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Patterns of chlorophyll-a distribution linked to mesoscale structures in two contrasting areas Campeche Canyon and Bank, Southern Gulf of Mexico

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ABSTRACT

The chlorophyll-a (Chl-a) distribution in Campeche Canyon and Campeche Bank, at the Southern Gulf of Mexico, as well as its relationship with hydrographic structure were analyzed. The results show the existence of the Gulf Common Water (GCW), the Caribbean Tropical Surface Water (CTSW) and the Caribbean Subtropical Underwater (CSUW) in the 120 m upper layer at the Campeche Canyon. While at the Campeche Bank only the Caribbean Tropical Surface Water (CTSW) was found. The 15 °C and 18.5 °C isotherms topography depict the presence of a mesoscale anticyclone-cyclone dipole. The nutrient pumping mechanism fertilizes the eutrophic zone promoted by the cyclonic eddy. Submesoscale processes in the border of an anticyclone and a cyclone results in maximum of nitrate concentration and vertically integrated Chl-a at the frontal zone. Two Chl-a vertical distribution patterns were found, a deep maximum at the base of the euphotic layer not associated to the thermocline over the Campeche Canyon and a peak associated to the thermocline related to the shallow bottom at the Campeche Bank. Oligotrophic conditions were observed in the 50 m upper layer and mesotrophic conditions were found below this layer. The differences between the Campeche Bank and Campeche Canyon are that: in the canyon, the nutrient and Chl-a peaks were linked with the cyclone, and the submesoscale processes in the border of an anticyclone and a cyclone, respectively. In the vertical the maximum Chl-a was associated to the base of the euphotic layer and dominated by coccolithophores. In the Campeche Bank the nutrient and Chl-a peaks were influenced by the shelf break in the vertical the maximum Chl-a was associated with the thermocline and the silicoflagellate was identified as the dominant species.

1. Introduction

Chlorophyll-a (Chl-a) is considered to be an indicator of the phytoplankton biomass (Boyer et al., 2009; Cullen, 2015) and due to its non-invasiveness and sensitivity, measurement of its *in situ* and *in vivo* fluorescence (the solar-stimulated in a narrow band centered at 683 nm) has become a widespread technique to evaluate photosynthetic performance (Falkowski and Kiefer, 1985; Falkowski, 1988; Kiefer et al., 1989; Chamberlin et al., 1990). Its vertical distribution is directly linked to the stratification and mixing of the water column (Ríos et al., 2016), as well as to the thickness of the euphotic layer and nutrient availability at various spatial and temporal scales (Li and Hansell, 2016). Buesseler et al. (2008) documented that these situations were generally originated due to diverse hydrodynamic processes such as internal waves, fronts, and eddies. Mesoscale eddies, often identified as cyclonic, anticyclonic, mode-water or thinnies are some of the highly energetic features of the ocean circulation supporting a variety of mechanism that create biological and biogeochemical variabilities at a wide range of temporal and spatial scales (McGillicuddy, 2015, 2016). Cyclone dome, the seasonal and main pycnoclines causes a nutrient pumping into the euphotic zone, where they are utilized by the biota, whereas, anticyclones depress the seasonal and main pycnoclines, pushing nutrient depleted water out of the well-illuminated surface layers. Mode-water eddies are composed of a lens-shaped disturbance that raises the seasonal pycnocline and lowers the main pycnocline lifting nutrients into the euphotic zone (McGillicuddy et al., 2007). Thinnies depress and dome the seasonal and main pycnoclines, respectively (McGillicuddy, 2015). The popular eddy-pumping paradigm implies that nutrient fluxes are enhanced in cyclonic and mode-water eddies, because of an upwelling inside them, leading to higher

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phytoplankton production. However, recent study by Dufois et al. (2016) challenged this paradigm considering environments in which anticyclonic eddies have elevated Chl-a compared with cyclones. Interdisciplinary studies regarding mesoscale eddies and their impact on plankton community have been addressed in different ocean environments. Recent progress in automated methods for tracking mesoscale eddies has facilitated to understand how these eddies can influence the Chl-a distribution, with emphasis in three regional subdomains like the Gulf Stream region, the South Indian Ocean and Southeast Pacific (Chelton et al., 2011; Gaube et al., 2014). Recent studies documented that nitrogen fixation in cyclonic and mode-water eddies off the Peru coast is related to the presence of cyanobacteria, and the maximum fixation occurs in the periphery and in the central parts of the eddies due to the consumption of phytoplankton (Arévalo-Martínez et al., 2016; Löscher et al., 2016). In addition, Chenillat et al. (2016) interpreted that eddies of the California Current are responsible for the transport of nitrate and plankton of nearly ~50% and 20%, respectively.

In the Southern Gulf of Mexico the vertical and horizontal structures of Chl-a have been related with the thermal and light structures (Signoret et al., 1998; Signoret et al., 2006a) as well as with the regional circulation pattern characterized by a permanent cyclonic circulation over the Campeche Bay delimited by the topography of the region (Pérez-Brunius et al., 2013). The presence of anticyclone-cyclone eddy pairs during summer, representing an interesting point of study (Salas-de-León et al., 2004). The Campeche Canyon (Fig. 1) is located

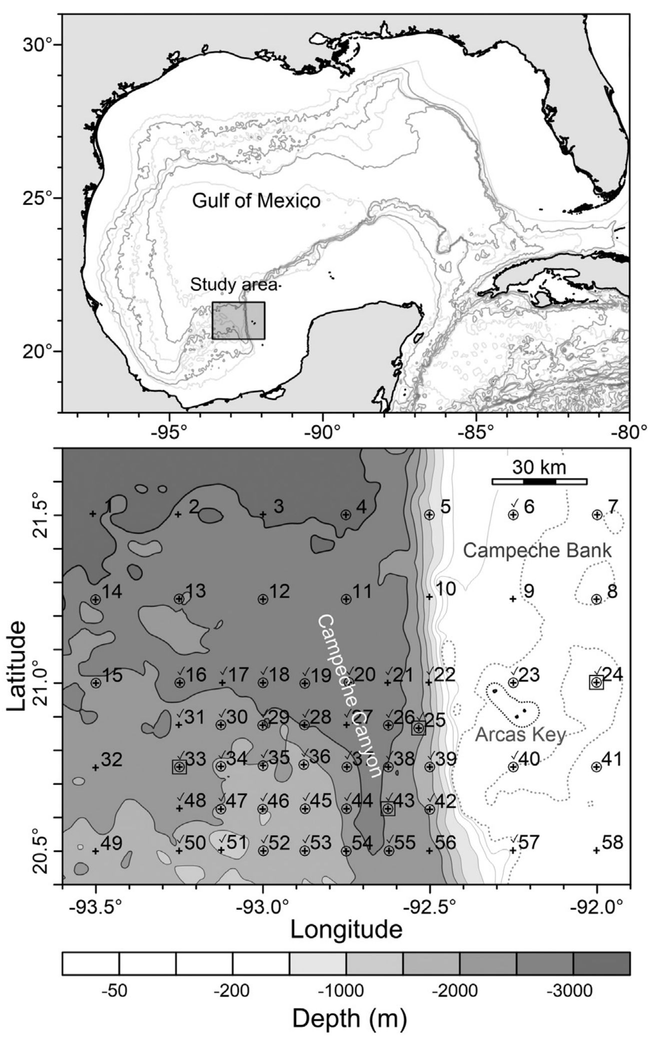

Fig. 1. Upper panel: Gulf of Mexico, and study area (small rectangle). Lower panel: sampling stations, CTD casts (+), PNF-300 casts (o), nitrate sampling (✓), phytoplankton sampling (□) and bathymetry (m).

in the Southern Gulf of Mexico, between 20° 30′–21° 36′ N and 92° 24′–93° 30′ W. The submarine canyon is an outstanding feature of the continental slope, located next to the escarpment and its origin is related to the tectonic evolution of the region (Escobar-Briones et al., 2008). The depth of the canyon ranges from 160 to 2800 m, which is a unique hydrodynamic environment with both anticyclonic and cyclonic eddies (Monreal-Gómez and Salas de León, 1997; Salas-de-León et al., 2004). Such hydrodynamic processes affect the phytoplankton biomass and sediment distribution, which originate from the occurrence of micro environments (Escobar-Briones et al., 2008). Submarine canyons, favor the downslope movement of dense shelf water (Canals et al., 2006; Bosley et al., 2004; Rennie et al., 2009; Chiou et al., 2011), moving continental shelf water onto the deep-ocean and act as regions of enhanced mixing and amplification on internal waves (Salas-Monreal et al., 2012; Santiago-Arce and Salas de León, 2012). This downslope movement can also result sub-superficial upwelling-downwelling processes (Ardhuin et al., 1999; Allen and de Madron, 2009; Aldeco et al., 2009), transportation of nutrient-rich dense water and sediments (She and Klinck, 2000), and further leads to the retention and/or resuspension of plankton and particulate matters (Palanques et al., 2005).

Submarine canyons are features of continental margins and are considered as privileged locations for the exchange of water between the coastal zone and the open ocean. The submarine canyons are significant, because they act as an agent for shelf-slope exchange of sediments; vertical motions steered by steep topography and by the formation of mesoscale eddies in their vicinity (Ardhuin et al., 1999). Mesoscale eddies are frequent in submarine canyons and studies have demonstrated that its formation and strength are directly dependent on the deep sea currents and the canyon's topography (Nof, 1983; Klink, 1996; Ardhuin et al., 1999; Salas-de-León et al., 2004; Rennie et al., 2008). At the southern Gulf of Mexico, the presence of canyon anticyclonic-cyclonic eddies has been studied and characterized by Salas-de-León et al. (2004). These authors used the 18.5 °C isotherm to characterize these eddies and stated that the formation of these eddies is derived from the canyon topography.

The Campeche Bank is a gently inclined, carbonate-dominated shelf, covering ~57,000 km^2 extending ~100–300 km from the coast to the shelf break at ~200–300 m depth (Goff et al., 2016) with an overall gradient of ~0.0002–0.001 (Logan et al., 1969). In the Campeche Bank region, cyclonic features have been identified with a life cycle that varies from 3 to 15 months (Zavala-Hidalgo et al., 2003). An important subsurface thermal gradient has been observed over the shelf break, which corresponds with a doming of low oxygen near to the base of the mixed layer. In addition, an anticyclone-cyclone dipole occurs over the region (Salas-de-León et al., 2004).

This study aimed to present the vertical and horizontal distributions of Chl-a and its relationship to the hydrography and mesoscale structures of the Campeche Canyon and Campeche Bank during June 2002. We hypothesize a vertical Chl-a distribution determined by the light supplied from the surface and nutrients supplied from the bottom and a region of high-nutrient concentration induced by mesoscale eddies that promotes a phytoplankton biomass higher than surrounding oligotrophic waters.

2. Materials and methods

Hydrographic records, Chl-a measurements and water samples for nitrate determination and phytoplankton cell quantification, were obtained during an oceanographic cruise PROMEBIO-VI carried out from 12 to 17 June 2002 on board of the R/V "Justo Sierra" of the Universidad Nacional Autónoma de México (UNAM). Using a Neil Brown III CTD, the conductivity, temperature and depth data were obtained at 58 stations, which cover both the Campeche Bank and Campeche Canyon (Fig. 1). On the basis of the CTD data, a T-S diagram was prepared to identify the water masses at the study area and in the first 120 m of the water column. The mixed layer was inferred using the maximum vertical