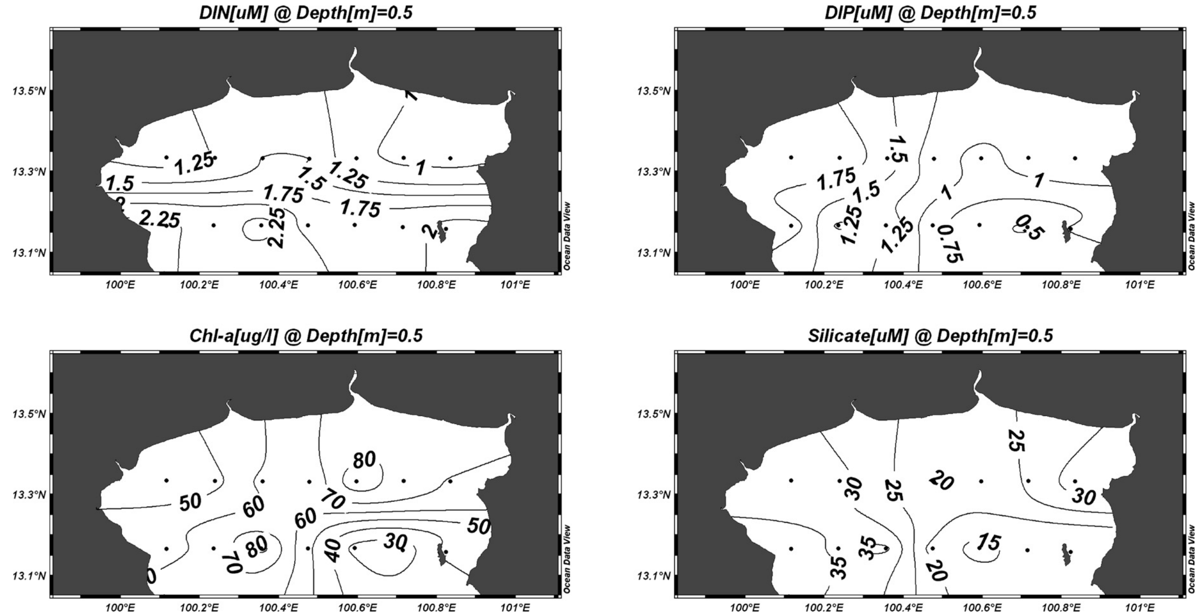

Fig. 4 Horizontal distributions of dissolved inorganic nitrogen (DIN) and phosphorous (DIP), chlorophyll-*a* (Chl-*a*) and silicate (DSi) at the sea surface (0.5 m depth).

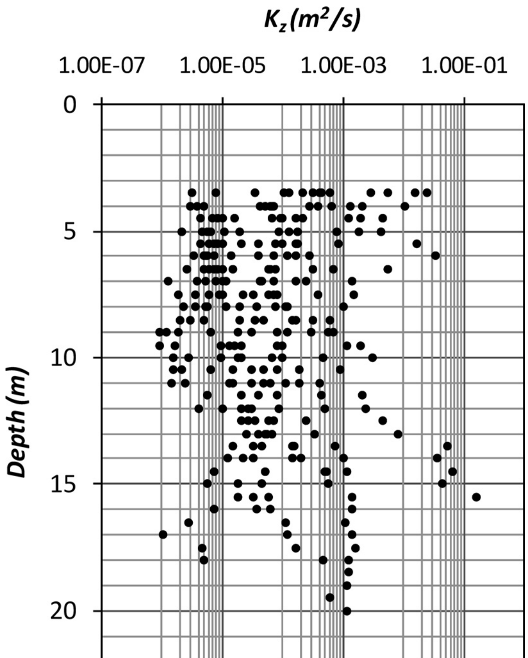

Fig. 5 A scatter plot of vertical diffusivity (K_z) with depth.

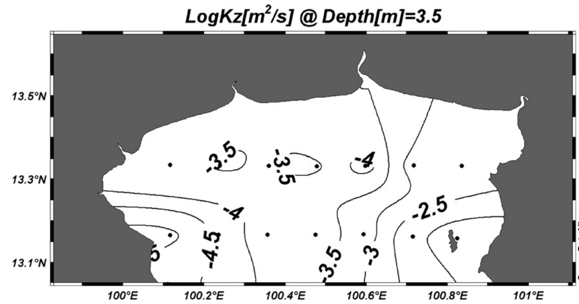

Fig. 6 Horizontal distribution of vertical diffusivity at 3.5 m depth.

just DIN and DIP, not DSi, were used by this plankton for photosynthesis; therefore DSi was unused and still remained in water column. The differences between the relationship of Chl-*a* and DIN, and Chl-*a* and DIP are unclear but may be arisen from the limitation of DIN to photosynthesis by phytoplankton. Average mole ratios of N : P : Si are 1.3 : 1 : 22.6 suggesting that DIN may be a limiting nutrient for marine and coastal water (Wu and Chou, 2003). Because DIN is used, but scarce, for photosynthesis, it is sometimes found in low concentration in the blooming areas. The correlation between Chl-*a* and DIN is then very low, or there is no relationship between them. The mechanism is complicated due to many factors such as the growth phases of phytoplankton, dynamic nature of marine environment, and blooming species. This assumption strongly needs further analyses and validation.

Inverse relationship between Chl-*a* and vertical diffusivity indicates that phytoplankton blooms in UGoT may favor low turbulence water. Low R^2, however, occur because phytoplankton needs not only low turbulence but also high nutrients to get blooms. This is understood that sometimes low turbulence located in low nutrient water, causing such a weak relationship. Chl-*a* and K_z distributions (Figure 4 and 6, respectively) suggest that the peak of blooming was located around K_z as low as 10^{-4} m^2/s. Such assumption and above discussing issues are very interesting and addresses the need for further investigation from both field observations and sophisticated ecosystem model analyses.

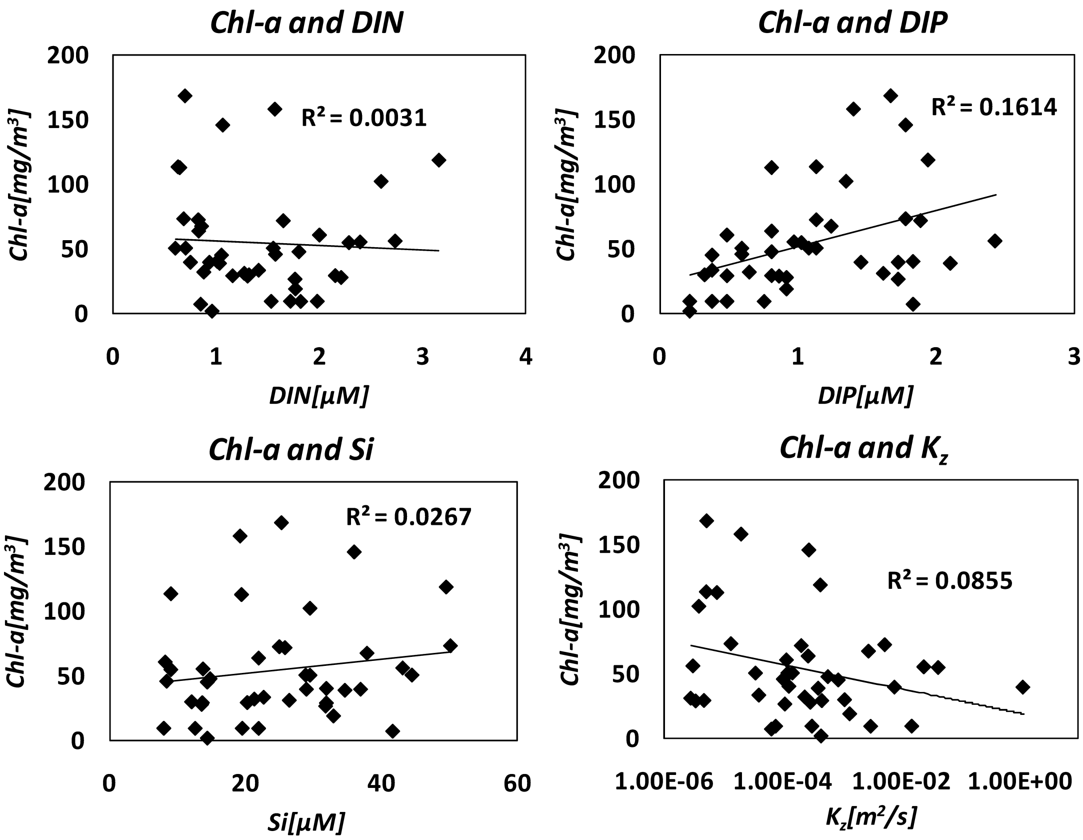

Fig. 7 Correlations of Chl-*a* and water properties including DIN, DIP, DSi and K_z.

Conclusion

Filed observation was conducted to investigate if water turbulence, besides nutrient enrichment, is a significant factor to stimulate red tides in UGoT in March 2009. Blooming areas did not exactly correspond to the area of freshwater influences and high nutrients, except DSi. Insignificant relationships between Chl-*a* and environmental parameters were found in the correlation analysis. The correlation trend line indicated that no relationship is evident in the case of Chl-*a* and DIN. Proportional relationships seem to happen for Chl-*a* and DIP, and Chl-*a* and DSi, while reverse relationships for Chl-*a* and K_z. Further investigations are still required from both filed observation and numerical ecosystem modeling to strengthen our understanding in the occurrence mechanism of red tide in UGoT.

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