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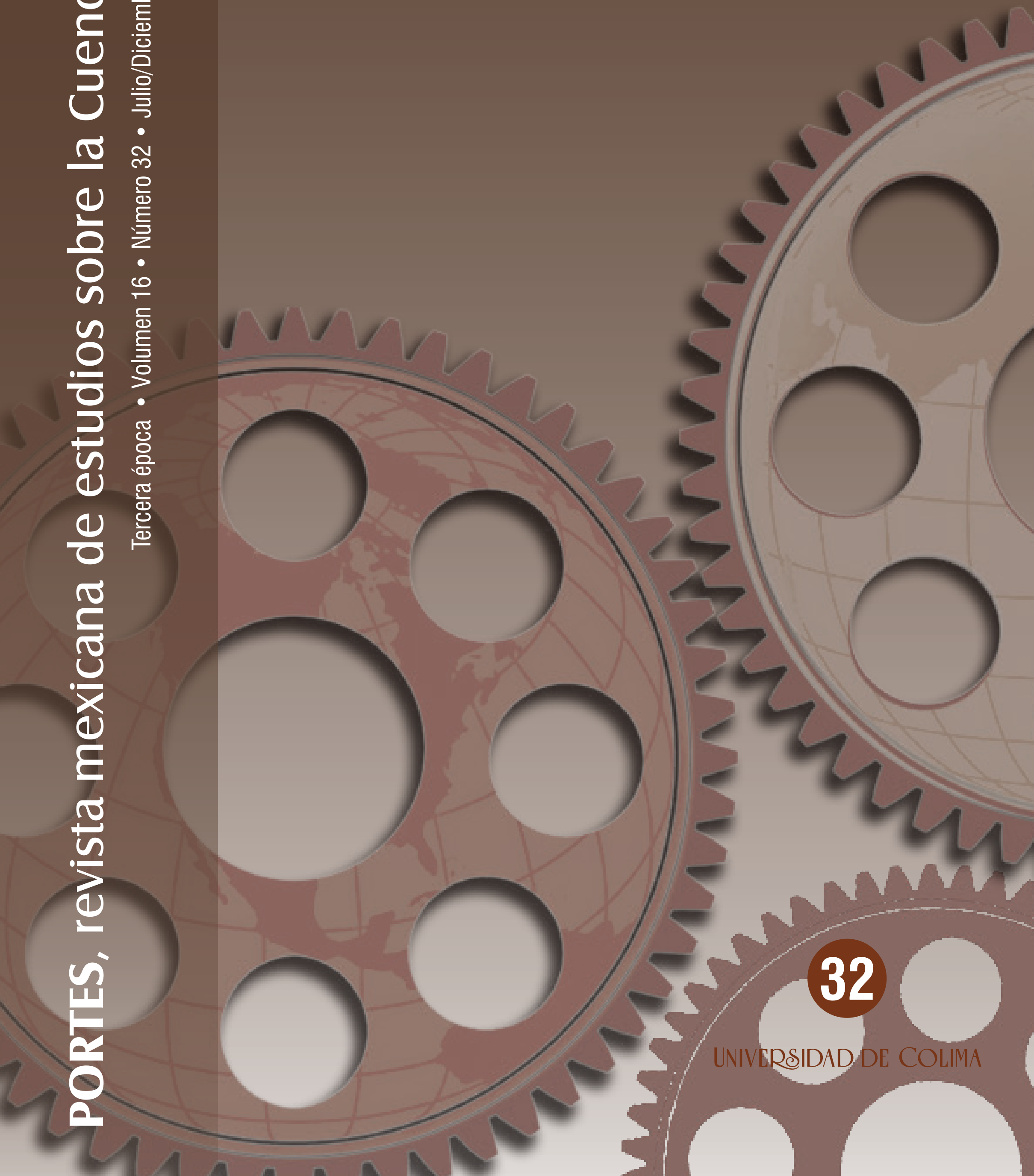

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Universidad de Colima

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Variaciones en un transecto profundo frente a la costa de Nayarit, México

Variations at a deep sea transect off the coast of Nayarit, Mexico

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Abstract

Six oceanographic cruises in a NE-SW transect were made nearshore of southern Sinaloa and Nayarit from March 2006 through May 2008, where no in situ hydrographic data are available. Applying the Thermodynamic Equation of Seawater 2010 (TEOS-10) to the observations, the hydrography and geostrophic currents of the region were characterized. Results indicate that surface variability (0-50 m) emerged mainly from seasonal atmospheric forcing. A relative salinity maximum was

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present during all cruises below this surface layer, which is attributed to a water mass intrusion of Subtropical Subsurface Water that could be associated with the Mexican Coastal Current. Another water mass intrusion is from the California Current. Samples from the 2007-2008 La Niña produced an uncommon circulation, where water flowing from the Gulf of California along the coast of Sinaloa was observed, opposite to what is commonly known as a mean circulation. This uncommon circulation matches the generation of anticyclonic eddies around the Islas Marias archipelago.

Keywords: Gulf of California, Mexican Coastal Current, Nayarit Coast, seasonal variation, La Niña.

Resumen

Se realizaron seis cruceros oceanográficos en un transecto NE-SW cerca de la costa del sur de Sinaloa y Nayarit desde marzo de 2006 hasta mayo de 2008, donde no se dispone de datos hidrográficos *in situ*. Aplicando la Ecuación Termodinámica del Agua de Mar 2010 (TEOS-10) a las observaciones, se caracterizó la hidrografía y las corrientes geostróficas de la región. Los resultados indican que la variabilidad superficial (0–50 m) surgió principalmente del forzamiento atmosférico estacional. Un máximo relativo subsuperficial de salinidad estuvo presente durante todos los cruceros, por debajo de esta capa superficial hay una intrusión de masa de agua subsuperficial subtropical que podría estar asociada a la corriente costera mexicana. Otra intrusión de masa de agua proviene de la corriente de California. Los muestreos durante La Niña 2007–2008 produjeron una circulación poco común, donde se observó agua que fluye desde el golfo de California a lo largo de la costa de Sinaloa, opuesta a lo que comúnmente se conoce como circulación media. Esta circulación poco común coincide con la generación de remolinos anticiclónicos alrededor del archipiélago de las Islas Marías.

Palabras clave: golfo de California, corriente costera mexicana, costa de Nayarit, variación estacional, La Niña.

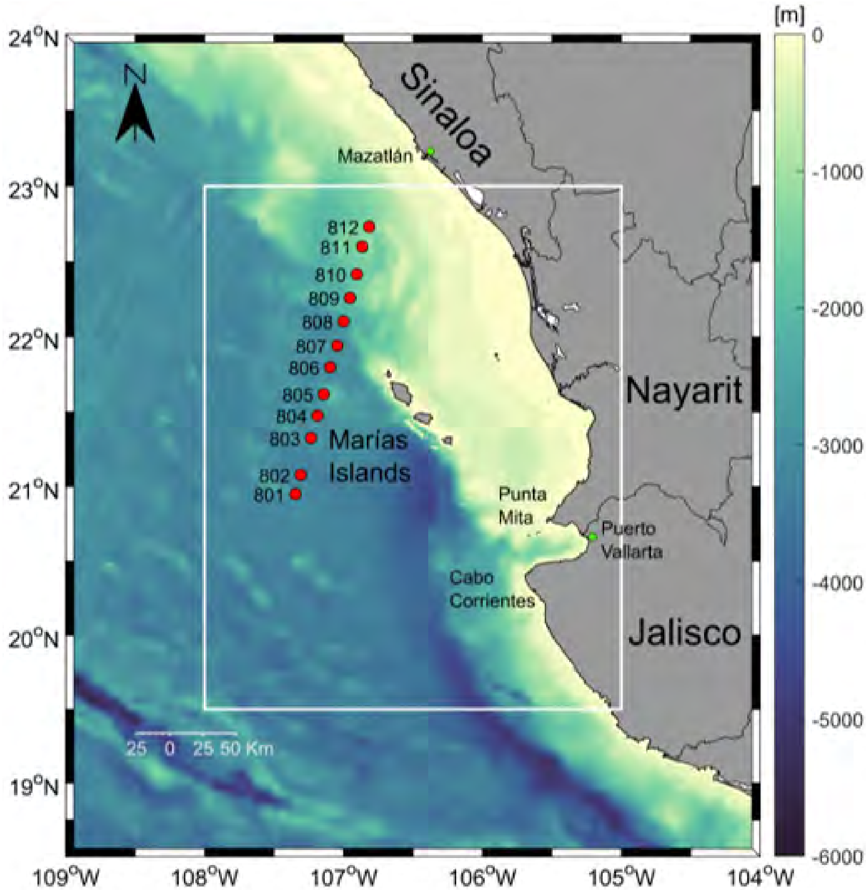
Introduction

Nayarit coastal hydrography at the mouth of the Gulf of California possesses prominent oceanographic features. For instance, different currents, such as the California Current, Gulf of California Current and Mexican Coastal Current converge in this zone. Many cyclonic and anticyclonic eddies are generated in this area and water masses that belong to the California Current, Gulf of California and the Tropical Eastern Pacific intermediate waters merge here, resulting in highly variable seasonal circulation (Fiedler and Talley, 2006; Kessler, 2006; Zamudio *et al.,* 2001; Zamudio *et al.,* 2007 and Pantoja *et al.,* 2012).

In this coastal zone, oceanographic studies with on-site observations are very scarce. This fact and the important dynamics of the region motivated the execution of a series of hydrographic surveys, covering the gaps northward of the summer observations made by Lavín *et al.,* (2006). From these observations, in this paper, we made a detailed description and analysis of hydrography and geostrophic circulation along one transect off the coast of Nayarit and southern Sinaloa. This transect was sampled several times to guarantee sufficient observations to describe the hydrographic cycle on several occasions of the area.

The study area is located offshore of the States of Nayarit and Sinaloa, south of the Gulf of California, extending from 20.5°N to 23°N, from about Puerto Vallarta to Mazatlán (Fig. 1), a brief description of the hydrographic characteristics and circulation are detailed below.

Figure 1. Nayarit coast and study area



Source: self made.

1.1 Hydrography

The water masses present in the area are (following the acronym of the waters masses, the values of the range of conservative temperature, absolute salinity and depth are indicated respectively): California Current Water (CCW; 10–21 °C, <34.6 , 0–150 m); Tropical Surface Water (TSW; >25.1 °C, <34.6 , 0–50 m); Gulf of California Water (GCW; >12 °C, >35.1 ,0–150 m); Subtropical Subsurface Water (StSsW; 9–18 °C, 34.6–35.1,75–400 m) and Pacific Intermediate Water (PIW; 4–9 °C, 34.6-34.9 , 400–1000 m; Portela *et al.,* 2016).

1.2 Circulation

Circulation in the study area has been inferred, based on the few measurements that have been made, in fact, Kessler (2006) indicates that the circulation of the area is an enigma implying the necessity to increase our knowledge about its features. This is one of the reasons why we carried out the present study.

The first reliable maps of the circulation were provided by Wyrtki (1965) from ship drift data, where the author mentions that in winter the main flow of the California Current moves westward away from the entrance of the Gulf of California feeding the nor-equatorial current.

In spring Wyrtki (1965), indicates that the Costa Rica dome generates a northward coastal current, which in the summer reaches the entrance to the Gulf of California, although the evidence is still fragmentary, it is clear that the northward circulation along the Mexican coast occurs in the form of short-range currents and in some cases forced by local winds (Trasviña and Barton, 2008).

During the summer the California Current reaches its highest intensity in June, when the most extensive surface presence is recorded at the entrance of the Gulf of California. In addition, the Eastern Tropical Pacific Ocean warm water pool (ETPOWWP), located in the Gulf of Tehuantepec, from April to June retracts to the south (17° N) following the minimum and maximum intensities of the California Current (Lynn and Simpson, 1987). Then the ETPOWWP during late summer and early autumn, reaches the entrance to the Gulf of California (23° N).

Other studies such as the study performed by Lavín *et al.,* (2006), describe the character of the coastal poleward current in southwestern Mexico during summer. More recent works describe the formation of the dissolved oxygen minimum layer, indicating that around the study area, the layer of minimum dissolved oxygen is shallower, with about 150 m depth (Cepeda-Morales *et al.,* 2013), and a thickness of 1100 m (Fiedler and Talley, 2006). Godinez *et al.,* (2010), using the data set from Lavín *et al.,* (2006), found that the seasonal circulation of the California Current in its equatorial branch can be explained by a long Rossby wave model forced by the annual wind and by radiation from the coast.

Many cyclonic and anticyclonic eddies are generated in this zone, through satellite altimetry data and numerical modeling, they have shown that eddies are generated as the intensified local currents pass cape-like features in the coastline or shelf break geometry. With 750 m depth and a mixed layer of 100 m depth, these eddies can travel up to 1000 km to the open ocean and might last 8 months before vanishing (Zamudio *et al.,* 2007; Kurczyn *et al.,* 2012 and Kurczyn *et al.,* 2013), Martinez-Flores *et al.,* (2011) indicate that these eddies advect nutrients from discharges of the rivers into the Nayarit's coastal area, towards open sea. Numerical simulations of the circulation that were made by Zamudio *et al.,* (2007) showed that Cabo Corrientes-María Island region is characterized by mean poleward coastal currents, driven by local wind forcing and the local currents are intensified by the arrival of baroclinic downwelling coastally trapped waves, generated in the equatorial Pacific, these results were later confirmed by Pantoja *et al.,* (2012).

However, all these studies used data from surrounding areas enhancing the need of using on-site observations of the study area. Therefore, key objectives of this study include improving our knowledge of the Nayarit coastal hydrography through on-site samplings.

Methodology

Samplings were collected as part of an ongoing program between March 2006 and May 2008, consisting of six CTD surveys from a research vessel Don Emilio M. González (see Table 1 for dates and Table 2 for CTD stations coordinates). Hydrographic data was collected with a factory-calibrated CTD (model SBE-911+, Sea-Bird Electronics, Bellevue, WA). The terminology used here for the surveys indicates the year and month; e.g., 0603 is a survey made in March 2006.

Table I. Cruises for this study
(for T-S diagrams all the casts were used)

Cruise	Dates (start / end)	CTD (Casts)
NAY0603	2006-03-11 / 2006-03-17	63
NAY0606	2006-06-04 / 2006-06-11	83
NAY0701	2007-01-18 / 2007-01-25	53
NAY0711	2007-11-07 / 2007-11-16	90
NAY0803	2008-03-08 / 2008-03-12	29
NAY0805	2008-05-09 / 2008-05-12	29

Source: self made.

Objective mapping was used to construct smoothed, regularly spaced grids for density and dynamic height profiles, (, where is the depth increment and is the distance increment). This technique eliminates variability with scales other than of interest (like internal waves variability, and variability that results from noise due to the time needed to complete a survey) and simplifies the calculation and presentation procedures (Roemmich, 1983; Denman and Freeland, 1985), in some cast we reached the 1600 m depth.

As in Portela *et al.,* (2016), temperature and practical salinity (S_p) were converted to Θ (conservative temperature [°C]) and S_A (absolute salinity) according to TEOS-10 (McDougall *et al.,* 2011; McDougall *et al.,* 2012).

Geostrophic currents were calculated from the vertical integration of the thermal wind equation, using the hydrographic field, with the 700 m depth as the reference level.

$$u = -\frac{1}{f\rho}\frac{\partial p}{\partial x} \qquad (1)$$

$$u = -\frac{1}{f\rho}\frac{\partial p}{\partial y} \qquad (2)$$

Table II. Positions of CTD surveys

Station	Latitude (N)/Longitude (W)	Distance between stations (km)	Times the station were sampled
801	20° 57’ 02.3”/ 107° 20’ 49.9”	801-802=14.9	6
802	21° 04’ 40.3”/ 107° 18’ 31.1”	802-803=29.0	6
803	21° 19’ 32.6”/ 107° 14’ 01.4”	803-804=17.8	6
804	21° 28’ 30.1”/ 107° 11’ 10.8”	804-805=17.0	6
805	21° 37’ 04.1”/ 107° 08’ 26.2”	805-806=21.0	6
806	21° 47’ 54.0”/ 107° 05’ 42.9”	805-806=21.0	6
807	21° 56’ 30.7”/ 107° 02’ 40.5”	806-807=17.0	6
808	22° 06’ 11.8”/ 106° 59’ 55.6”	807-808=18.9	4
809	22° 15’ 32.1”/ 106° 57’ 11.0”	808-809=18.0	4
810	22° 24’ 59.4”/ 106° 54’ 16.1”	809-810=18.0	3
811	22° 35’ 59.4”/ 106° 52’ 00.0”	810-811=20.5	4
812	22° 43’ 50.5”/ 106° 48’ 52.9”	811-812=15.5	2

Source: self made.

u and v are the east-west and north-south velocities respectively, ρ is density and f is the Coriolis parameter, where pressure is given by

$$p = p_0 + \int_{-h}^{\zeta} g(\phi, z)\rho(z)\,dz \qquad (3)$$

p_0 is the atmospheric pressure at $z = 0$ and ζ is the sea level height (Gill, 1982).

Results

Hydrography

Temperature

Figures 2 displays the composite plots of conservative temperature, absolute salinity and density for the months of winter (Figs. 2a-c; January 2007, March 2006 and March 2008, respectively; note the depth scale change from 0–200 m and from 200–1400 m, this was made in order to highlight the main seasonal variations in the upper 200 m; red-yellow dashed lines with blue numbers is conservative temperature, only every 4°C are numbered), spring (Fig. 2d; May 2008), summer (Fig. 2e; June 2006), and autumn (Fig. 2f; November 2007).

Below 400 m the water is stratified in quasi-parallel horizontal temperature layers with similar gradients (3 °C <T <10 °C). This pattern is relatively stationary for the individual months. Moving upward from the 400 m-axis temperature and salinity layers of different configurations and at different levels arise. For example, on the surface, a mixed layer is well defined in the first 50 m being most pronounced in January 2007 (Fig. 2a) with temperatures of around 24 °C.

The warmest surface waters were observed in June 2006 (Fig. 2e) and November 2007 (Fig. 2f) reaching 28 °C in a thick layer of ~25 m and of ~40 m, respectively. Although temperature gradient differs in all cases from the surface to a deep of 400 m displaying an increase in variability relative to deeper layers, it is in the first 100 m that temperatures show a strong gradient. At ~100 m temperatures decrease to 14 °C in all months. Between 100 m and 400 m, temperature gradient changes in a smoother way than it does in the first 100 m but some distinct characteristic can be observed at these depths.

For example, in June 2006 (Fig. 2e), the 14 °C isotherm fluctuates in a layer from 80 m to 60 m being deeper at stations 804, 805 and 809 and shallower at stations 802, 806 and 807. In November 2007 (Fig. 2f) the 12 °C and 26 °C, isotherms enclose a layer of water that is slightly higher by 30 m near the coast than in the open sea.

Salinity

Salinity (Absolute Salinity S_A is implied in all cases) had high seasonal variability in the upper 100 m in all months (Fig 2a-f; color contour with white numbers is absolute salinity). In the upper 80 m salinity changes from 34.3 January 2007 (Fig. 2a) to 34.7 in November 2007 (Fig. 2f), to >35 in June 2006 (Fig. 2e).

Below 400 m, salinity remains unchanged at 34.7 during the year. At a salt front observed in March 2008 (Fig. 2c) between stations 808 and 809, salinity decreased rapidly from 35.1 to 34.7 in a short distance (~18km) at 20 m – 60 m. The most distinct characteristic of salinity is a subsurface water layer of ~34.7 centered at 100 m – 200 m that was present in all the months.

Density (Sigma-t, σt)

In general, density (Fig. 2; black numbers and solid lines, only pair values density are numbered) indicates a stable water column. At the surface it was 24 kg m^{-3} in March 2006 (Fig. 2b), 22 kg m^{-3} in November 2007 (Fig. 2f) and 25 kg m^{-3} in March 2008 (Fig. 2c). Below 600 m, density reached values > 28 kg m^{-3} in all months. At higher depths, density shows no significant changes. In January 2007 (Fig. 2a), density was 23 kg m^{-3} at the surface between stations 802 and 801 while the 24 kg m^{-3}, 25 kg m^{-3} and 26 kg m^{-3} isopycnals were about 40 m lower than in March 2006 and March 2008 (Figs. 2b and 2c, respectively).

In general hydrographic data reveal a recurrent structure in all surveys, that is, a relative maximum subsurface salinity of 34.7 between 100 and 250 m; a stationary pattern below 400 m, with almost no changes in hydrography and highly variable conditions at the first 100 m, indicating that this surface layer is affected by seasonal and atmospheric variations.

Figure 2ab

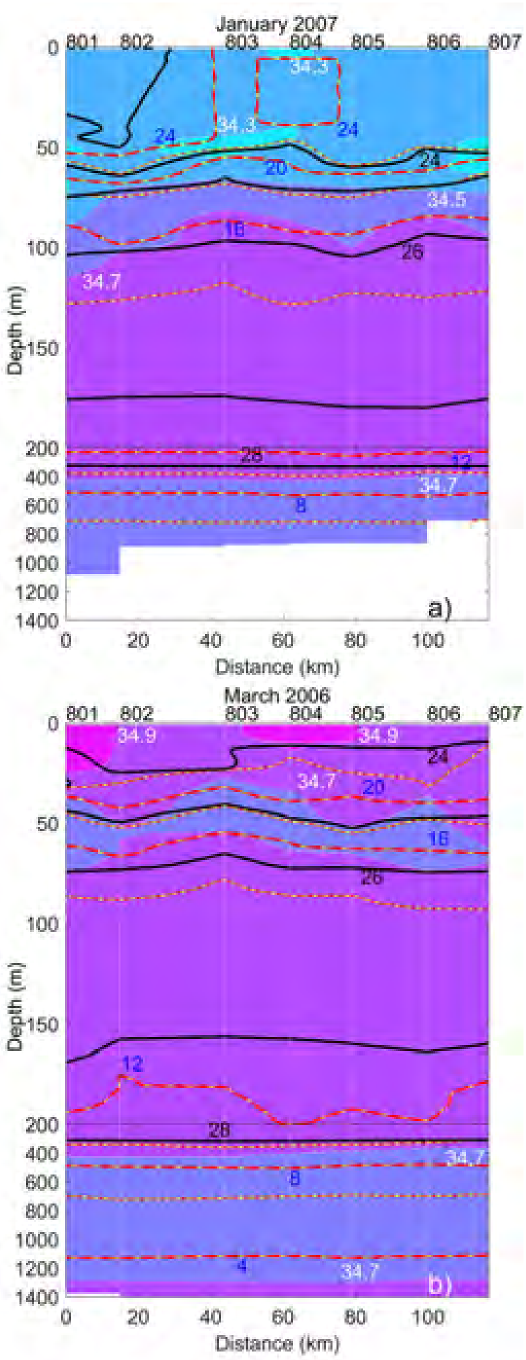

January 2007
801
802
803
804
805
806
807
Depth (m)
Distance (km)
a)
March 2006
b)

Figure 2cd

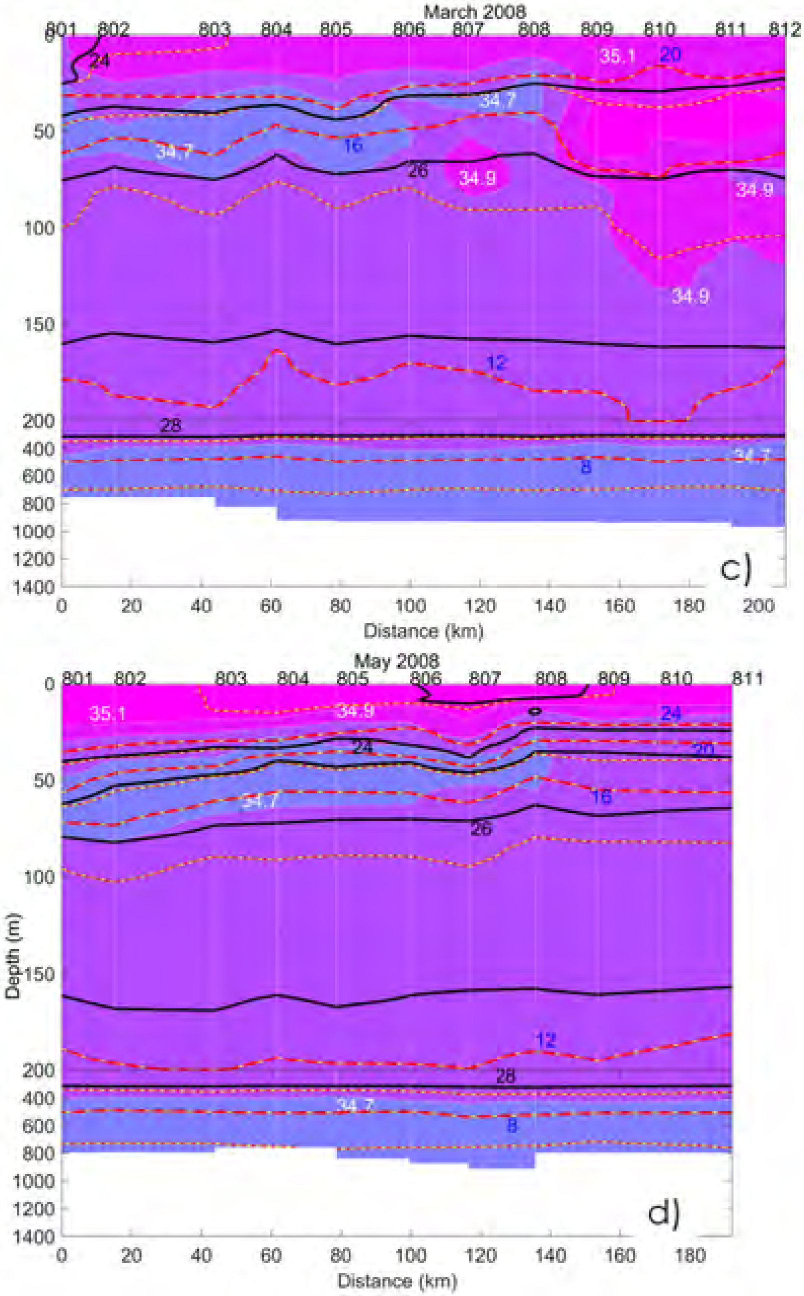
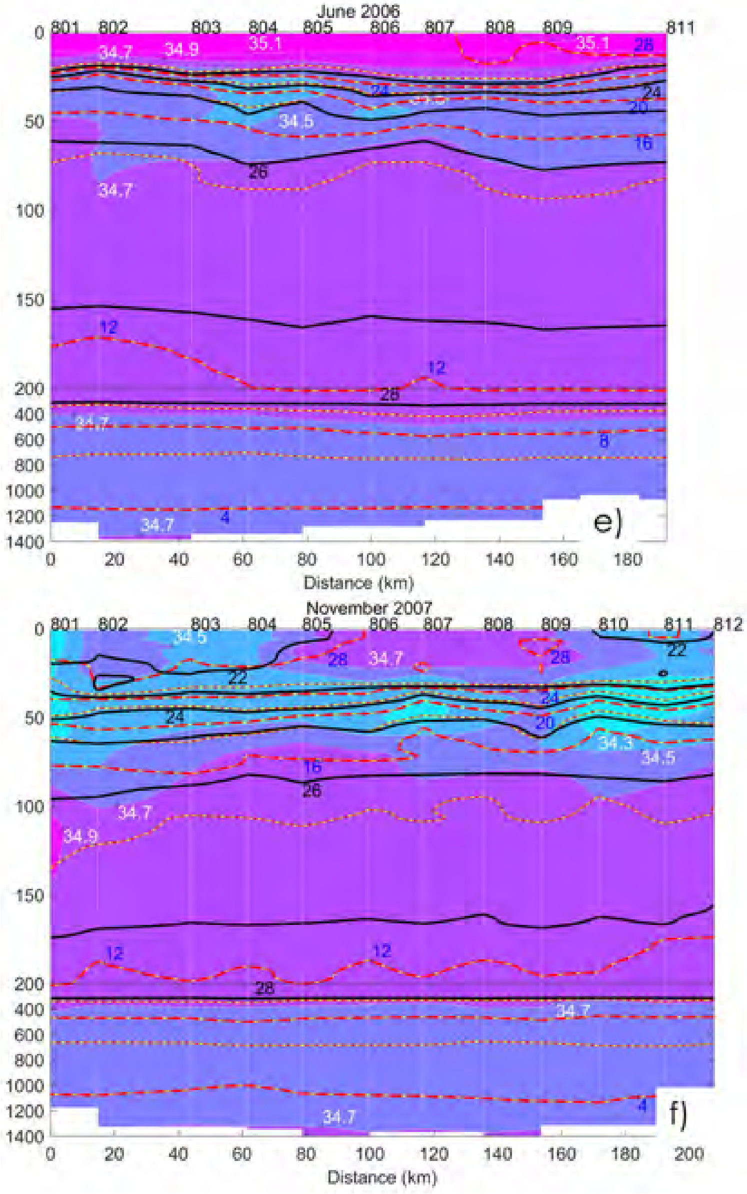

March 2008
801 802 803 804 805 806 807 808 809 810 811 812
Distance (km)
c)
May 2008
801 802 803 804 805 806 807 808 809 810 811
Depth (m)
Distance (km)
d)

Figure 2ef



Source: self made.
Temperature (red-yellow dashed lines with blue numbers; every 4° multiples are numbered), salinity (color scale with white dotted lines), and density (black solid lines with black numbers; only pair values are numbered) occurring in: (a) January 2007; (b) March 2006; (c) March 2008; (d) May 2008; (e) June 2006; and (f) November 2007. Note the change in vertical scale between 0–200 and 200–1400 m.

Conservative temperature-Absolute salinity (T-S) diagrams

The T-S diagrams for the months of winter (Figs. 3a-c; January 2007, March 2006, March 2008), spring (Fig. 3d; May 2008), summer (Fig. 3e; June 2006), and autumn (Fig. 3f; November 2007, color bar indicates the depth of the sample) show that Subtropical Surface Water Mass (StSsW; Fiedler and Taller, 2006) is present in all surveys.

Below the surface layer, the maximum subsurface salinity was ~34.8 g kg^{-1}, typical of the water body designated as 13CW by Wijffels *et al.,* (1996), which was described initially by Montogomery and Stroup (1962). It is clearly distinguishable as equatorial water of 13 °C or Subtropical Subsurface Water Mass in figure 3a-f.

This water interacts with water from the California Current and is affected by local seasonal conditions resulting in high variability in the first 150 m. The water from the California Current is more abundant in January (Fig. 3a) and November 2007 (Fig. 3f).

Deeper in the water column (600 m –1000 m), North Pacific Intermediate Water is located as a tongue of water mass of lower salinity and cold waters clearly seen in all months (Fig. 3a-f). Intrusions of water from the Gulf of California (>35.1, >12 °C) can be distinguished at the stations nearest to the coast in March 2008 (Fig. 3c), May 2008 (Fig. 3d), and June 2006 (Fig. 3e) while tropical surface water is present in all months.

Geostrophy

To compare geostrophic conditions between all months (Fig. 4), calculations were performed only with data from stations 801–807 and within the water column between the surface and 700 m, where water has virtually no motion.

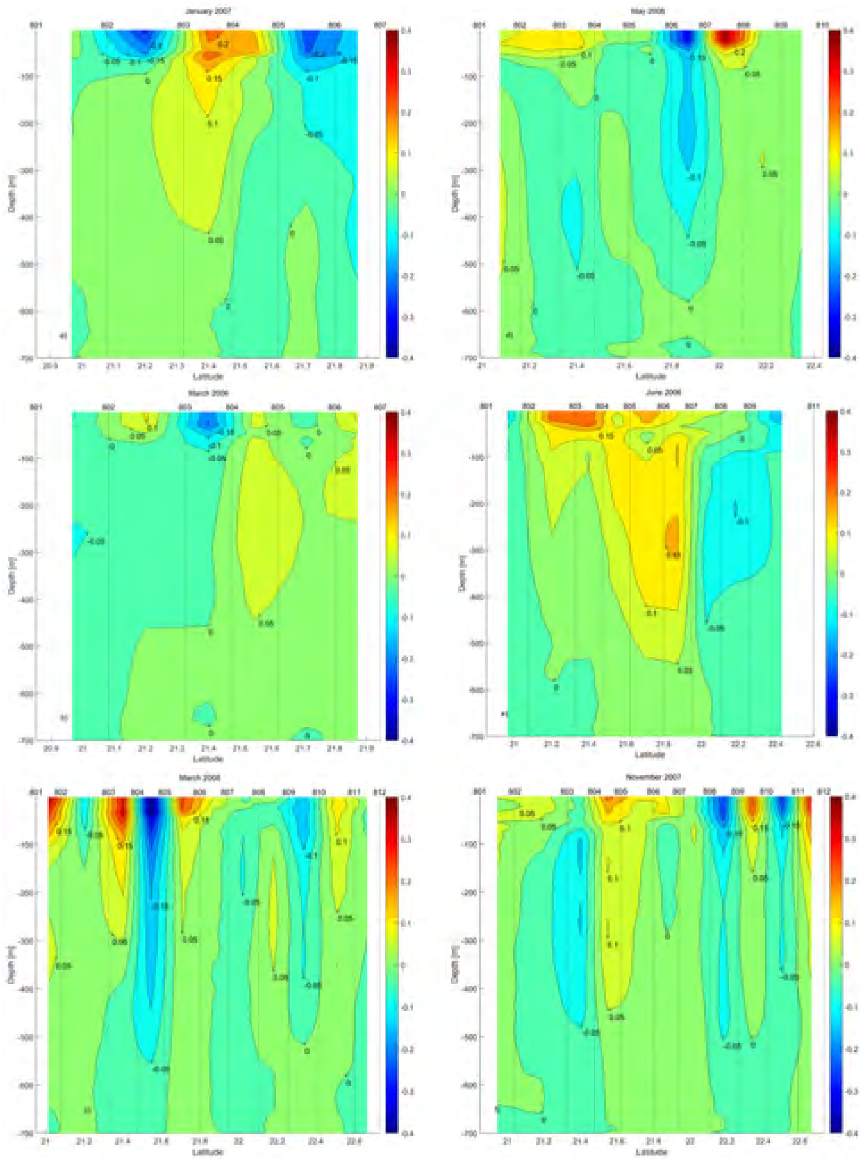
In January 2007 (Fig. 4a), a core of a northwestward flow was located between stations 803 and 804 with a maximum velocity of 0.2 m s^{-1} at the surface and minimum velocity of 0.05 m s^{-1} near 400 m. Adjacent to each side of this flow, there were two southeastward surface flows up to 70 m with maximum flow of 0.2 m s^{-1} each. In March 2006 (Fig. 4b), the arrangement of flows relative to the flows observed in January 2007 reversed in such a way that a southeastward flow know was located between stations 803 and 804 from the surface up to 70 m, and with maximum flow of 0.2 m s^{-1}.

Adjacent to each side of this flow were observed two northwestward flows, one of them of 0.1 m s^{-1} between stations 802 and 803, and the other at stations 804 and 805, reaching deeper in the water column, down to 500 m, also of 0.1 m s^{-1}. This last northwestward flow occurred in water with a maximum subsurface salinity of 34.8 that is the trademark of the Subtropical Subsurface Water.

In March 2008 (Fig. 4c), the arrangement of flows changed significantly relative to previous cruises. In this case, depending on the position of the water body a given flow was part of a northwestward stream (between stations 801–802, 803–804, 805–807, and 810–811) or a southeastward stream (between stations 802–803, 804–805, and 809–810). The weakest of these flows were observed at stations 810–811 (northwestward), and 802–803 and 809–810 (southeastward); which had each a current of 0.1 m s^{-1}.

All the streams were shallow (~0–100 m), except the northwestward flow between stations 803–804, which reached 0.05 m s^{-1} at 300 m. This flow was accompanied by a southeastward flow between stations 804–805 with a velocity of 0.4 m s^{-1} at 50 m. Apparently these two streams were part of an eddy between stations 803–805. In May 2008 (Fig. 4d) two shallow northwestward flows at 0–70 m were observed; one between stations 802–803 and another between stations 807–808. The latter was stronger, with velocities >0.3 m s^{-1}. A deeper, southeastward flow at 70–400 m, between stations 806–807, with a maximum speed of 0.2 m s^{-1} also was present.

Figure 3. Geostrophic current for: (a) January 2007; (b) March 2006; (c) March 2008; (d) May 2008; (e) June 2006; (f) and November 2007.

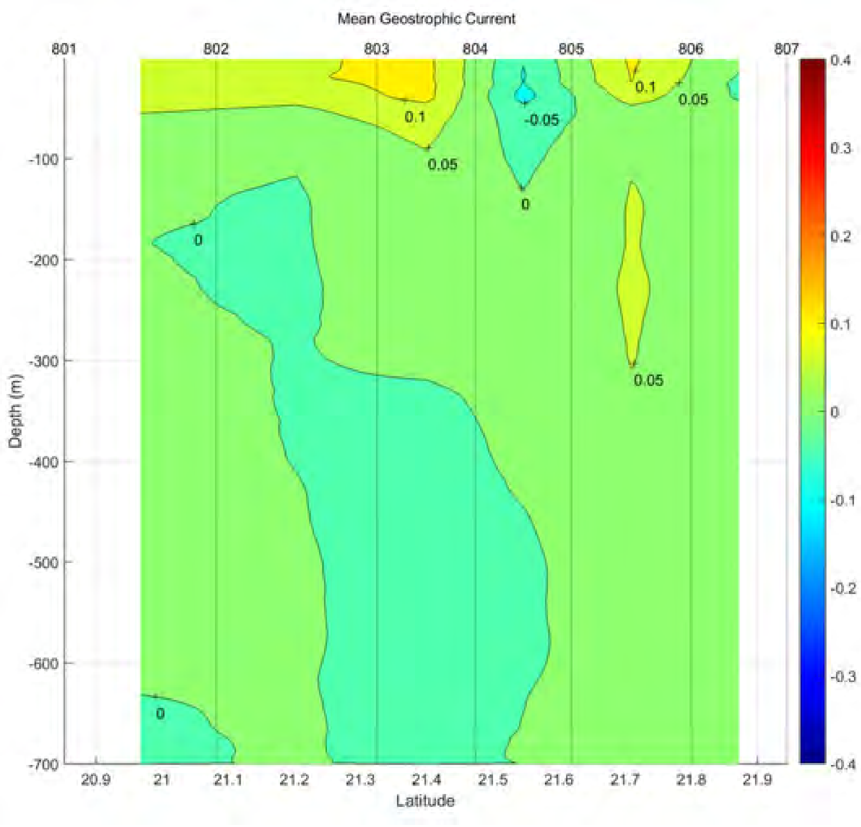


Source: self made.

In June 2006 (Fig. 4e), a northwestward flow was present from stations 802 through 807, reaching a maximum of 0.2 m s^{-1} at depths up to 500 m at station 803. From stations 807–811, a southeastward flow at 0.1 m s^{-1} reached a depth of 400 m. Geostrophic currents, based on data from the November 2007 cruise (Fig. 4f), showed four northwestward flows, interspersed with three southeastward flows; all flows reaching a depth of 500 m. Southeastward flows were located between stations 803–804, 808–809, and 810–811; northwestward flows were located between stations 801–803, 804–807, 809–810, and 811–812.

Geostrophic currents (Fig. 5) had a mean northwestward flow (0.1 m s^{-1}) between stations 805–806 from 100 to 350 m that is associated with the relative subsurface maximum salinity of 34.8 and a water mass at 13 °C, known as the Subtropical Subsurface Water. A hefty northwestward flow (0.1 m s^{-1}) in the first 50 m was present at stations 803–804.

Figure 4. Mean geostrophic current for all cruises



Source: self made.

Discussion

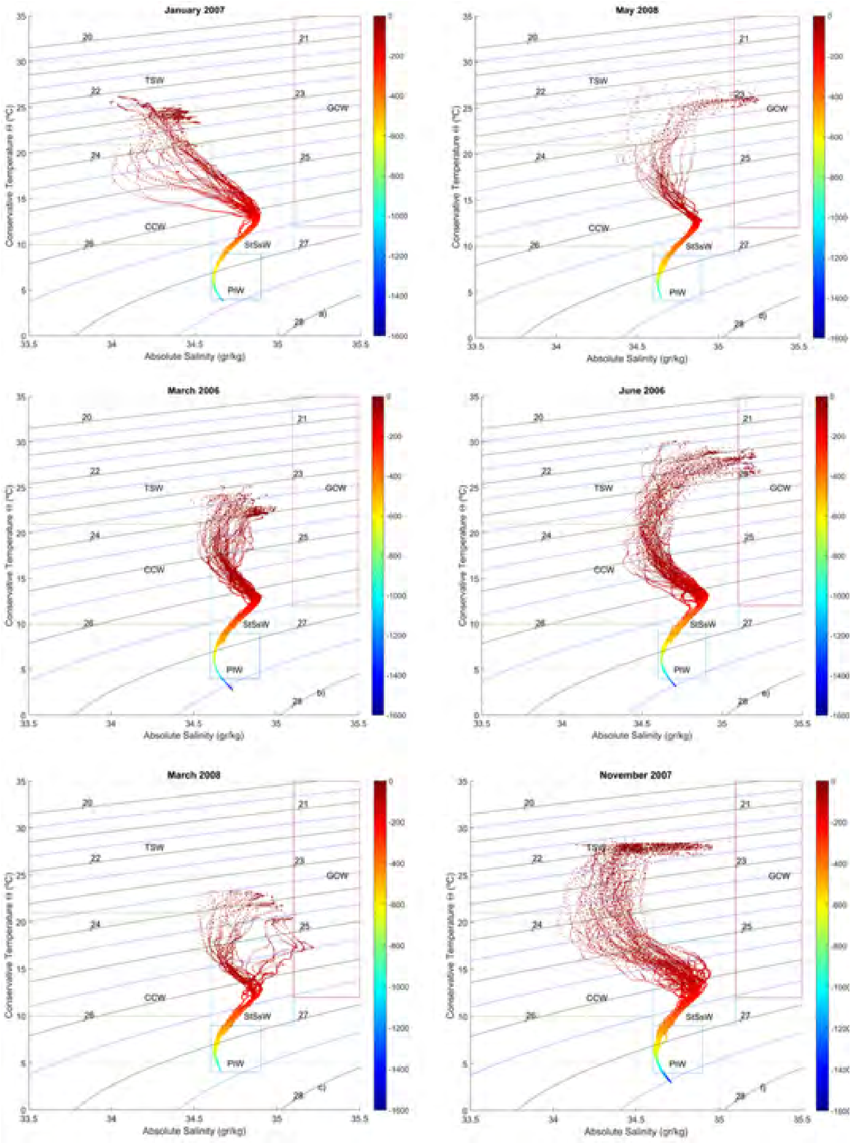
The oceanographic studies along the coast of Nayarit, Mexico are few. It is known that in this region several currents converge, such as the California Current, the Gulf of California Current, and the Mexican Coastal Current, resulting in highly variable seasonal circulation (Fiedler and Talley, 2006; Kessler, 2006; Zamudio *et al.,* 2001, Zamudio *et al.,* 2007 and Pantoja *et al.,* 2012). Since on-site measurements in this area are practically nil, this study is the first attempt to make a detailed description and analysis of hydrography and geostrophic circulation of the area.

A NE-SW transect nearshore of southern Sinaloa and farther away from the coast of Nayarit was sampled several times to have sufficient observations to achieve this goal. Our results indicate that seasonal changes and subsequent increase of internal variability were observed primarily in the first 150 m, while certain structures were present during all seasons below 150 m. Right away, we address the causes of the changes and their links with water masses and currents that are present in the area.

Water masses

Our measurements indicate that at the thermocline depth of 50–150 m, a thin layer of low salinity (34.1–34.3) was present during all seasons (Fig. 3a-f). This water mass is associated with intrusions of California Current Water (salinity of <34.6, 10–21 °C; Portela *et al.,* 2016), confirming the results of Cepeda-Morales *et al.,* (2013), who used data around the study area.

Figure 5. T-S diagram for: (a) January 2007; (b) March 2006; (c) March 2008; (d) May 2008; (e) June 2006; and (f) November 2007. PSW = North Pacific Intermediate Waters; StSsW = Subtropical Subsurface Waters; CCW = California Current Waters; TSW = Tropical Surface Waters; and GCW = Gulf of California Waters.



Source: self made.

At depths between 100 and 300 m, a mid-depth water layer with a relatively high salinity was present during all surveys (Fig. 3; 34.6–35.1 salinity and 9–18 °C temperature). This water is known as the Subtropical Subsurface Water (Portela *et al.,* 2016), which was previously characterized by Wijffels *et al.,* (1996) as 13 °C water. Unlike Portela *et al.,* (2016), Wyrtki (1967) states that this water mass is South Pacific Subtropical Subsurface Water, although Tsuchiya (1968) described it as originating in the Western South Pacific. Sloyan *et al.,* (2003) discovered that this water is transported north of the Equator by the Subsurface Counter Current and was present in all surveys. It was identified as part of the Mexican Coastal Current, first suggested by Wyrtki (1965, 1967).

More recently, it was identified as a part of the circulation in the eastern tropical Pacific Ocean in several papers (Kessler 2006; Lavin *et al.,* 2006; Godínez *et al.,* 2010; Pantoja *et al.,* 2012 and Cepeda-Morales *et al.,* 2013). However, it is necessary to indicate that in these studies, the presence of the Mexican Coastal Current had been postulated from modeling simulations (Pantoja *et al.,* 2012) or from observations outside of the study area in summer (Lavin *et al.,* 2006; Godinez *et al.,* 2010 and Cepeda-Morales *et al.,* 2013). For instance, Cepeda-Morales *et al.,* (2013) indicated that the Mexican Coastal Current has low dissolved oxygen intrusions in the study area and is associated with advection into this area of Subtropical Subsurface Water. Lavin *et al.,* (2006), from samplings made southward of the study area, indicated that this current has the following characteristics: speed of 0.15 to 0.35 m s^{-1}, width of 90 to 180 km, and moving at 400 m below the surface.

Our study showed that the Subtropical Subsurface Water is present all year at a depth of 150–400 m, with speeds of 0.05–0.10 m s^{-1} and is associated with the Mexican Coastal Current, supporting the findings of Godinez *et al.,* (2010). These authors mention that the mean circulation in the study area is affected by a cyclonic circulation near Cabo Corrientes, which in turn is explained by the Sverdrup balance, resulting from the wind stress at the surface of the open ocean and the vertically integrated transport of ocean water. This water enters the Gulf of California, which is an evaporative environment that changes its properties and becomes the water of the Gulf of California (Bray 1988b and Torres-Orozco 1993).

Our measurements also indicate that the North Pacific Intermediate Water at 34.6–34.9 salinity and 4–9 °C is found at 500 to 1200 m-layer (Portela *et al.,* 2016). This layer displayed relatively stationary patterns of temperature, salinity and density in all the individual months (Fig. 2). Fiedler and Taller (2006) state that this water mass has a relative minimum salinity centered at 900 m and its temperature and salinity characteristics are from the North Pacific Ocean. The Pacific Deep Water also appears in the cruises, with temperature ~4 °C and increased salinity to 34.6 near the bottom Fiedler and Taller (2006).

Generally, surface characteristics of the water column indicate that they are mainly a response of seasonal forcing, from heating in the summer to cool in the winter. However, some observed patterns do not necessarily result from seasonal variations. In March 2008, a haline front was present at 50 m (Fig. 2c) with a salinity gradient of 0.3 between stations 808–809. Apparently, there is an anticyclonic eddy in this layer resulting from a northwestward flow oriented to the Gulf of California (between stations 809 and 811), and parallel to this movement a southeastward flow at the coast side (between stations 809 and 810), with relative high-salinity water (35 g kg^{-1}) at 18 °C, characteristic of the Gulf of California Water (Fig. 3c). In fact, only on this cruise was this water detected, moving near the coast of Sinaloa (Fig. 4c). Several authors (Zamudio *et al.,*; Cepeda-Morales *et al.,* 2013; Godinez *et al.,* 2010; Martínez-Flores, Nava-Sánchez and Zaitzev, 2011; Kurczyn *et al.,* 2012; Kurczyn *et al.,* 2013 and Pantoja *et al.,* 2012) have shown that this area generates cyclonic and anticyclonic eddies that are an important component of the dynamics of the area.

2007–2008 La Niña

In March 2008, a moderately cold episode of La Niña took place during 2007–2008. Samplings indicate Gulf of California Water (salinity >35.1, T >12 °C) near the coast of Nayarit and Sinaloa flowing from the Gulf of California, although several studies report that the output of this type of water occurs on the peninsular side of the Gulf of California (Roden, 1964; Bray, 1988a; Ripa and Marinone, 1989; Castro *et al.,* 2000 and Mascarenhas *et al.,* 2003). Pantoja *et al.,* (2012), state that the pressure and intrusion of water from the Gulf of California off the coast of Sinaloa occur during the generation of an anticyclonic eddy at the mouth of the

Gulf of California and that this is an unusual event. Zamudio *et al.,* (2007) state that pulses of trapped coastal waves generate the formation of eddies. From our results and extrapolating the results of Zamudio *et al.,* (2001), we hypothesize that La Niña produces a trapped coastal wave that propagates northward, as it passes off the coast of Jalisco, Nayarit, and Sinaloa and generates an anticyclonic eddy in the Islas Marías Archipelago.

Conclusions

Hydrographic data from an oblique direction transect from the Sinaloa seashore are described for an area where available information and measurements are scarce and out-of-date. The seasonal features of hydrography and circulation are defined through a set of data of in-place observations. Previously, the hydrography of this regions was originally described by Kessler (2006) but without these kinds of observations.

In general, hydrographic data reveal a recurrent structure in all surveys, that is, a relative maximum subsurface salinity of 34.7 between 100 and 250 m; a stationary pattern below 400 m, with almost no changes in hydrography and highly variable surface conditions at the first 100 m, indicating that this surface layer is affected by seasonal and atmospheric variations.. Below this layer, a subsurface, relatively salinity maximum associated with the Subtropical Subsurface Water Mass that could be related with the Mexican Coastal Current is present. This salinity maximum had only been directly observed in the summers of 2003 and 2005, although our results indicate that it was present during all cruises and is a permanent structure in the area, as it is an intrusion of the California Current and the Gulf of California waters. Apparently, the 2007–2008 La Niña generated a unique circulation pattern, where water of the Gulf of California was observed coming out and flowed along the Sinaloa coast, a result that was suggested when an anticyclonic eddy is generated near the Islas Marias.

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