Physical aspects of seawater between Providence and Cayo Bajo Nuevo Islands during the rainy season of 2016

Aspectos físicos del agua de mar entre las islas de Providencia y Cayo Bajo Nuevo durante la época de lluvias de 2016

DOI: 10.26640/22159045.428 **Reception date:** 2017-02-10 **/ Acceptance date:** 2017-05-03

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Monroy Silvera, J. & Zambrano, A. (2017). *Physical aspects of seawater between Providence and Cayo Bajo Nuevo Islands during the rainy season of 2016.* Bol. Cient. CIOH (35):3-12. ISSN 0120-0542 and ISSN online 2215-9045. DOI: 10.26640/22159045.428

ABSTRACT

The most important physical parameters of seawater are presented for an area within the San Andres and Providencia archipelago, between Providencia Island and Cayo Bajo Nuevo island, Colombia. Seven oceanographic stations were sampled from September 19th through September 21st, 2016, collecting CTD data up to a maximum depth of 1000 meters. With the collected data, temperature, salinity and density profiles were obtained, as well as the vertical distribution for the same variables along the entire transect. A general description of this parameters was made, identifying high salinity values greater than 37 in all stations up to a maximum of 37.11, for the North Atlantic subtropical underwater water mass (NASTU) at a depth of 150 m approximately, an elevated value for the Western Caribbean Sea that apparently has been present in the last decade.

KEYWORDS: San Andres, Providencia, Bajo Nuevo, Caribbean Sea, Physical Oceanography.

RESUMEN

Son presentados los parámetros físicos más relevantes del agua de mar en un área del archipiélago de San Andrés y Providencia, entre la isla de Providencia y la isla Cayo Bajo Nuevo, Colombia. Se llevaron a cabo siete estaciones oceanográficas entre el 19 y 21 de septiembre de 2016, recolectando información de CTD hasta una profundidad máxima de 1.000 metros. Con esta información se obtuvieron los perfiles de temperatura, salinidad y densidad, así como la distribución vertical de las mismas variables a lo largo de todo el transecto. Se realizó una descripción general de estos parámetros, identificando unos altos valores de salinidad superiores a 37 en todas las estaciones hasta un máximo de 37.11 para la masa de agua subsuperficial subtropical del Atlántico Norte (NASTU) a 150 metros de profundidad aproximadamente y, un valor de salinidad elevado para el mar Caribe Occidental que aparentemente se ha mantenido en la última década.

PALABRAS CLAVE: *San Andrés, Providencia, Bajo Nuevo, Mar Caribe, Oceanografía Física.*

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Introduction

In recent years, the study in detail of the Archipelago of San Andrés and Providencia, including the smaller islands and keys, has been of great national interest. A current example of this is the fulfillment of the National Nautical Cartography Plan of the General Maritime Directorate, which is being updated in 2016 with the use of modern multibeam echo sounders aboard the oceanographic vessels ARC Malpelo and ARC Providencia, complemented by bathymetric surveys of shallow water with single beam echo sounders, obtaining a complete knowledge of the geomorphology of the seabed and generating better quality nautical charts for the safety of human life in the sea near this territory. In addition to nautical cartography, the oceanographic characterization of the Archipelago of San Andrés and Providencia plays an important role in the deepening the knowledge of our maritime spaces.

The inter-institutional activity in Colombia has allowed the development of research and management in the Archipelago based on its insular particularity, facilitating the progress of its management, always oriented toward the preservation of this important area for the world (Colombian Commission of the Ocean, 2015).

The state of the art regarding the description of the physical aspects of the sea in the study area is mainly made up of the research published by González (1987), Garay *et al.,* (1988); Andrade, Giraldo & Lonin (1996), Andrade & Barton (2000), Andrade (2001), Molares, Vanegas, Bustamante & Andrade (2004) & Andrade (2009), in addition to other national and international publications; and although some do not exclusively describe the area of the Archipelago of San Andrés and Providencia, they make reference to their participation in the oceanographic dynamics of the western Caribbean Sea.

The insular platform of the Archipelago of San Andrés and Providencia is the geological and geomorphological continuation of the great Central American continental shelf, but it is not part of it (Molares *et al.,* 2004). The islands, banks and keys that make up the archipelago and the Central American elevation, close the so-called "Colombia basin", separating it from the Cayman Sea (Andrade, 2009).

Due to the nature of its oceanic parameters, the waters of the San Andrés and Providencia archipelago are classified as those of a stratified warm sea, poor in nutrients, with varied phytoplankton, but with low biomass (Márquez, 1987). The stratification has favored a stable pelagic ecosystem of low fertility, although with local alterations due to the presence of eddies (Andrade *et al.,* 1996).

Studies suggest that oceanography research in the area of the San Andrés Archipelago is still scarce and it is necessary to strengthen oceanographic research programs and allow the development of phases in addition to those already underway, ensuring their continuity with the purpose of generating complete information about the marine processes in the different areas of the Archipelago (CCO, 2015).

Also due to its high importance, the area of the Archipelago of San Andrés and Providencia is currently a great source of knowledge for the marine scientific research institutions of Colombia; as well as for the Colombian Maritime Authority, where great efforts have been undertaken in recent years such as the "Seaflower" scientific expeditions led by the Colombian Ocean Commission. This research seeks to continue contributing to this knowledge, taking advantage of the resources available during the campaigns carried out by the oceanographic vessels of the DIMAR in the Archipelago.

Study area

The study area is located within the Archipelago of San Andres and Providencia, a group of islands that are part of the Northwest of the Colombian Basin in the Caribbean Sea, occupying an approximate area of 180 000 km^2.

The area of interest (Figure 1) was established between island of the Providencia located 60 nautical miles north of San Andres Island and Bajo Nuevo Cay Island, at the north-eastern end of the archipelago, to the south of Pedro Bank (Jamaica).

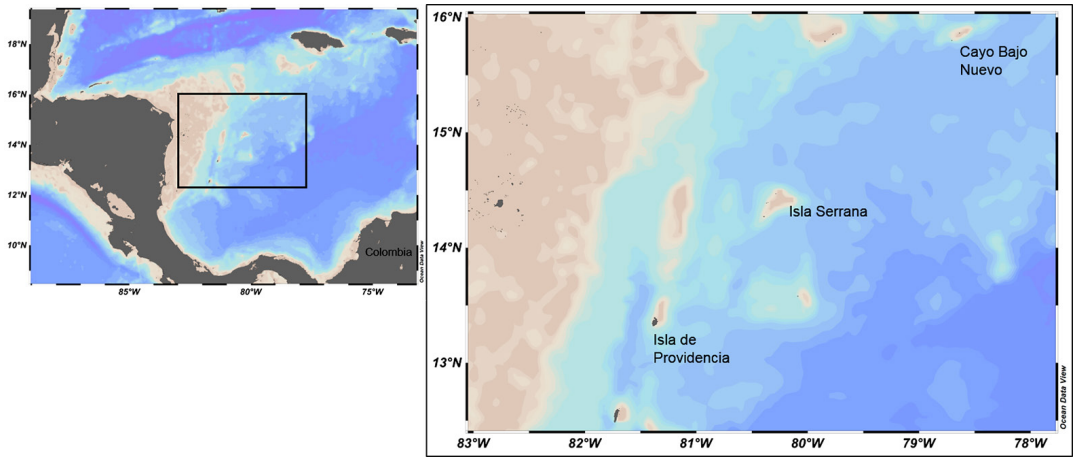

Figure 1. Study Area.

The characteristics of all the archipelago's platforms are similar: a strong slope that emerges from average depths of 1500 meters, reefs and coral sands (DAINCO, 1980). Andrade *et al.,* (1996) describe the islands, keys and banks as having volcanic origin and conformation. The insular platform is independent of the Central American continental shelf, separated from it with depths of up to 2400 m in the Providencia depression, which is why this whole complex of islands is considered oceanic.

For the area of the San Andrés and Providencia archipelago, in previous works (González, 1987, Garay *et al.,* 1988, Andrade *et al.,* 1996, Molares *et al.,* 2004) it has been possible to establish the presence of four bodies of water (Figure 2); the first superficial (Caribbean Surface Water - CSW) up to 50 m deep; the second with characteristics of subtropical subsurface water (North Atlantic Subtropical Underwater - NASTU) between 50 and 200 m; an intermediate Antarctic water body (Antartic Intermidiate Water - AIW) between 200 and 1000 m and finally, deep Atlantic waters (North Atlantic Deep Water - NADW) below 1000 m in depth.

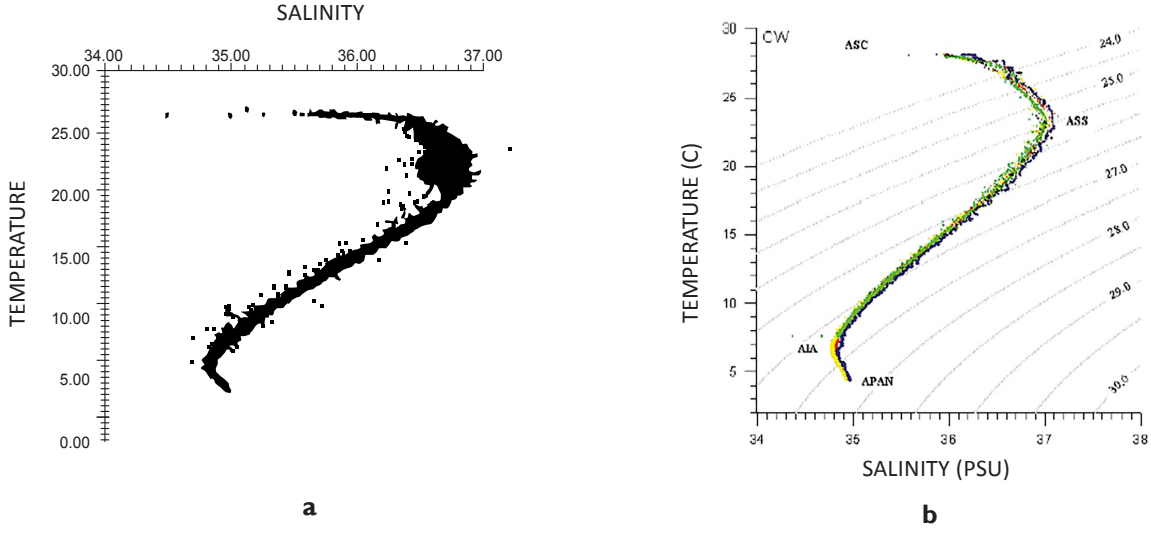

Figure 2. Characteristic T-S curves for the study area: a) T-S curve for the Bajo Alicia area in February 1996 (Andrade *et al.,* 1996). b) T-S curve for the area of the Providencia Depression for May-June 2004 (Molares *et al.,* 2004).

Methodology

The SAI-II cruise was carried out onboard the oceanographic vessel ARC Malpelo, from September 15, 2016, whose main mission was to carry out the bathymetric survey of the Bajo Nuevo Cay island and Providencia island, in the Archipelago of San Andres and Providencia. During the route taken by the oceanographic platform, seven CTD stations were defined with a separation of 30 nautical miles (56 km) between them (Figure 3).

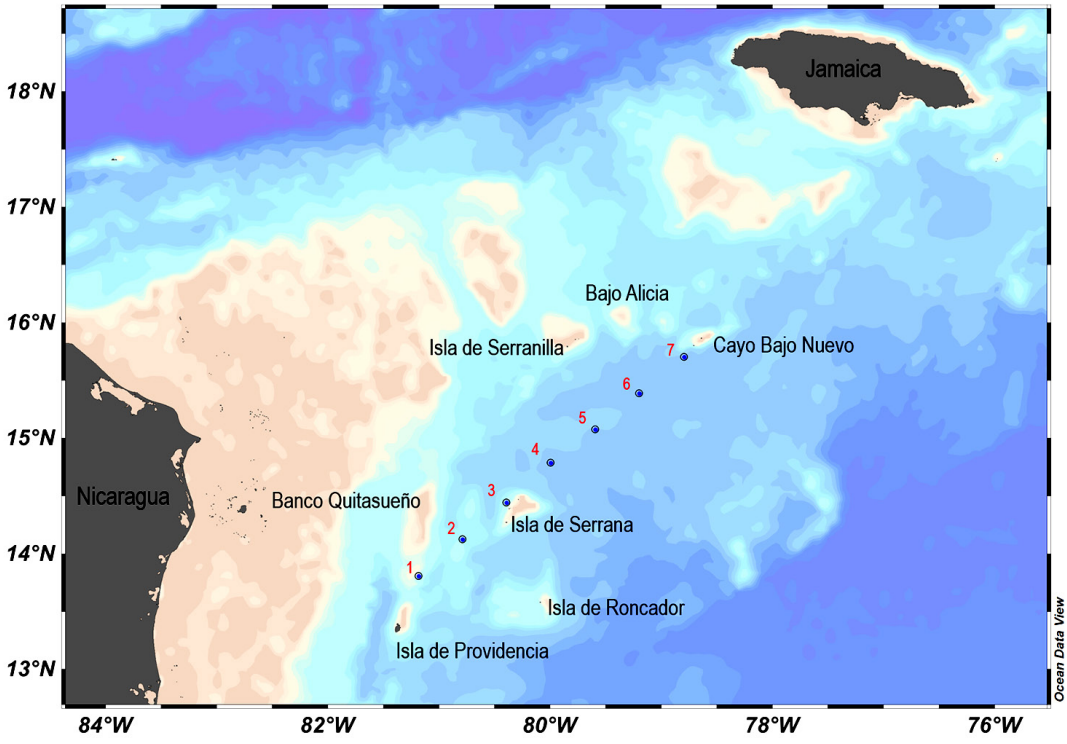

Figure 3. CTD stations in the study area.

These stations were established in an equidistant way and sufficiently separated to observe any change in the physical variables measured, allowing various characteristics of seawater in the area to be identified.

An SVP/CTD Valeport Midas SVX2 was used to collect data together with the deck equipment of the ARC Malpelo research platform. The maximum sampling depth was 1000 meters. The profiles and transects graphs were obtained using the Ocean Data View software.

Likewise, the meteorological conditions and sea conditions at each station were recorded using a Kestrel 5500 weather station and observations on the deck.

Results

The meteorological parameters taken into account during the data collection in each season correspond to the characteristics of the main wet season (September - November) for the Colombian basin (Bernal, 2010). The average of the air temperature between September 19 and 21, 2016, was 28.8°C and the observed atmospheric pressure was between 1009 to 1012 millibars (Table 1). The stations were created in ascending order starting from the North of the island of Providencia (Station 1) up to the surrounding area of the Bajo Nuevo Cay island (Estation 7).

Table 1. General data of oceanographic stations.

Estation number	Depth (m)	Depth profiles (db)	Sea state	Wind		Wavs			Atmospheric time		
				DIR (°)	VEL (knt)	DIR (°)	ALT (m)	T (s)	TEMP (°C)	HUM. R (%)	P. ATM (mbar)
1	720	400	1	090	10.4	230	0.5	4	29	79	1011
2	1098	1000	1	077	7.8	240	0.4	5	28.5	81	1010
3	1486	1000	1	116	12	225	0.5	4	28	78	1012
4	2085	650	1	100	11	290	0.5	5	29.5	79	1009
5	2087	900	1	085	16	290	0.7	5	29	65	1011
6	2286	1000	2	095	11	300	0.7	5	29	70	1009*
7	2255	1000	2	089	11	250	0.7	5	29	76	1011

* There was light rain at the station.

Profiles of temperature, salinity and density were obtained, as well as cross sections of the same variables in the whole path, which are described below.

Temperature

The temperature of the layer closest to the sea surface for all the stations was around 29.3°C. It was observed that in stations 1 to 4, the mixing layer is up to a maximum depth of 35 meters (Figures 4 and 5). In the stations closest to the Bajo Nuevo Cay (5, 6 and 7), it was possible to appreciate a deepening of the mixture layer, reaching up to 65 meters. The extension of the thermocline was consideredfrom the temperature of the mixture layer up to 10°C (CORALINA-Invemar, 2012), finding that it was located for stations 1 and 2, up to 460m in depth, descending in the vicinity of the Bajo Nuevo Cay, with thermocline up to 500 m being observed for stations 4 and 5, and for stations 6 and 7, a lower limit of 570 m. From the end of the thermocline the temperature drops to a minimum of 5.3°C.

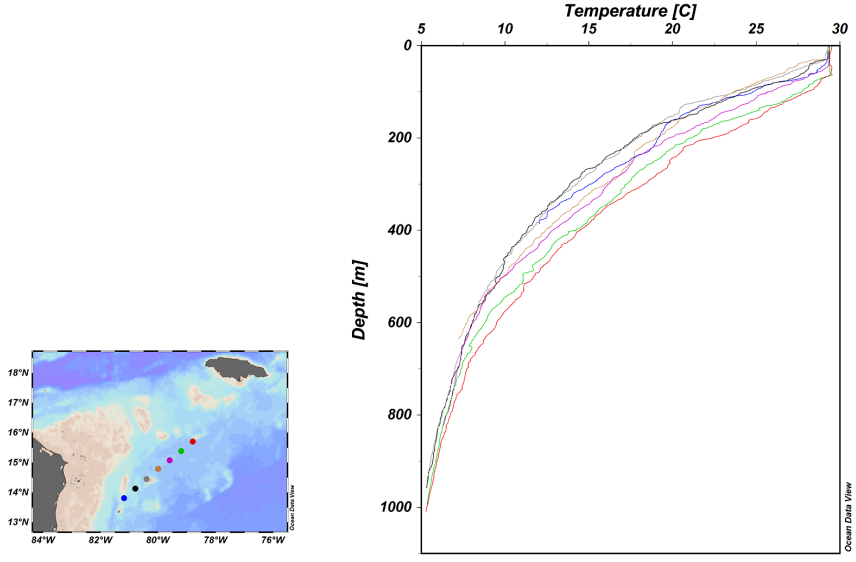

Figure 4. Temperature profiles for the seven oceanographic stations. Each color corresponds to a map station in the lower left corner.

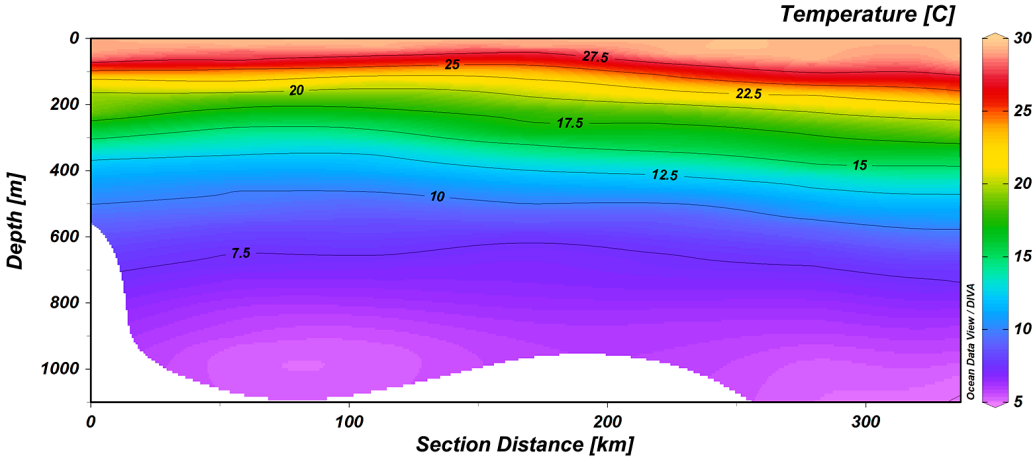

Figure 5. Cross section of temperature for the study area.

Salinity

Near the surface of the sea, the salinity observed was between 36.14 and 36.4. The maximum values of salinity registered in the vertical for all the stations corresponded to the interval between 37 and 37.11, this salinity being located in ever increasing depths according to the ascending order of the stations; with the depth in the first station being 124 m and in the seventh station 192 m. The minimum salinity obtained was 34.8 at depths ranging between 700 and 800 meters, and from these depths the salinity did not exceed 34.99 (Figures 6 and 7).

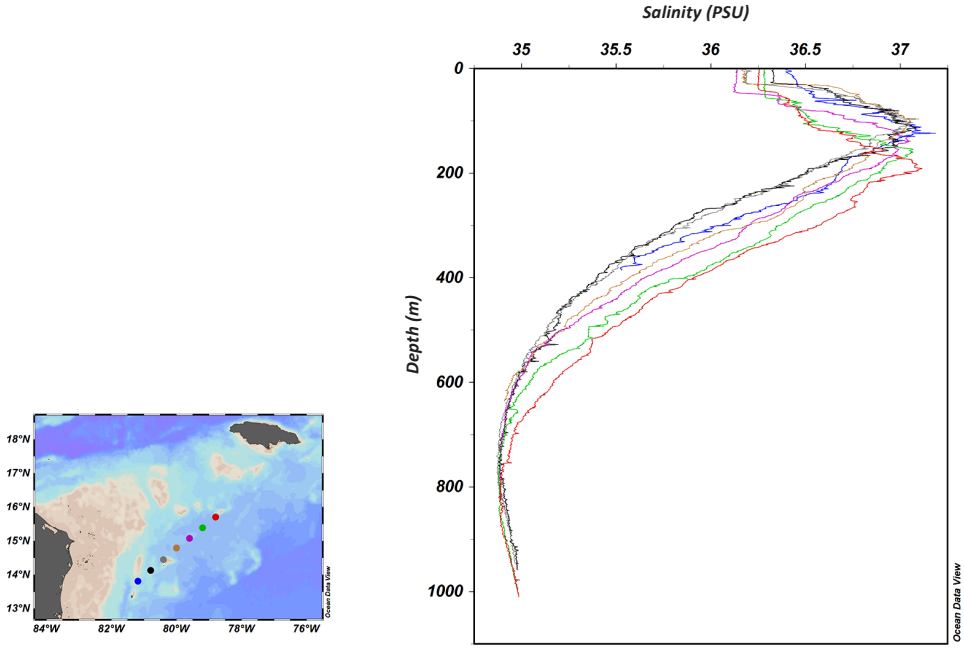

Figure 6. Salinity profiles for the seven oceanographic stations. Each color corresponds to a map station in the lower left corner.

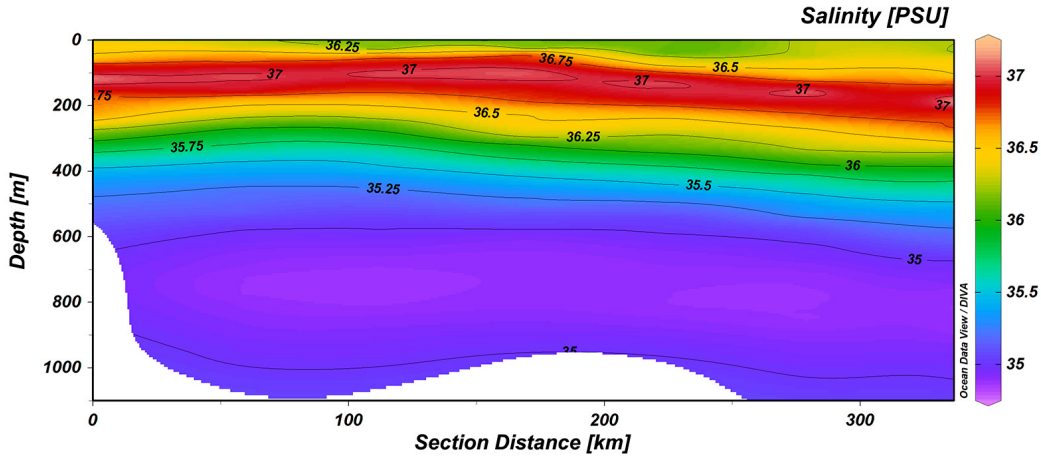

Figure 7. Cross section of salinity for the study area.

Density

The density values close to the surface of all the profiles coincided in close proximity to 1022.9 kg/m^3. The density increased significantly in all profiles up to 1027 kg/m^3, where the lower limit of the pycnocline could be considered, which in depth varied between 180 m in the first station decreasing proportionally to 230 m in the last. From these depths the variation of the density in the vertical was smaller, with all the profiles coinciding near to 630 m in depth, where the value of the density was 1030 kg/m^3 and a smooth increase continued up to the end of the sampling depth (Figures 8 and 9).

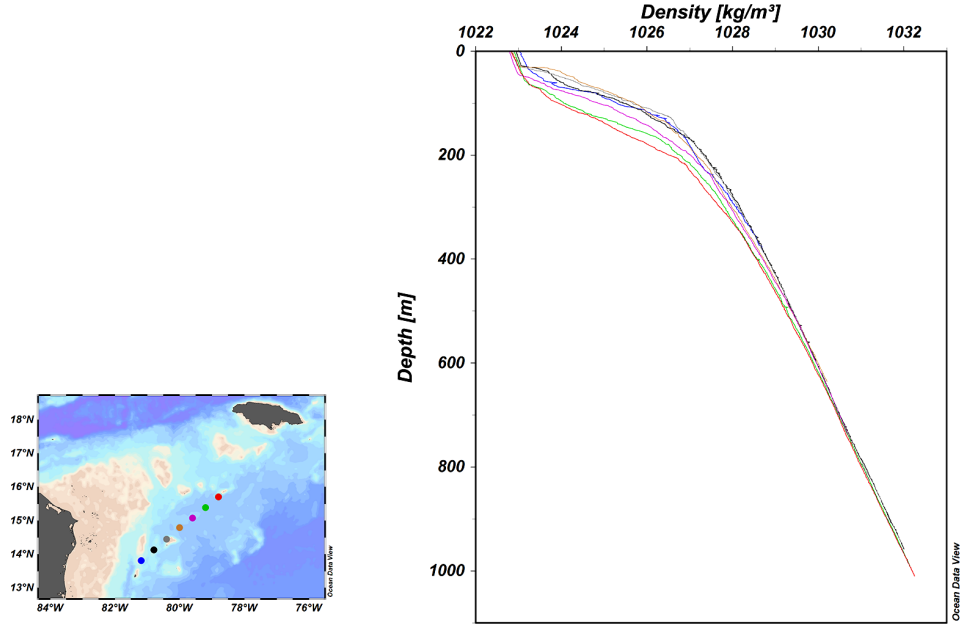

Figure 8. Density profiles for the seven oceanographic stations. Each color corresponds to a map station in the lower left corner.

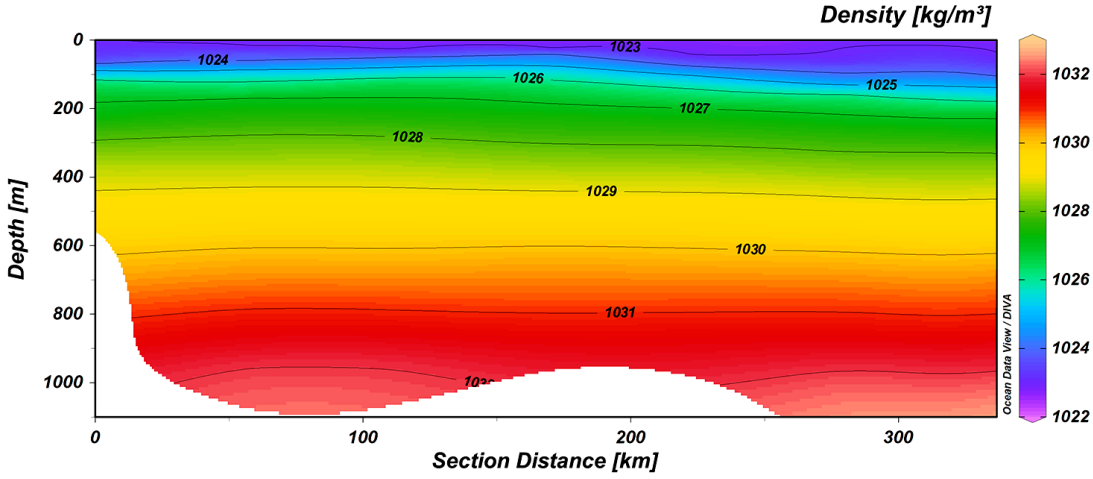

Figure 9. Cross section of density for the study area.

Discussion

The temperature observations in the vertical correspond to the typical behavior of this profile for the rainy season, according to the seasonal average calculated in the Atlas of Oceanographic Data of Colombia 1922 - 2013 (Andrade *et al.,* 2015).

Depth variations in the mix layer can be influenced by two processes: heat fluxes and turbulence produced by wind speed and wave breakers (Stewart, 2008). In this case, the wind speed records were within a range from 7.8 to 16 kn, and the wave height did not reach one meter during the days of data collection (Table 1). It can be deduced that the heat fluxes were important for the formation of the observed mixture layer; however, in stations 5, 6 and 7 the deepening of this layer was observed, which also corresponds with a slight increase in wind (16kn in station 5) and waves (up to 0.7 m in the three stations) factors that in the previous seasons had been below 12 knots and 0.5 m, respectively.

In terms of salinity, the registered values were higher than the annual average indicated by the NOAA World Ocean Atlas (WOA) 2013 (Zweng *et al.,* 2013) for the study area of between 0 and 400 m in depth (36.8) and for depths of up to 1000 m, a behavior similar to that described in the WOA was presented. In the same way, the average values for the main wet season in the study area (SON quarter) are approximately 36.6, calculated using the Atlas of Oceanographic Data of Colombia (Andrade *et al.,* 2015) from oceanographic cruises, and are below the values measured in the current campaign. These readings account for the presence of Subtropical North Atlantic Subtropical Waters (NASTU) for the study area, at around 150 m deep; however, the high salinity measured (~ 37.1) for these waters could be indicating a much higher proportion of the NASTU in the mixture with the waters of the South Atlantic that enter the Caribbean through the Lesser Antilles (less saline); a mixture proportion that according to Andrade (2009) will oscillate with the weather, which means it could still be in the presence of an upper end of the cycle as proposed by the above research.

In Figure 9 some curvatures can be seen, shown by the isopycnals from 1024 to 1026 Kg/m^3 between 80 and 200 meters deep; this may be an indicator that at the time of sampling, near station No. 4 (Northwest of Serrana Bank island), a phenomenon could be present that generates an anomaly in the dynamic topography of the area, more precisely a circulation event mesoscale (eddie) that during the wet season are common in the area of the archipelago of San Andres and

Providencia (Andrade & Barton, 2000). To determine this with accuracy, it is necessary to calculate the geostrophic currents and/or perform the validation with satellite altimetry data for the days of the sampling, which was not within the scope of the present investigation.

In accordance with Andrade *et al.,* (1996) & Molares *et al.,* (2004), the four bodies of water (CSW, NASTU, AIW and NADW) described above were identified in the study area (Figure 10). The strong presence of the NASTU with salinity values above 37 around the 150m depth is highlighted, taking into account that the regional climatology shows lower values (Molares *et al.,*2004). These high salinity values for NASTU are in accordance with the readings found above 66°W in latitudes between 14°N and Puerto Rico (17°N) by Hernández-Guerra & Joyce (2000), which an increase in the influence of NASTU towards the westernmost waters of the Colombian Basin (81°W for the present case) could be inferred.

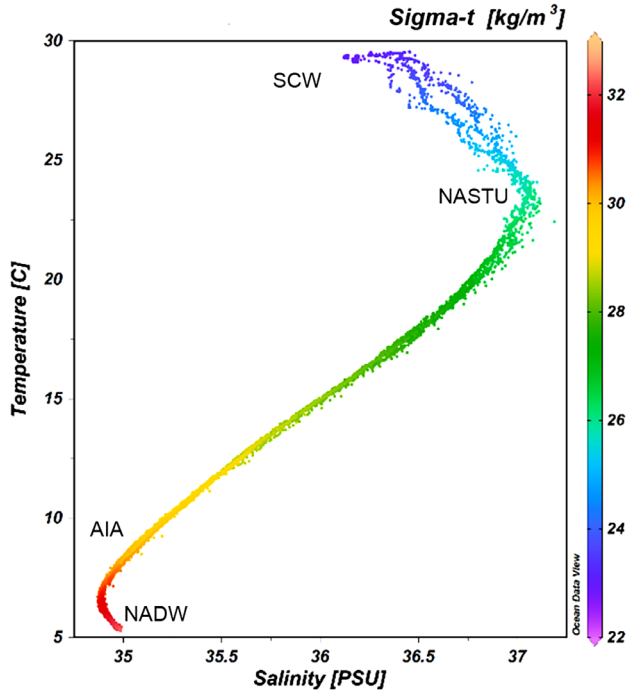

Figure 10. T-S curve from the CTD profiles obtained .

It is very important to continue with systematic sampling of the oceanographic aspects of the San Andrés and Providencia Archipelago, in order to obtain clear knowledge about the general conditions that affect this marine environment of great natural wealth for the country.

It is very important in these future studies to take into account the observation of salinity in at depths around 150 m, in order to continue monitoring the influence of NASTU in areas of the Caribbean Sea out from the North Atlantic basin.

Conclusions

The physical characteristics observed in the sea water of the area between Providencia Island and Bajo Nuevo Cay, were the usual ones for the wet season in the Caribbean Sea, framed within the physical-chemical province of the Interior Caribbean, due to its general conditions of warm waters with high salinity and high clarity of the water (Chollett, Mumby, Müller-Karger & Hu, 2012).

It is noteworthy that the salinity measurements in all the stations just below 100 m depth, exceed

the value of 37 and some even exceeded 37.1; values that contrast with those obtained before in the ´90s by the oceanographic campaigns carried out in the area, where values higher than 36.85 were not recorded (Andrade, 2009). This indicates a stronger presence, at least in the humid SON period, of the subtropical subtropical waters of the North Atlantic, revealing, in turn, the absence of the Caribbean Water Mass that had been established as the result of the mixture of Central South Atlantic Water (less saline due to the presence of waters from Amazonian rivers, Orinoco, etc.) and the NASTU (Molares *et al.,* 2004).

References

Andrade, C., L. Giraldo y S. Lonin. (1996).Nota sobre la circulación de las aguas en el Bajo Alicia y el sector de San Andrés. Boletín Científico CIOH, No. 17. pp 27 – 36.

Andrade, C. y E. Barton. (2000). Eddy development and motion in the Caribbean Sea. Journal of Geophysical Research, No. 105. pp 191 – 201.

Andrade, C. (2001). Las Corrientes superficiales en la cuenca de Colombia observadas con boyas de deriva. Revista de la Academia Colombiana de Ciencias Exactas, Físicas y Naturales, Vol. 25, No. 96. pp 321 – 335.

_____. (2009). Variaciones temporales termohalinas en la Cuenca Colombia. Boletín Científico CIOH No.27. pp 8 – 21.

Andrade C., O. Rangel, y E. Herrera. (2015).Atlas de los datos oceanográficos de Colombia 1922 – 2013 Temperatura, Salinidad, Densidad, Velocidad Geostrófica. Dirección General Marítima – Ecopetrol S.A. Ed. Dimar. Bogotá, Colombia. 117 pp.

Bernal, G., Ruiz Ochoa, M.y Beier, E. (2010). Variabilidad estacional e interanual océano-atmósfera en la cuenca Colombia. Cuadernos del Caribe, 8(14).

Chollet, I., P. Mumby, F. Müller-Krager, y Ch. Hu. (2012). Physical environments of the Caribbean Sea. Limnology and Oceanography, No. 57(4). pp 1233 – 1244.

Comisión Colombiana del Océano. (2015). Aportes al Conocimiento de la Reserva de Biósfera Seaflower. pp 108.

CORALINA-Invemar. Gómez-López, D. I., C. Segura-Quintero, P. C. Sierra-Correa y J. Garay-Tinoco. (2012). Atlas de la Reserva de Biósfera Seaflower. Archipiélago de San Andrés, Providencia y Santa Catalina. Instituto de Investigaciones Marinas y Costeras "José Benito Vives De Andréis" -Invemar- y Corporación para el Desarrollo Sostenible del Archipiélago de San Andrés, Providencia y Santa Catalina -CORALINA-. Serie de Publicaciones Especiales de INVEMAR # 28, p 55.

Dainco. (1980). Proyecto para el desarrollo de la pesca artesanal y la investigación en el archipiélago de San Andrés y Providencia. San Andrés Isla, Colombia. Dainco, 240 pp Editor, pags.

Garay, J., F. Castillo, C. Andrade, J. Aguilera, L. Niño, M. De la Pava, W. López, G. Márquez. (1998). Estudio oceanográfico del Caribe Colombiano en el área del Archipiélago de San Andrés y Providencia y cayos adyacentes. Boletín Científico CIOH, No. 9. pp 3 – 73.

González, E. (1987). Oceanografía física descriptiva del Archipiélago de San Andrés y Providencia con base en el análisis de los cruceros OCEANO VI a IX. Boletín Científico CIOH, No. 7. pp 73 – 100,.

Hernández-Guerra, A. y T. Joyce. (2000). Water masses and circulation in the Surface layers of the Caribbean at 66°W. Geophysical Research Letters, Vol. 27, No. 21. pp 3497 – 3500.

Molares R., T. Vanegas, J. Bustamante y, C. Andrade. (2004). Aspectos oceanográficos sobre la Depresión Providencia en mayo de 2004. Boletín Científico CIOH No. 22. pp 11 – 25.

Stewart, R. (2008). Introduction to physical oceanography. Department of Oceanography Texas A y M University. Edition, p 82.

Zweng, M.M, J.R. Reagan, J.I. Antonov, R.A. Locarnini, A.V. Mishonov, T.P. Boyer, H.E. Garcia, O.K. Baranova, D.R. Johnson, D.Seidov y M.M. Biddle, 2013. World Ocean Atlas 2013, Volume 2: Salinity. S. Levitus, Ed., A. Mishonov Technical Ed.; NOAA Atlas NESDIS 74, 39 pp.