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Differences in coastal and oceanic SST trends north of Yucatan Peninsula

R. Varela[a,*], X. Costoya[b], C. Enriquez[c], F. Santos[a,b], M. Gómez-Gesteira[a]

[a] Ephyslab, Environmental Physics Laboratory, Facultad de Ciencias, Universidad de Vigo, 32004 Ourense, Spain
[b] CESAM, Departamento de Física, Universidade de Aveiro, 3810-193 Aveiro, Portugal
[c] Facultad de Ciencias, Universidad Nacional Autónoma de México, Sisal, Yucatán, Mexico

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ABSTRACT

The coastal area north of Yucatan has experienced a cooling SST trend from 1982 to 2015 during the upwelling season (May–September) that contrasts with the warming observed at the adjacent ocean area. Different drivers were analyzed to identify the possible causes of that unusual coastal cooling. Changes in coastal upwelling and in sea-atmosphere heat fluxes are not consistent with the observed coastal cooling. The eastward shift of the Yucatan Current observed over the last decades is hypothesized as the most probable cause of coastal cooling. This shift enhances the vertical transport of cold deeper water to the continental shelf from where it is pumped to the surface by upwelling favorable westerly winds.

1. Introduction

Over the last decades, the scientific community has focused its attention on the impact of climate change. Ocean plays a key role in regulating that impact since it has absorbed the vast majority of the heat gained by the Earth (Levitus et al., 2005; Mikaloff-Fletcher et al., 2006; Levitus et al., 2012).

Upwelling systems are productive oceanic areas with important socio-economic implications. In fact, upwelling systems only occupy 1% of the world's ocean but > 20% of fish catches occurs there (Pauly and Christensen, 1995). These systems are especially vulnerable to climate change that can affect not only the physical component (water temperature and wind patterns) but also productivity of the area.

Regarding ocean temperature, several authors have observed different rates of warming depending on the location (Harrison and Carson, 2007; Lima and Wethey, 2012; Cheung et al., 2013). This variability is even more marked at regional scale. In this way, a different warming rate has been observed for coastal and oceanic locations in some of the most important upwelling systems: Benguela, Canary, West Iberian Peninsula, Java or La Guajira (Lemos and Sansó, 2006; Santos et al., 2012a, 2012b, 2012c; Santos et al., 2016; Varela et al., 2016). Most of these studies have linked the different warming rates at coast and ocean with the strengthening of coastal upwelling, which can act as a moderator of climate change. A complete study about the evolution of upwelling in the main upwelling areas worldwide can be observed in Varela et al. (2015).

In the coastal zone of the Yucatan Peninsula two very different upwelling processes occur: a typical wind related upwelling in the northern coast of the Peninsula and a dynamic upwelling in the northeastern corner of the Peninsula. Yucatan is localized in the southeastern area of the Gulf of Mexico around 21°N and between 269 and 274°E (Fig. 1). The northern coast of the Yucatan Peninsula follows a marked zonal orientation. In general, the area is characterized by a wide continental shelf that extends over 250 km (Ruiz-Castillo et al., 2016), being much narrower east of the Yucatan Peninsula. Easterly and northeasterly winds (trade winds) prevail throughout the year giving rise to conditions that favor upwelling over the northern coast of the Yucatan shelf (Merino, 1997; Pérez-Santos et al., 2010; Enríquez et al., 2013; Ruiz-Castillo et al., 2016). Ruiz-Castillo et al. (2016) examined coastal upwelling using Advanced Very High Resolution Radiometer (AVHRR) and Cross-Calibrated Multi-Platform (CCMP) from 1986 to 2009 and 1988 to 2011, respectively, to analyze SST and wind patterns. These authors obtained positive values of upwelling index (UI) throughout the year, with the highest values observed from March to July. Similar results were obtained by Pérez-Santos et al. (2010), who considered that Ekman Transport was the main process favoring permanent coastal upwelling at the northern coast of the Yucatan Peninsula. The prevalence of upwelling favorable winds confers this region distinguishable chlorophyll-a properties when compared with adjacent areas, highlighting the biological impact of upwelling (Salmerón-García et al., 2011; Pérez-Santos et al., 2014).

A different upwelling process occurs form April to September in the form of sharp and intense pulses of deeper water masses into the northeastern corner of Yucatan, attracting species of ecological and

* Corresponding author.
E-mail address: ruvarela@uvigo.es (R. Varela).

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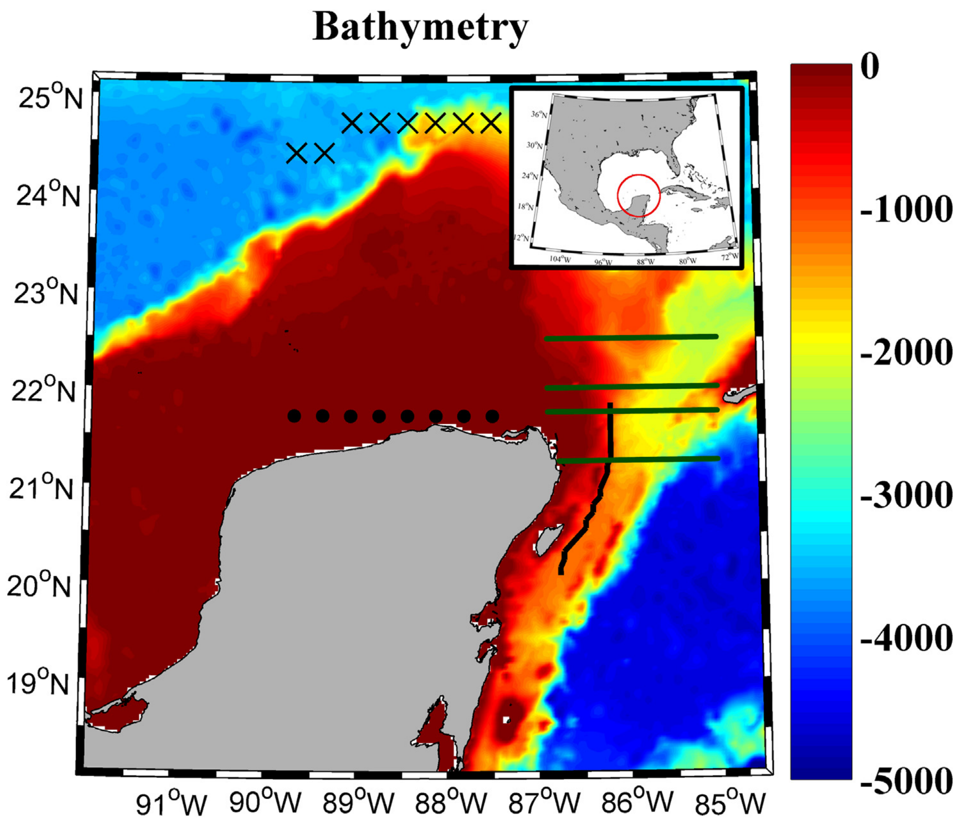

Fig. 1. Bathymetry of the area under study. Dots (crosses) mark the coastal (oceanic) location where wind and SST were obtained. The solid black line represents the transect where temperature variability was analyzed along the Yucatan current. The solid green lines represent the transects where subsurface water that upwells to the Yucatan shelf was analyzed. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

commercial interest as the whale shark (*Rhincodon typus*) (Cárdenas-Palomo et al., 2015). Actually, the upwelling region has been declared a biosphere reserve for this specie. It is crucial to analyze temperature variation in this area, especially within the context of climate change, since changes in warming patterns can induce changes in biodiversity at the ecosystem level (e.g: latitudinal shifts on the distribution of species).

Different authors have focused their research on SST patterns in this area. A cold band is observed during summer months along the coast associated with upwelling favorable winds (Zavala-Hidalgo et al., 2006; Ruiz-Castillo et al., 2016). A 7 years analysis of SST from AVHRR satellite carried out by Zavala-Hidalgo et al. (2006) showed cold coastal water in Yucatan from May to August with a peak in July, during these months the difference in temperature between coast and ocean can be up to 2 °C. del Monte-Luna et al. (2015) related the recurrent upwelling in the area to the cold water found north of Yucatan Peninsula. Ruiz-Castillo et al. (2016) observed a cold water band in the inner shelf starting in April with differences up to 1 °C with the warm waters off the Yucatan shelf. This effect continues at least until October. Regarding SST trends, Lima and Wethey (2012) used data from AVHRR to analyze SST variations over the period 1982–2010. For the case of Yucatan, they obtained a slight cooling during most of the year. However, that cooling trend cannot be associated with positive trends of UI in the area as observed in other regions (Santos et al., 2012a, 2012b, 2012c). In fact, Varela et al. (2015) obtained negative trends of wind stress for the area of Yucatan using wind stress data from the Climate Forecast System Reanalysis (CFSR) over the same period.

Other authors have pointed out that wind forcing is not enough to explain the appearance of colder water in the innermost area of the Yucatan shelf (Enríquez and Mariño-Tapias, 2014; Reyes-Mendoza et al., 2016; Souza et al., 2016; Carrillo et al., 2016). Enríquez and Mariño-Tapias (2014) found that the characteristics of the Yucatan Current (YC) could influence the upwelling in the area, in such a way that, when YC separates from the continental slope, favors the enhancement of positive vertical velocities, which raise cold, nutrient rich water to the surface layer. Similar results were obtained by Carrillo et al. (2016) who observed an uplifting of the isotherms under the action of the YC, which evidence the existence of upwelling in the area. Thus, the enhancement of the YC can lead to the reinforcement of upwelling in the area (Enríquez and Mariño-Tapias, 2014; Carrillo et al., 2016; Souza et al., 2016).

The aim of this paper is to analyze SST variability along the Yucatan upwelling system over the last three decades. This variability will be related to different drivers like upwelling index, heat exchange with the atmosphere or changes in the Yucatan current. As far as we know, this is the first long term study on SST variability in the area. Previous works analyzed upwelling and SST pattern (Zavala-Hidalgo et al., 2006; Ruiz-Castillo et al., 2016), but they were not focused on long term SST changes within a framework of global warming. In addition, the present work also relates the observed SST changes to the different drivers that affect water temperature in the zone.

2. Data and methods

2.1. Temperature data

Daily SST values were retrieved from the Optimum Interpolation Sea Surface Temperature (OISST) ¼ database (https://www.ncdc.noaa.gov/oisst). This database was built by means of Advanced Very High Resolution radiometer (AVHRR) infrared satellite SST data and data from ships and buoys (Reynolds, 2009 and Reynolds and Chelton, 2010). A special method of kriging (Optimum interpolation) was used to construct a regular grid (0.25° × 0.25°) containing data from 1982 to 2015.

Sea Temperature data along the water column was obtained from the Hybrid Coordinate Ocean Model (HYCOM). HYCOM uses satellite altimeter observations, satellite and in-situ sea surface temperature. Also, in-situ vertical temperature and salinity profiles from XBTs, ARGO floats, and moored buoys, using the NRL-developed Navy Coupled Ocean Data Assimilation (NCODA) system (Cummings, 2005;