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# Dispersion in the Yucatan coastal zone: Implications for red tide events

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A B S T R A C T

The mechanisms governing dispersion processes in the northern Yucatan coast are investigated using a barotropic numerical model of coastal circulation, which includes wind-generated and large scale currents (i.e. Yucatan Current). This work provides the foundations for studying the dispersion of harmful algal blooms (HABs) in the area. Modelling experiments include effects of climatic wind (from long term monthly mean NCEP reanalysis), short term wind events (from *in situ* point measurements), and Yucatan Current (YC) characteristics. Its magnitude was approximated from published reports, and its trajectory from geostrophic current fields derived from altimeter data. These provided a range of real and climatic conditions to study the routes in which phytoplankton blooms may travel. The 2-D model results show that a synthetic and conservative bloom seeded in the Cabo Catoche (CC) region (where it usually grows), moves along the coast to the west up to San Felipe (SF), where it can either move offshore, or carry on travelling westwards. The transport to the west up to SF is greatly influenced by the trajectory, intensity and proximity of the YC jet to the peninsula, which enhances the westward circulation in the Yucatan Shelf. Numerical experiments show that patch dispersion is consistently to the west even under the influence of northerly winds. When the YC flows westward towards the Campeche Bank, momentum transfer caused by the YC jet dominates the dispersion processes over wind stress. On the other hand, when it flows closer to Cuba, the local processes (i.e. wind and bathymetry) become dominant. Coastal orientation and the Coriolis force may be responsible for driving the patch offshore at SF if external forcing decreases.

## 1. Introduction

The coastal sea of the northern Yucatan Peninsula (Fig. 1) has a wide and shallow continental shelf (up to 245 km wide with a nearly monotonic 1/1000 slope). It is located between the Caribbean Sea and the Gulf of Mexico, two ecosystems communicated through the Yucatan Channel, which is 196 km wide and reaches 2000 m depth. The YC flows through this channel, carrying with it different water masses. This current can generate a dynamic upwelling pushing cold and nutrient-rich water uphill across the steep continental slope, reaching the Yucatan Shelf where it is dispersed at the bottom (Cochrane, 1969; Merino, 1992; Merino 1997; Ruiz-Renteria, 1979; Sahl et al., 1997). This upwelling provides conditions for development of algal blooms and the resulting food web enhancement that supports species such as the whale shark (*Rhincodon typus*) in the Cabo Catoche (CC) region (Fig. 1). In addition to the upwelling processes, nutrients may be supplied by groundwater discharges. Continental water in the region drains to the sea as submarine groundwater discharges (SGD), which happen in several locations such as Dzilam Bravo (DB). There is some evidence showing that algal blooms are fed initially by the upwelling at CC and enhanced by SGD as they travel to the west near the populated areas of the northern coast of Yucatan (Alvarez-Gongora, 2009; Herrera-Silvera et al., 2004).

Nonetheless, under certain circumstances algal blooms develop harmful characteristics (HABs) creating havoc on the local environment, fisheries and tourist industry (Alvarez-Gongora and Herrera-Silveira, 2006; Herrera-Silvera et al.,2004). In Yucatan, phytoplankton blooms have been recorded since 1948. The most recent and harmful events happened in 2001, 2003 and 2008. Based on the damage caused by these events, research and monitoring programs were implemented to determine the hydrological conditions and oceanographic processes related with the frequency, spatial distribution and species composition of HABs in order to understand their behaviour and minimize the negative ecological and economic impacts. The ultimate goal is to have a forecast system to aid an adequate management of red tide threats.

So far, red tide studies have focused on hydrological characterization, taxonomy of HAB species, water quality and ecological impacts (Alvarez-Gongora and Herrera-Silveira, 2006; Hernandez-Becerril et al., 2007). However, hydrodynamics and the resulting dispersion are poorly understood in the Yucatan

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Shelf, which is the north-eastern region of the so-called Campeche Bank. The information available in the literature regarding the hydrodynamics in this region is scarce. Capurro-Filograsso and Reid (1972) provided the first collection of oceanographic studies from the Gulf of Mexico; most of these studies were large scale oceanographic surveys where the Yucatan Shelf was covered partially or not included. Merino (1992; 1997) conducted a series of field campaigns measuring thermohaline distribution in the Yucatan Shelf, particularly in the Cabo Catoche region, to study the upwelling process. The currents have not been studied in detail in the Yucatan Shelf but it is commonly known by the locals that the dominant current in the coastal region is to the west. The westward current has been mentioned in other studies around the region (Merino, 1997; Monreal, et al., 1992). More recently, Zavala-Hidalgo et al. (2003) and later Morey et al. (2005) studied the circulation on continental shelves of the Gulf of Mexico using numerical modelling forced with climatic winds. Both confirm the known westward circulation, which coincides with a dominant westerly wind on the region throughout the year. Morey et al. (2005) suggest that over wide shelves, such as the Yucatan Shelf, sub tidal variability of circulation is dominantly forced by local surface momentum fluxes (wind stress). Zavala-Hidalgo et al. (2003) presented evidence that this applies for most of the GOM continental shelves. Using 7 years of model data, they found high correlation (values $r > 0.5$) between monthly mean surface currents and the along-coast wind stress component at ten locations around the GOM, demonstrating the importance of wind stress as the main force in coastal circulation. The exception to this behaviour was their eastern-most site, Puerto Progreso, located on the Yucatan Shelf. At this site the along-coast wind stress and monthly mean surface currents share sign (westward) but its correlation is the lowest (0.13). This is an indication that over the Yucatan Shelf, processes other than wind stress must have significant influence on the westward current behaviour.

This study gives a first step (including only hydrodynamics) to explore the way in which different forces contribute to the local current field and ultimately to the dispersion of phytoplankton blooms. This is achieved by testing the sensitivity of the currents to two processes: the local wind blowing over the wide and shallow continental shelf and the characteristics of the YC, mainly its position, trajectory and intensity, using the DELFT3-D numerical model.

The details of the model set up and parameters used in the different runs are presented in Section 2. Section 3 describes the wind and YC variability, which are the forces used to drive the numerical experiments. Section 4 gives the analysis of red tide dispersion and includes discussions on model validation and comparison with observational data. The paper ends with conclusions in Section 5.

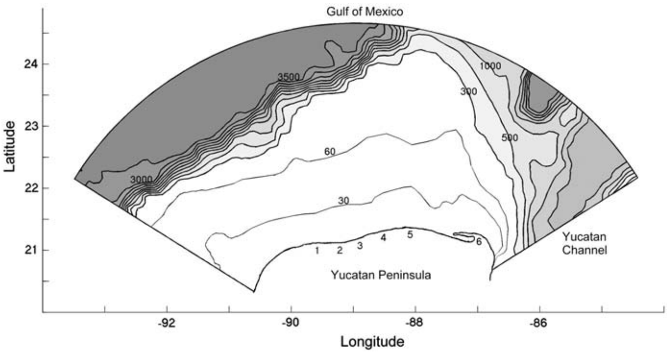

**Fig. 1.** Map of the Yucatan Shelf (Campeche Bank) showing the bottom topography used in this study. It also shows the location of Progreso (1), Telchac (2), Dzilam Bravo (3), San Felipe (4), Rio Lagartos (5) and Cabo Catoche (6) at the coast.

## 2. Model set up

The 2-D version of the flow module of Delft3-D numerical model developed by WL/Delft Hydraulics [http://delftsoftware.wldelft.nl/index.php] is used to estimate the circulation and the resulting dispersion of a synthetic and conservative (no growth/decay included) red tide event introduced in the Cabo Catoche (CC) region, where this event typically grows.

The model was implemented for the Yucatan continental shelf (northern Campeche Bank) in a fan-shaped grid with radial length similar to the Yucatan Channel length. The curvilinear grid of $186 \times 92$ grid points ranges from 21° to 24° latitude and 267° to 276° longitude (Fig. 2) with a spatial resolution, which goes from approximately 3 km near the coast to 5.5 km at the offshore boundary. The model is barotropic and does not include density distribution at this stage, but 4 vertical sigma layers were set to allow vertical variable current forcing at the eastern boundary. After a series of sensitivity tests, the adequate time step for achieving stable results was 10 min. The bed roughness was estimated with the Chezy formula and a cyclic advection scheme was used for momentum and transport. The values for horizontal eddy diffusivity and eddy viscosity were 10 and 1 $m^2/s$, respectively. Bottom topography was extracted from the ETOPO5 database (NOAA/AOML 1988) and complemented with higher resolution bathymetric data with along-coast resolution of

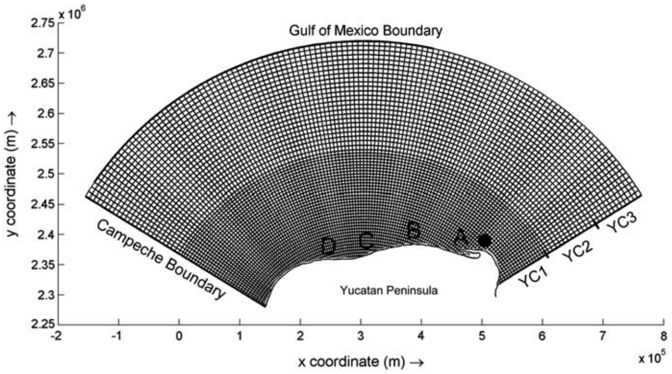

**Fig. 2.** Model grid, showing the open boundaries. The figure also shows the red tide discharge location, marked with a black dot and the observation points A, B, C and D located near the coast.

**Table 1**
Detail of the model scenarios to study red tide dispersion.

| Exp no. | GM boundary | | Wind | | | Source |
|---|---|---|---|---|---|---|
| | Total | Partial | | (m/s) | (°) | |
| 1 | ▨ | | NE | 5.05 | 242.9 | NCEP |
| 2 | ▨ | | E | 4.07 | 269.8 | NCEP |
| 3 | ▨ | | SE | 4.75 | 284.8 | NCEP |
| 4 | | ▨ | NE | 5.05 | 242.9 | NCEP |
| 5 | | ▨ | E | 4.07 | 269.8 | NCEP |
| 6 | | ▨ | SE | 4.75 | 284.8 | NCEP |
| 7 | ▨ | | January 2003 | Real variability | | Rio Lagartos Stn. |
| 8 | | ▨ | January 2003 | Real variability | | Rio Lagartos Stn. |
| 9 | ▨ | | June 2003 | Real variability | | Rio Lagartos Stn. |
| 10 | | ▨ | June 2003 | Real variability | | Rio Lagartos Stn. |
| 11 | | ▨ | July 2008 | Wind prediction | | For Telchac, Yuc. |