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# Hydrography and phytoplankton biomass in the Campeche Canyon and Bank, southern Gulf of Mexico, during February of 2011

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**Abstract.** The present study discusses the relationship between the hydrography and the phytoplankton biomass in the Campeche Canyon and Bank in the southern Gulf of Mexico (GM) during February of 2011 (a "Nortes" season). High-resolution observations were gathered during a research cruise covering 48 hydrographic stations, where a CTD probe equipped with a fluorescence sensor was used to collect data. The results indicated the presence of five water masses in different proportions. The phytoplankton biomass distribution showed dependence on the water column hydrographic conditions, particularly the thermal structure, which showed that the highest horizontal values were closely related with the presence of a warm temperature core. Two vertical distribution patterns were observed: 1) a maximum peak related with the thermocline in the stations over the Campeche Canyon and 2) a maximum peak closely related with the bottom at the stations over the Campeche Bank. The results presented here contribute to the knowledge of the phytoplankton ecology of the southern GM during a "Nortes" season, a time of year when in situ measurements from ships are scarce, and highlight the need to obtain more observations in order to determine patterns of phytoplankton biomass distribution and explore their seasonal variations.

**Key words:** mesoscale eddies, phytoplankton biomass, "Nortes" season, Campeche Canyon, Campeche Bank, Gulf of Mexico.

**Resumen: Hidrografía y biomasa fitoplanctónica em el Cañón y Banco de Campeche, sur del Golfo de México, durante febrero de 2011.** El presente estudio discute la relación entre la hidrografía y la biomasa fitoplanctónica en el Cañón y el Banco de Campeche, sur del Golfo de México (GM), durante febrero de 2011 (temporada de "Nortes"). Se obtuvieron observaciones de alta resolución durante un crucero de investigación en una red de 48 estaciones hidrográficas, donde se utilizó una sonda CTD equipada con un sensor de fluorescencia. Los resultados indicaron la presencia de cinco masas de agua en diferentes proporciones. La distribución de la biomasa fitoplanctónica mostró una clara dependencia con los parámetros hidrográficos de la columna de agua, particularmente con la estructura térmica. Se observaron dos patrones de distribución vertical: 1) un pico máximo relacionado con la termoclina en las estaciones sobre el Cañón de Campeche y 2) un pico máximo estrechamente relacionado con el fondo en las estaciones sobre el Banco de Campeche. Los resultados presentados aquí contribuyen al conocimiento de la ecología del fitoplancton del sur del GM durante la época de Nortes, y resaltan la necesidad de obtener más observaciones para determinar los patrones de distribución de la biomasa fitoplanctónica y explorar sus variaciones estacionales.

**Palabras clave**: vórtices de mesoescala; biomasa fitoplanctónica; temporada de "Nortes"; Cañón de Campeche; Banco de Campeche; Golfo de México.

## Introduction

Phytoplankton comprise a diverse group of microscopic photosynthetic organisms distributed in the euphotic layer of the world oceans. They are responsible for about 50% of the total amount of primary production around the globe (Simon *et al*. 2009). As a whole, phytoplankton represent the base of the trophic web and contribute to the sustenance of high commercial value fisheries, and they play a crucial role in global warming by reducing global $CO_2$ levels (Durán-Campos *et al*. 2019).

As chlorophyll-*a* (Chl*a*) is the pigment present in all autotrophic phytoplankton organisms, it has been commonly used as a *proxy* of phytoplankton biomass (Davies *et al.* 2018), and its seasonal and interannual variability depends, mainly, on physical conditions in the ocean.

In recent years, different physical mechanisms have been recognized. These include mixing/stratification of the water column (Cullen 2015), changes in the optical conditions in the water column due to photosynthesis (Coria-Monter *et al.* 2019a), presence of hydrodynamic processes at different scales, such as internal waves (Tweddle *et al.* 2013), fronts (Durán-Campos *et al.* 2019), and mesoscale eddies (radii range of 10–100 km), either cyclonic (with cold-core structures) or anticyclonic (with warm-core structures) (McGillicuddy 2016).

The effect of physical forcing on phytoplankton distribution has been the subject of intense research over the years, and it is well recognized that hydrodynamic processes, such as mesoscale eddies, impact the phytoplankton structure in different ways throughout the world oceans, which have been demonstrated in several domains, such as the Sargasso Sea (McGillicuddy *et al.* 2007), the South Atlantic Ocean (Carvalho *et al.* 2019), the Red Sea (Kürten *et al.* 2019), the Gulf of California (Coria-Monter *et al.* 2014), the oceans off the coasts of eastern Australia (Liu *et al*. 2018) and western Madagascar (Noyon *et al.* 2019), among others.

In the southern Gulf of Mexico (GM), studies on the impact of physical forcing on phytoplankton structure has been addressed by different authors, carried out mostly during the warmest period of the year (June-August). Salas de León *et al.* (2004) analyzed the circulation pattern in August and identified the presence of a cyclonic-anticyclonic eddy pair, which created a thermal gradient and, in turn, affected the phytoplankton structure. Signoret *et al.* (2006) analyzed the hydrography and the Chl*a* levels during August and evidenced a strong correlation between temperature and Chl*a*, with maximum values related to the thermocline. More recently, Durán Campos *et al*. (2017) analyzed the patterns of Chl*a* distribution in two areas of the southern GM, the Campeche Canyon and Bank; when linked to the hydrography of the water column during June, it revealed the presence of a dipole eddy (cyclone-anticyclone) inducing uplifting by the cyclonic eddy and promoting high Chl*a* values. The vertical distribution of Chl*a* showed two patterns, a deep maximum peak associated with the thermocline in the canyon and a peak associated with the bottom of the shelf.

Although these studies have contributed to the knowledge of phytoplankton ecology in the southern GM, they are limited to a single season of the year. Studies focused in determine the effect of physical forcing in different seasons are scarce, and the seasonal variability in dynamics and climatology suggest that there will be a pronounced relationship between the physics of the water column and phytoplankton distribution.

This study aims to assess the distribution of the phytoplankton biomass, expressed as Chl*a* concentration, based on high-resolution *in situ* observations. Also evaluate its relationship with the hydrography in the Campeche Canyon and Bank with information gathered during a research cruise in February 2011 (a "Nortes" season). We hypothesize that there will be changes in the horizontal and vertical phytoplankton biomass distribution induced by changes in the hydrographic conditions. With this information, we contribute to the knowledge of phytoplankton ecology in the southern region of the GM during a "Nortes" season, a period where *in situ* measurements are scarce due to the challenges posed to marine expeditions during a time of the year when winds and waves are extreme, thus inhibiting acquisition of high-quality data.

The GM is a semi-enclosed sea considered to be one of the largest marine ecosystems in the world due to its high biological productivity (Sherman & Hempel 2009) characterized by the confluence of a wide diversity of pelagic fishes of high commercial and ecological value such as sharks, billfishes, and tunas (Ramírez *et al.* 2019). Additionally, the GM represents a region of high economic significance due to oil exploration and extraction activities (Dorr *et al.* 2019).

In the southern portion, the GM is characterized by two geomorphic features: 1) the Campeche Bank, a carbonate shelf with depths ranging from 200 to 300 m extending from the coast out to 300 km and 2) the Campeche Canyon with depths greater than 2500 m (Goff *et al.* 2016) (Fig. 1A).

Dynamically, the Loop Current characterizes the GM. It is derived from the Yucatan Current, which penetrates the strait of the same name and forms a meander due to instabilities in water circulation, forming mesoscale eddies that spin off into the western GM (Díaz-Flores *et al.* 2017). These eddies transfer energy to the environment in the form of filaments. One of the forms of energy loss is attributed to the generation of cyclonic eddies which in turn uplift cold water bringing fresh nutrients to the euphotic zone promoting phytoplankton productivity in the southern region (Salas de León *et al.* 2004; Durán-Campos *et al.* 2017).

Climatically, the southern GM is characterized by three periods: 1) the dry season (March to May), 2) the rainy season (June to October), and 3) the season of “Nortes” (November to February). "Nortes" are characterized by strong winds (> 80 km/h) that cross the GM from North America, exerting a great influence on the surface waters and causing relative low surface temperatures (< 22 ºC) (Pérez *et al.* 2014; Ojeda *et al.* 2017).

## Materials and methods

*Sampling:* High-resolution *in situ* observations were gathered during the research cruise “CAÑON-IV” on board the R/V Justo Sierra owned by the National Autonomous University of Mexico (UNAM) from February 22 to 27 of 2011. The sampling strategy consisted of a regular grid of 48 equidistant hydrographic stations (with a distance between them of 26 km) covering the Campeche Canyon and a portion of the Campeche Bank (Fig. 1B).

At each station, a CTD probe (Sea Bird 19 plus) equipped with an ECO Wet Labs fluorometer sensor in a General Oceanics Rosette was used to

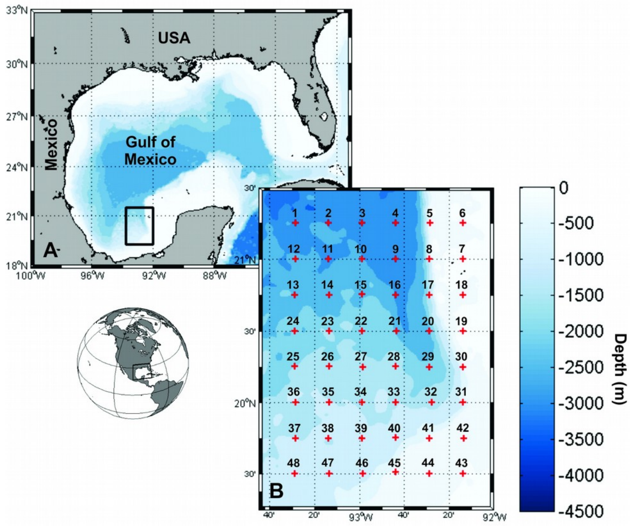


**Figure 1.** Study area: A) The Gulf of Mexico, the rectangle indicates the Campeche Canyon and Bank area and B) the sampling domain, + represents the hydrographic stations. Bathymetry is shown in meters.

acquire high-resolution data to determine both the hydrographic structure of the water column, as well as the Chl*a* levels.

*Data processing:* The acquired data were initially converted and processed using the protocols and recommendations of the manufacturer, (SBE data processing v7.26.7). In order to purge data, a low-pass filter was applied; then the data set was averaged for each decibar. The algorithms presented by the Thermodynamic Equation of Seawater - 2010 (TEOS-10) (IOC *et al.* 2010) were used to derive the conservative temperature (Θ, °C), absolute salinity (SA, g $kg^{-1}$), and density (kg $m^{-3}$) in each cast, from which horizontal distribution maps of these parameters were constructed. The fluorescence sensor data were converted and expressed as Chl*a* concentration (mg $m^{-3}$) using the calibration factor of the fluorometer and standard algorithms. Using these data the horizontal and vertical distribution of Chl*a* in several profiles was evaluated.

In order to establish a comparison with the *in situ* measurements, sea surface temperature (SST) and Chl*a* satellite images were obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS-AQUA) for concurrent dates with the research cruise. Available images were obtained from NASA's OceanColor Web (https://oceancolor.gsfc.nasa.gov/cgi/browse.pl) for February 23, 2011. The images were obtained with a spatial resolution of 1 x 1 km/pixel, processed at Level 2, and extracted with SeaDAS software version 7.4. In order to screen bad or low-quality data, the flags/masks CLDICE, HILT, STRAYLIGHT, and LAND were applied.

## Results

Five water masses were evidenced by temperature-salinity (T-S) diagrams and according to the classification of Durán-Campos *et al.* (2017) and Portela *et al.* (2018): 1) Antarctic Intermediate Water (AAIW) characterized by 5.5 < T < 6.5 ºC and 35.0 < S < 35.1 g kg$^{-1}$, 2) Tropical Atlantic Central Water (TACW) characterized by 8 < T < 20 ºC and 35.1 < S < 36.6 g kg$^{-1}$, 3) Gulf Common Water (GCW) characterized by 22 < T < 28 °C and 36.2 < S < 36.4 g kg$^{-1}$, 4) Caribbean Subtropical Underwater (CSUW) with 22 < T < 26 °C and 36.4 < S < 36.6 g kg$^{-1}$ and 5) North Atlantic Subtropical Underwater (NASUW) characterized by 20 < T < 25 ºC and S > 36.8 g kg$^{-1}$; the last three occurred in the top 150 m of the water column (Fig. 2).

The horizontal distribution of surface hydrographic variables, showed that the temperature ranged from 23.3 to 25 ºC with an interesting distribution pattern, indicating the presence of cores of different temperatures; a warm core, of ~24.9 ºC at its center, was observed in the southwestern portion indicating the presence of an anticyclonic eddy (Figure 3A). The surface salinity distribution also showed the presence of a low salinity core (~35.3 g kg$^{-1}$) in the southwestern portion of the study area, extending to the north and forming a tongue of low salinity water. Two cores of high salinity were observed in the northwestern and northeastern portions of the study area, reaching values greater than 36.5 g kg$^{-1}$ (Fig. 3B). As expected, the surface density distribution was in concordance with temperature and salinity showing a low-density core coincident with the warm-core, while two cores of high density (> 24.8 kg m$^{-3}$) were observed in the northern portion of the study area (Fig. 3C). The surface distribution of Chl*a* ranged from 0.001 to 0.19 mg m$^{-3}$, with two cores of high values; one located in the southwestern portion coincident with the warm core, reaching values of 0.19 mg m$^{-3}$; and another core, with high Chl*a* values (> 0.16 mg m$^{-3}$) in the northeastern portion in the area of the Campeche Bank (Fig. 3D).

Satellite images (February 23, 2011), matched well with *in situ* measurements, showing a distribution pattern with highest temperatures (> 24 ºC) located in the southwestern portion of the study area (Fig. 4A). Chl*a* distribution also showed high values in the southwestern region, closely related with the highest temperatures, as well as in the

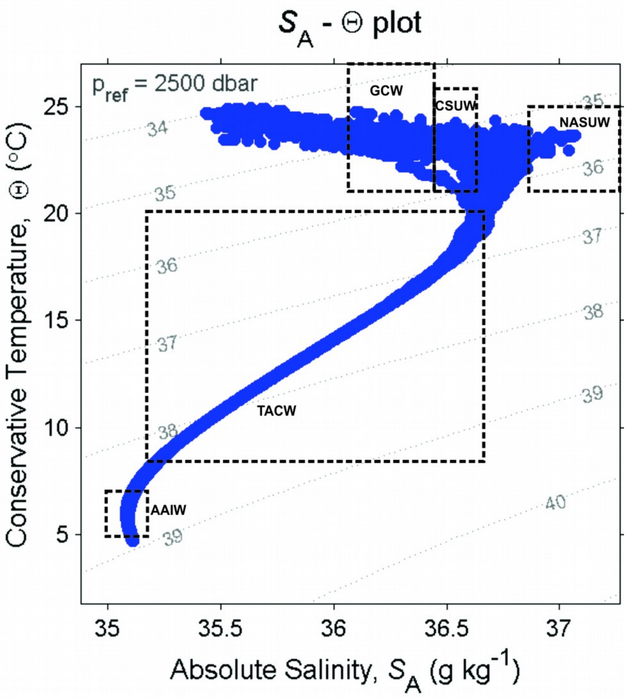


**Figure 2.** Temperature-Salinity (T-S) diagram during the "Nortes" season of 2011. The abbreviations for each water mass are referred to in the main text.

northeastern portion (Fig. 4B). Although the absolute values showed some differences with respect to the *in situ* measurements, there are natural variations due to the relationship between *in situ* fluorescence measured from a ship and those measured by satellite (Coria-Monter *et al.* 2019b), explaining the differences in the values observed.

Vertical profiles were constructed for all stations in order to analyze Chl*a* distribution and its relationship with the hydrographic parameters in the water column. Figure 5 presents the vertical distribution at six representative stations, three over the Campeche Canyon and three over the Campeche Bank. The stations over the Campeche Canyon (Fig. 5A-C) showed that the thermocline and the pycnocline were located at a 60 m depth with a maximum of Chl*a*, reaching values of 1.40 mg m$^{-3}$. The vertical distribution in stations over the Campeche Bank (Fig. 5D–F) showed a well-mixed water column, due to its shallowness, and the maximum peaks of Chl*a* were associated with the bottom, reaching values of 1.45 mg m$^{-3}$.

## Discussion

The distribution of water masses showed some coincidences with those presented by Durán-Campos *et al.* (2017) and Portela *et al.* (2018) with respect to the presence of AAIW, TACW, GCW, CSUW, and NASUW; however, the proportions

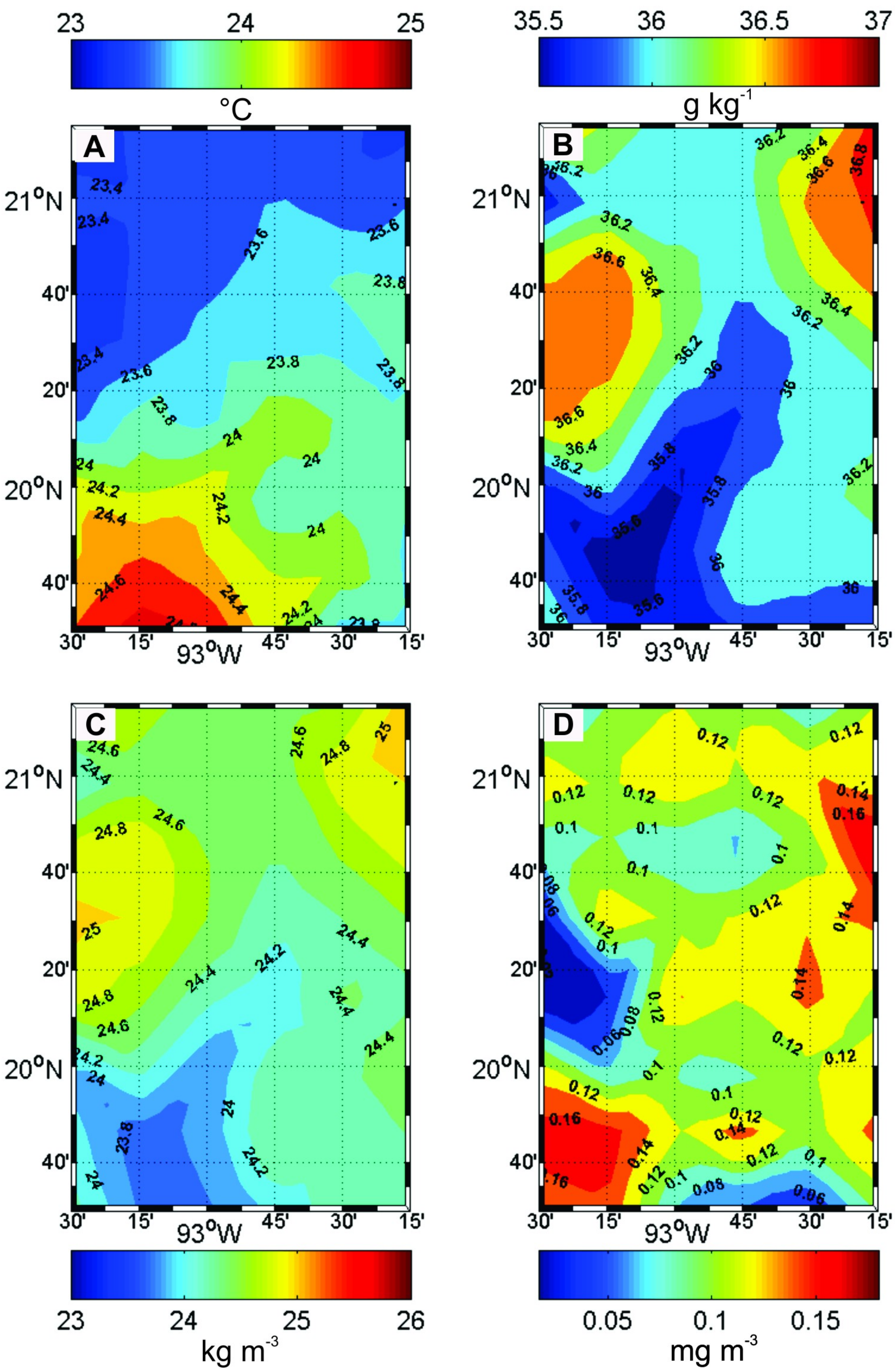


**Figure 3**. Horizontal surface distribution of: A) conservative temperature (ºC), B) absolute salinity (g kg$^{-1}$), C) density (kg m$^{-3}$) and D) chlorophyll-*a* (mg m$^{-3}$).

observed in this study were different because the distribution of water masses inside the GM has a wide seasonal and interannual variability due to the hydrodynamics of the gulf. The presence of "Nortes" in the winter season produces a cooling of the surface waters and induces the formation of the GCW (Vidal *et al.* 1994; Durán-Campos *et al.* 2019). This feature explains the greater proportion of this water mass observed in this study compared with that reported in summertime.

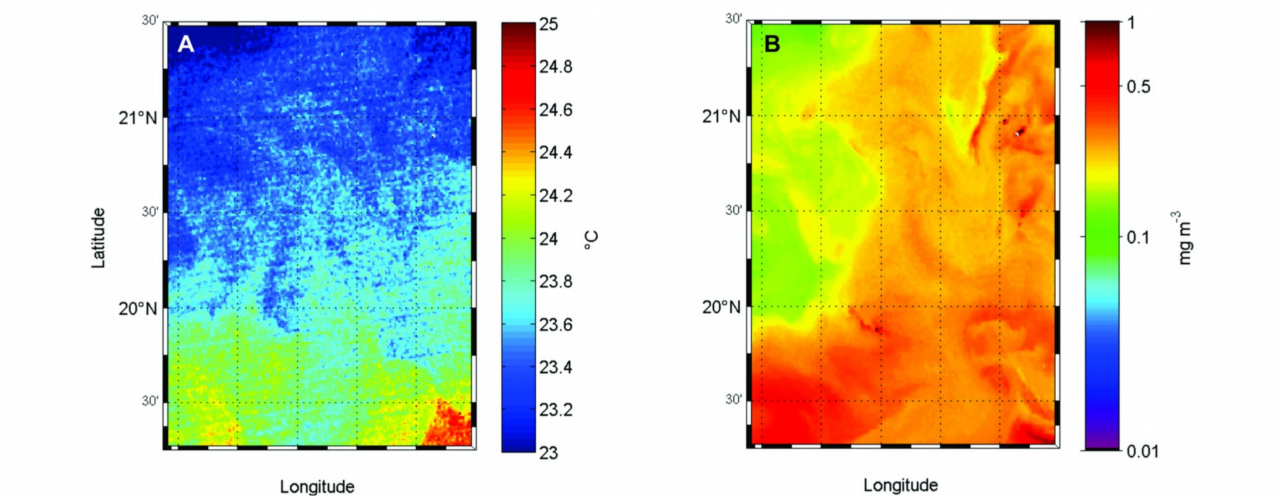


**Figure 4.** Satellite images from MODIS for February 23, 2011 of: A) sea surface temperature (ºC) and B) chlorophyll-*a* (mg $m^{-3}$).

Submarine canyons around the world are considered as particular locations due to the exchange of water between the open ocean and coastal areas. These features of the continental margins are also significant for the interchange of sediments between the two environments and for inducing vertical motion in the water column because of the steep topography. They also aid in the generation of mesoscale eddies (Ardhuin *et al.* 1999). To date, it is well known that mesoscale eddies, either cyclonic (cold-core structures) or anticyclonic (warm-core structures) are recurrent features in submarine canyons, and their origins have been linked to deep-sea currents and canyon topography (Nof 1983; Rennie *et al.* 2008).

Mesoscale eddies are recognized as critical components in many marine ecosystems due to stirring and mixing thus affecting biogeochemical fluxes in the ocean and may trap plankton communities for months, and then transport them hundreds of kilometers (Braun *et al.* 2019). To date, it is well recognized that cyclonic eddies in the ocean positively impact phytoplankton biomass due to the divergence of cold and nutrient-rich water cores that fertilize the euphotic zone (McGillicuddy *et al.* 2007). Scientific evidence for these cyclonic eddies appears in literature from around the globe including the southern GM (Durán-Campos *et al.* 2017). On the other hand, anticyclonic eddies, characterized by warm cores due to convergence, are thought to reduce biological productivity because they cause sinking surface water below the euphotic zone (McGillicuddy & Robinson 1997).

However, recent evidence suggests that anticyclonic eddies can be very productive areas contradicting the classic paradigm that anticyclonic eddies are “ocean deserts” (Braun *et al.* 2019). This could be the case of this study, where a high Chl*a* core was observed in association with a warm cold core, and even a secondary high Chl*a* core was observed in the northeastern portion of the study area with the highest concentration in the entire domain and close to the warmest temperature observed.

Previously, the impact of eddies (particularly cyclonic) in the planktonic ecosystem of the southern GM was noticed by Salas de León *et al.* (2004) who showed that their presence impacted the phytoplankton biomass of the region. Similar observations were reported by Durán-Campos *et al.* (2017) who showed that the presence of an eddy positively impacted the phytoplankton biomass, inducing an area of enhancement associated with mesoscale eddies. However, both studies were made during June-August when the hydrographic conditions of the water column are different than those presented during the “Nortes” season, which are influenced by strong winds from North America that produce extreme waves.

Previous studies of phytoplankton ecology in oceanic waters in the southern portion of the GM during a “Nortes” season are limited to the work of Linacre *et al.* (2015) who showed a clear dependence in the picoplankton biomass associated with mesoscale eddies, particularly anticyclonic (warm) eddies that modulated the hydrographic parameters of the surface mixed layer and induced changes in the picoplanktonic communities. The presences of eddies (cyclonic and anticyclonic) in the southern GM during a "Nortes" season, have

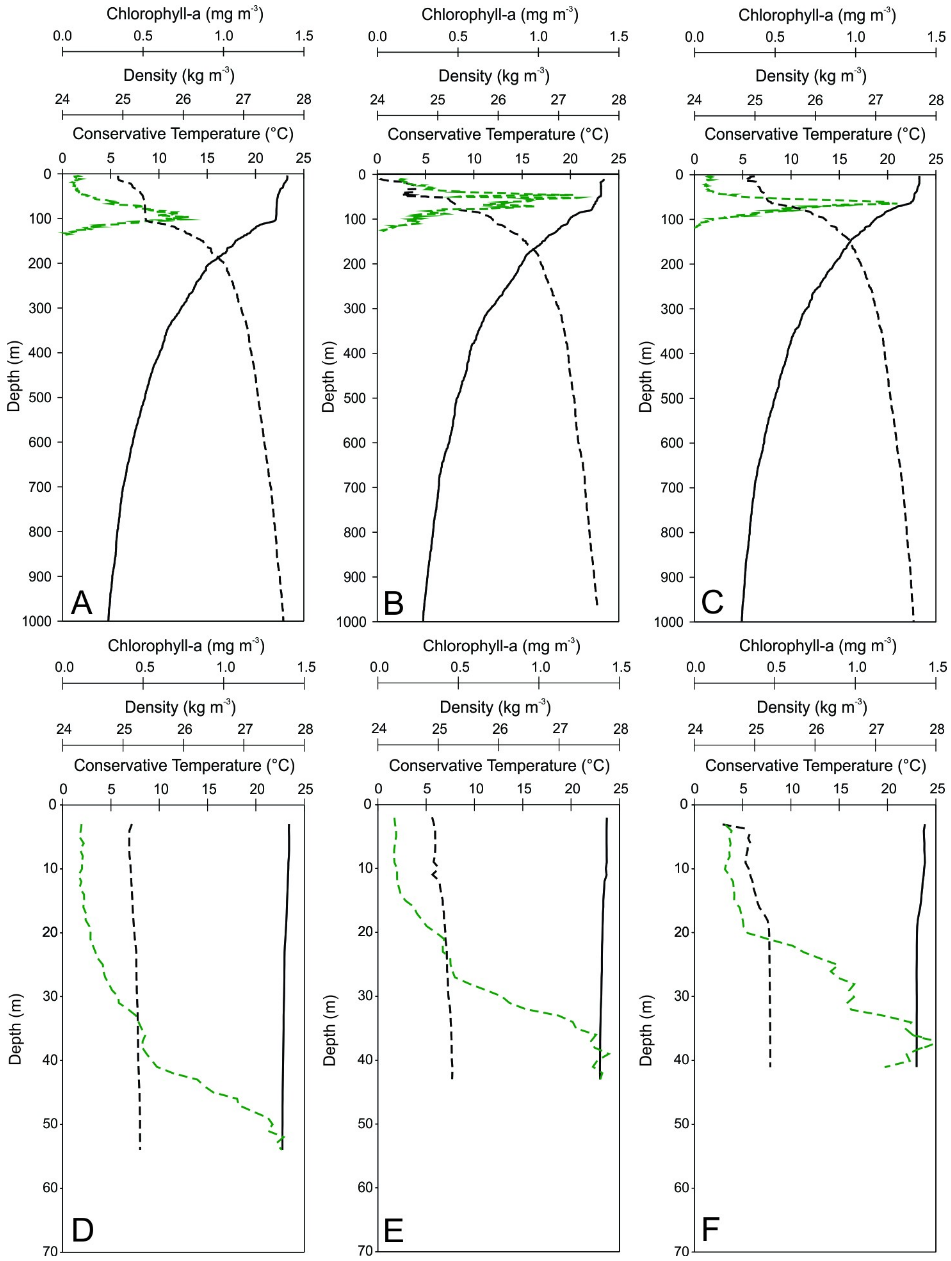


**Figure 5**. Vertical distribution of conservative temperature (ºC, black solid line), density (kg $m^{-3}$, black short dashed line), and Chl*a* (mg $m^{-3}$, green short dashed line) from representative stations in the study area: A–C are stations over the Campeche Canyon (stations # 1, 12, 13); D–F are stations over the Campeche Bank (stations # 6, 7, 18). Note the change in depth scale.

been closely related with high Chl*a* values which in turn impact the zooplankton distribution in the region (Färber-Lorda *et al.* 2019). However, in oceanic waters of the southern GM, studies showing the relationship between hydrography and phytoplanktonic biomass during a "Nortes" season are still scarce.

Two vertical distribution patterns of Chl*a* were detected at time of our observations involving a deep maximum peak associated with the thermocline and pycnocline at the stations over the Campeche Canyon, and a peak of Chl*a* associated with the bottom over the Campeche Bank. These two vertical distribution patterns were previously reported by Durán-Campos *et al.* (2017) in the southern portion of the GM; however, there were marked differences in the values. While these authors reported maximum Chl*a* peaks of 0.6 mg $m^{-3}$, the Chl*a* observed in this study reached values of 1.45 mg $m^{-3}$. Similarly, Salas de Leon *et al.* (2004) showed maximum Chl*a* values of 0.35 mg $m^{-3}$ in August while Signoret *et al.* (2006) showed values of 0.5 mg $m^{-3}$ also during summertime. These differences are explained by changing hydrodynamics during the “Nortes” season when strong winds induce mixing of the water column and subsequent resuspension of nutrients, thus positively impacting the phytoplankton biomass. Although there were no nutrient measurements collected during this study, we assume that the concentration was high considering the Chl*a* levels observed.

## Conclusions

The presence of the water masses observed in this study agrees with previous reports in Campeche zone, but was variable in terms of their relative proportions due to changing dynamics during the “Nortes” season. The phytoplankton biomass, expressed as Chl*a*, showed a clear dependence with the hydrographic parameters of the water column, particularly with the thermal structure, and closely related with the presence of a warm-water core.

Two vertical distribution patterns were consistent with previous reports in the region, however the values observed were highest due to the season of the year. The results presented here contribute to the knowledge of phytoplankton ecology in the southern region of the GM during a “Nortes” season, a period when *in situ* measurements from ships are scarce due to the challenges posed to maritime expeditions when the winds and waves are extreme, thereby inhibiting acquisition of high-quality data. The results presented here also highlight the need to combine both *in situ* and satellite observations to explore patterns of phytoplankton biomass distribution and their seasonal variations, particularly in regions that are characterized by high productivity such as the GM.

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