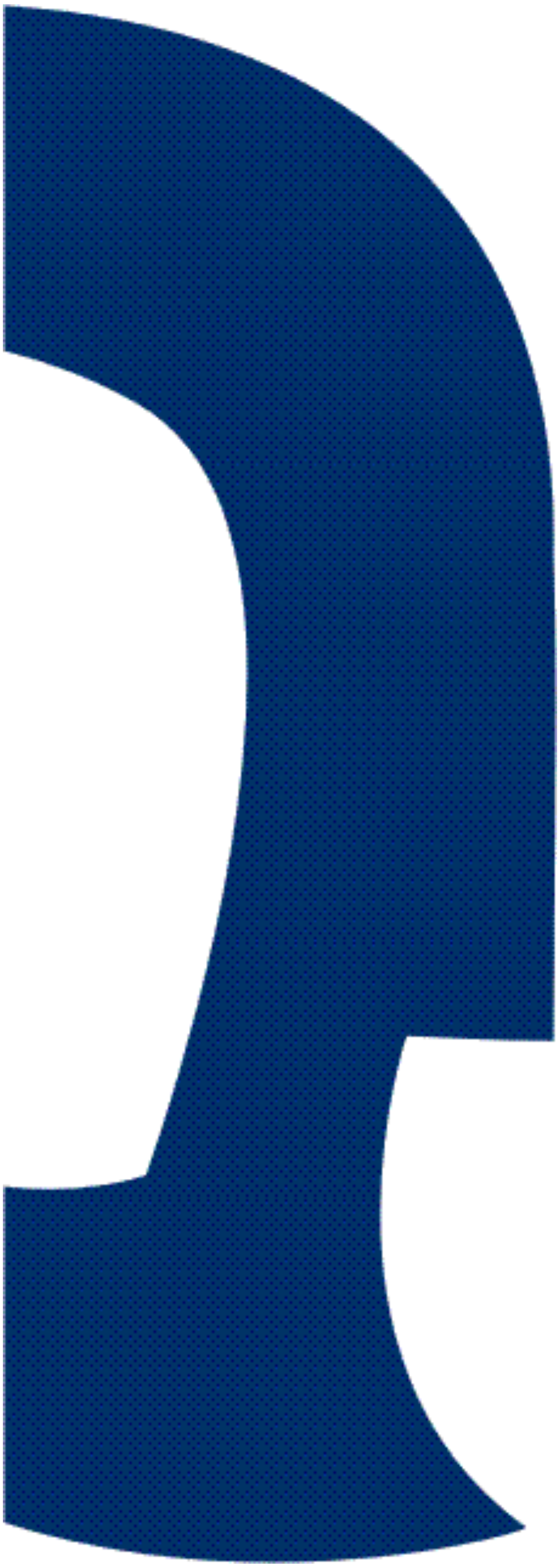

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DE GRAN CANARIA

Study of the oceanographic conditions in the Caribbean in 2003.

Déborah Vega Carreño
Curso 2015/2016

Tutor: Alonso Hernández Guerra

Trabajo Fin de Título para la obtención del título de Graduada en Ciencias del Mar

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FINAL DEGREE WORK

Study of the oceanographic conditions in the Caribbean in 2003.

Final degree work presented by Déborah Vega Carreño to obtain the title of graduated in Marine Science from the University of Las Palmas de Gran Canaria.

Directed by: Dr Alonso Hernández Guerra, Department of Physics, University of Las Palmas de Gran Canaria. Instituto de Oceanografía y Cambio Global (IOCAG).

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Alonso Hernández Guerra	Déborah Vega Carreño

LAS PALMAS DE GRAN CANARIA
JUNE 2016

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Abstract

A meridional hydrographic section was made in October 2003 at 66ºW from the coast of Venezuela to Puerto Rico. In this report, we concentrate from surface to 1700 m depth in the Caribbean. The data show two distinct water masses with different origins: Caribbean Surface Water, with salinity values less that 35.5, and Subtropical Underwater (SUW), with subsurface salinity higher than 37, with their source in the North Atlantic and subtropics respectively, as previously observed. Different velocity patterns in the water masses from Atlantic Ocean to the Caribbean are observed. Mass transport through the section is westward and about 30 Sv that matches the transport of the Florida Current.

1. Introduction

The Caribbean Sea is located at the cast of the Atlantic Ocean in the range of latitude of 11ºN-18ºN. It is a semienclosed sea surrounded by the landmasses of South and Central America and separated from the Atlantic Ocean by islands, banks, and sills of the Antilles Islands Arc (Figure 1). The Caribbean Sea has three major parts: the eastern Caribbean north of Venezuela, the Cayman Sea in the west, and the southwestern Caribbean Sea bounded by Colombia and Central America [Andrade et al., 2000].

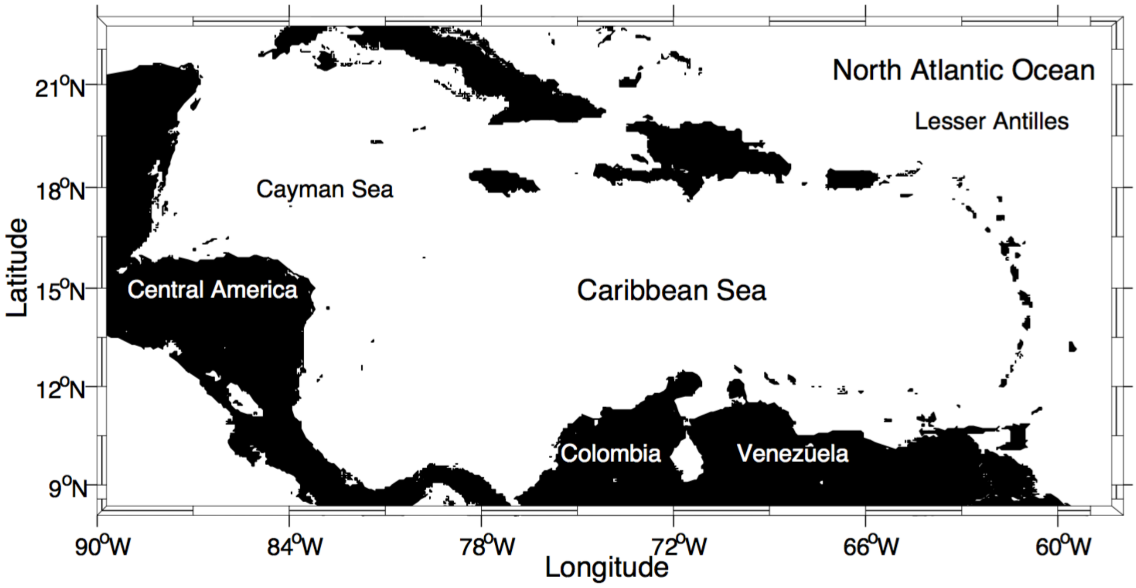


Figure 1. Caribbean Sea, geographic description.

The Caribbean Sea plays an important role as a conduit for mass, hear, salt, and other tracers in the Atlantic circulation system. The upper ocean circulation in the region is characterized by a warm and persistent through-flow known as the Caribbean Current, which flows westward about 200-300 km off the northern coast of South America and then northward along the eastern coast of Central America [Lin et al., 2012].

The Caribbean Sea is influenced by the dispersal of freshwater from the Amazon and Orinoco Rivers, which is discharged into the tropical Atlantic and advected into the Caribbean Sea [Chérubin et al., 2007].

The inflow from the Atlantic through these passages in this chain feeds a mean Florida Current transport of approximately 30 Sv. The forcing mechanisms that drive the Caribbean inflow and Florida Current transport have evolved considerably in recent years. Previously viewed as simply a return current for the wind-driven Sverdrup flow of the subtropical gyre, the Florida Current is now known to be an important conduit for northward transport of upper ocean waters in the global thermohaline circulation [Johns et al., 2002].

The objective of this paper is to study the oceanographic conditions of the A22-2003 cruise done in 2003. This study uses 19 stations (figure 2) out of the 22 original. Station 1 was removed because it was used to test the equipment, also station 20 and 21 because they are very closed between them. In section 2 data collection is described and the method used, in section 3 the results obtained and in section 4 the conclusions obtained.

2. Data and methods

From 24 to 28 October 2003, a hydrographic section (A22-2003) at 66ºW from Venezuela to Puerto Rico was carried out. The data were obtained from a CTD, a SADCP (Shipboard Acoustic Doppler Current Profiler) and a LADCP (Lowered Acoustic Doppler Current Profiler).

In this cruise, 22 stations were made collecting salinity, dissolved oxygen and temperature measurements from CTD following the methodology described in the WHP technical operations manual [Joyce,1994] together with velocity from SADCP and LADCP. SADCP data give detailed insights into the upper-ocean dynamics to a maximum depth of approximately 790 m. LADCP data provide velocity profiles over the full range of depths of standard hydrographic casts [Comas Rodríguez, 2011].

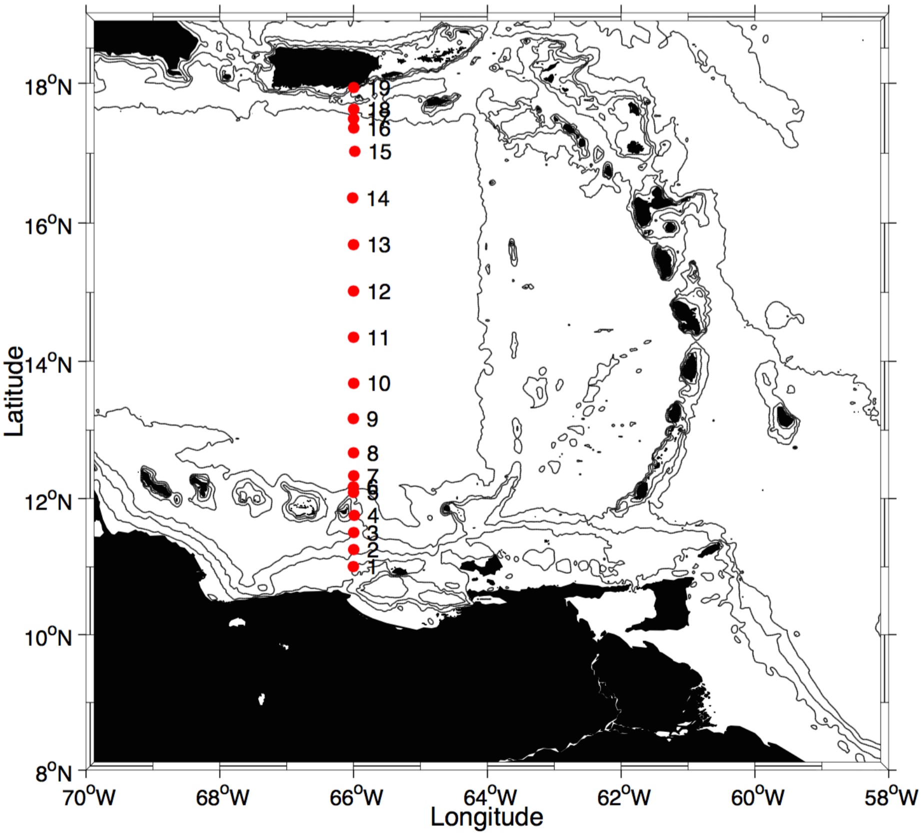


Figure 2: Location of the study area with the 19 stations.

The data from the A22 cruise of the 19 selected stations have been processed through matlab program. With this program, θ/S diagram, station maps, potential temperature and salinity plots were made.

The SADCP and LADCP data were downloaded from the database of our cruise. The SADCP data records continuously, and it was processed with the matlab software. The LADCP data are collected in each station from the surface to the bottom of the ocean, and also it was processed with the matlab software

The geostrophic velocity is calculated using the thermal wind equation. The velocity of the layer of no motion has been estimated using SADCP or LADCP data. A comparison between each station pair's geostrophic profile and LADCP data is made. Figure 3 shows the initial geostrophic velocity and corrected using the SADCP and LADCP data. Data from the whole water column has been used to estimate the velocity at the layer of no motion although the study is only focused in the first 1700 m depth.

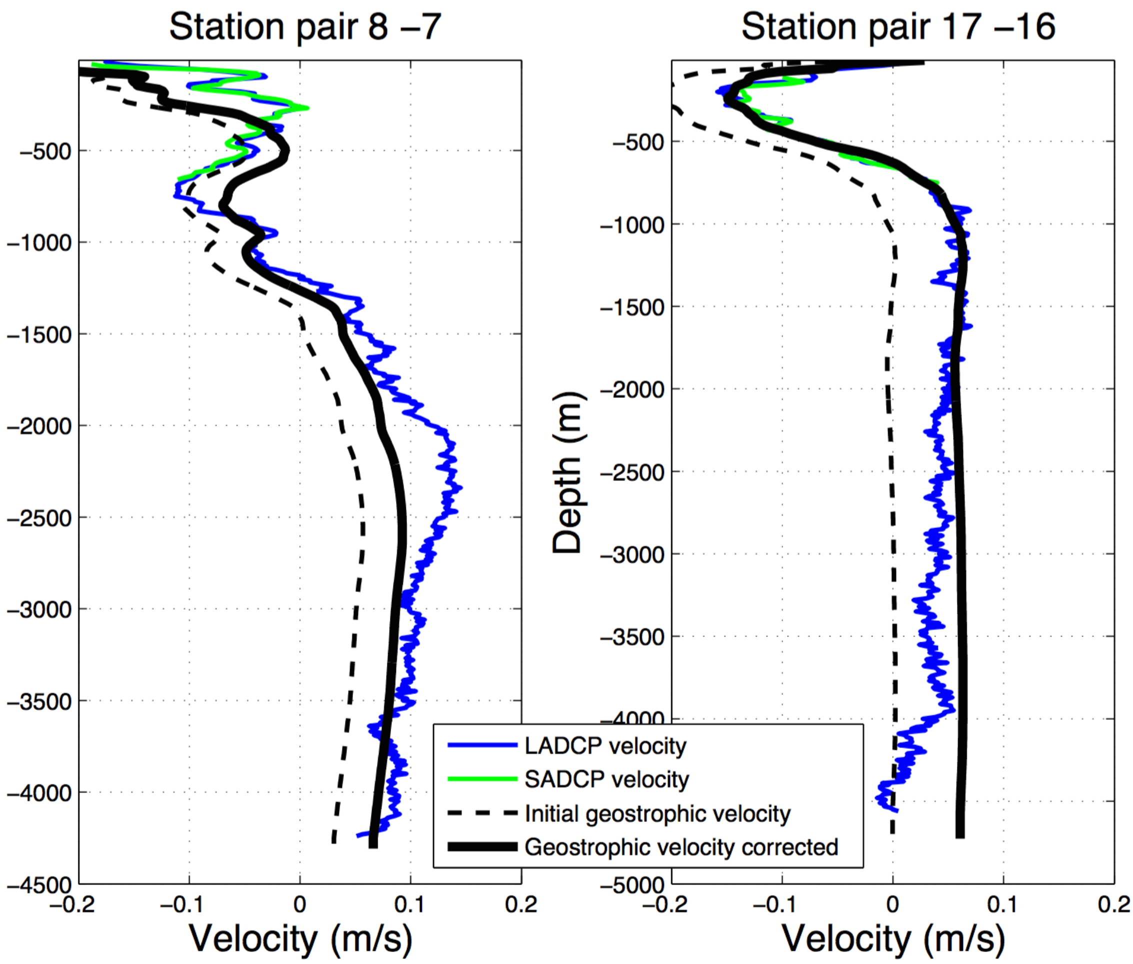


Figure 3: Comparison between the geostrophic velocity initial and corrected, SADCP velocity and LADCP velocity for station pair 17-16 and 8-7. The dashed line represents the initial calculation while the solid one is corrected using SADCP data. Green line show the SADCP velocity calculated as the mean of the measurements taken during each cast. Blue line show the LADCP velocity calculated as the mean of the measurements taken during each of stations pair. LADCP is shown to prove the fit to their data.

The tide component has been subtracted from the measures of the LADCP. For this calculation, the tide global model (TPXO) was used. This global model of ocean tides best fits, in a least squares sense, the Laplace Tidal Equations and along track averaged data from TOPEX/POSEIDON and Jason obtained with OTIS (Oregon State University Tidal Inversion Software). The time considered for the tidal prediction is the bottom track time, which is half way through the time spent at the station [Comas Rodríguez, 2011].

The calculation of the reference velocity is performed from geostrophic velocity, SADCP and LADCP data in layer no motion. The initial geostrophic velocity field was calculated with a zero-velocity reference layer at γ_n=27.875 kg m^{-3} (approximately 1500 m depth). This layer has been taken due to the feet that it is slope is approximately flat (Figure 5a). The reference velocity across the study area, is shown in figure 4. Negative values correspond to input flow from the Atlantic Ocean to the Caribbean Sea. Positive values show a recirculation. Gaps are due to bad adjustment between geostrophic velocity and SADCP and LADCP data. The reference velocity is used to estimate absolute mass transport.

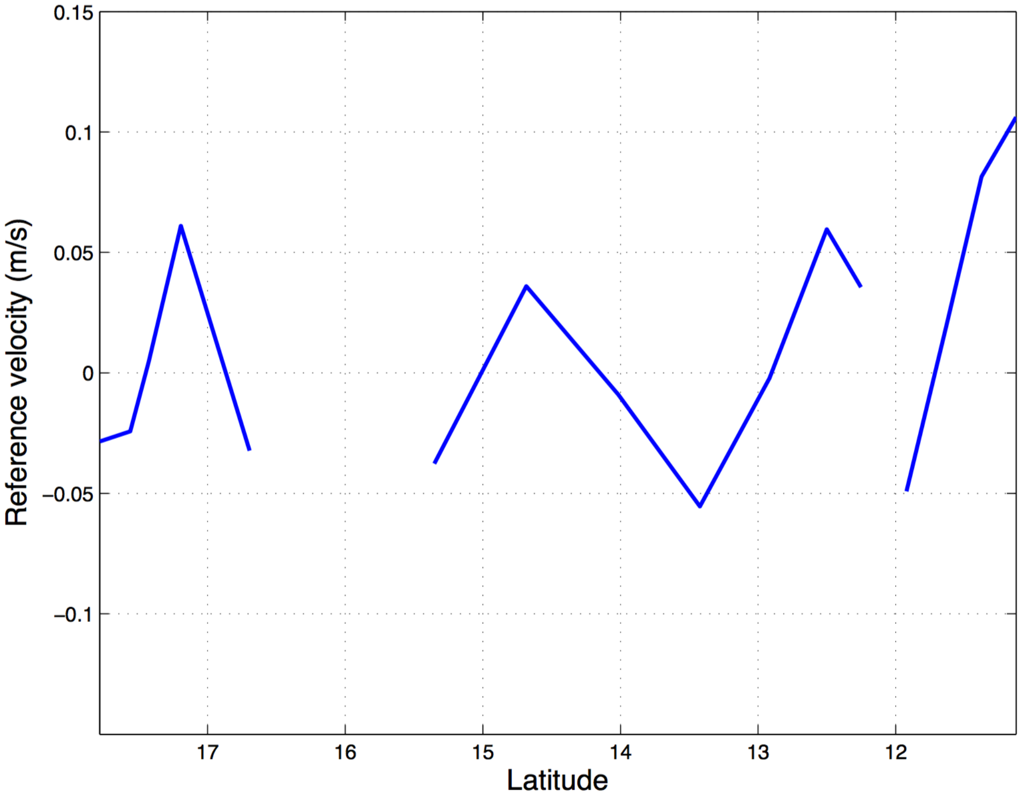


Figure 4: Velocities at the reference layer from the comparison of geostrophic velocity and SADCP and LADCP data.

3. Results

Water masses

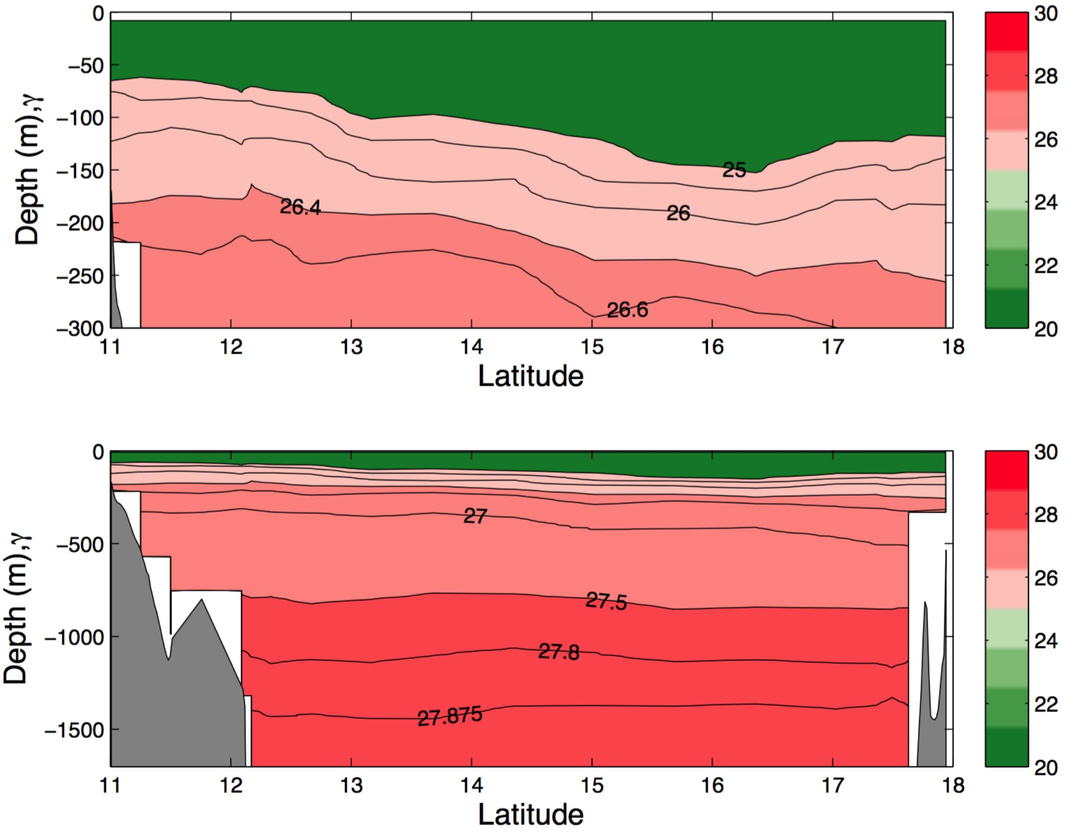
Vertical section of neutral density, salinity and potential temperature (Figure 5) together with potential temperature/salinity diagram are used to determine the water masses in the area under study.

In the first 50 m (Figure 5b), the northern half of the section has a relatively fresh water with salinity values less than 35.5, called Caribbean Surface Water. It is thought that it is a mixture of North Atlantic surface waters, Amazon river water, and local freshwater runoff from South America. In the middle of the section, we observe a region of minimum salinity (<34.5) also shown in figure 5 near the 30 ºC and σ_θ < 22 kg m^{-3}. The origin of this low salinity water is the Orinoco river [Hernández-Guerra et al., 2000].

A subsurface salinity maximum (≥37) can be seen as a tongue, extending into the northern part of the Caribbean (from approximately 14ºN to Puerto Rico) at a depth of about 150 m (Figure 5b). This Subtropical Underwater (SUW) was also identified in the Caribbean by Wüst [1964], who attributed its origin to be in the high evaporation regions of the subtropics [Joyce et al., 2001].

The θ/S diagram (Figure 6) shows three different salinity values for σ_θ=25.4 kg m^{-3}: 36.8 near the Venezuelan coast, 37 corresponding to a northern half of the section and 37.2 corresponding to an area close to Puerto Rico [Hernández-Guerra et al., 2000].

a)


0
−50
−100
−150
−200
−250
−300
Depth (m),γ
25
26
26.4
26.6
11
12
13
14
15
16
17
18
Latitude
30
28
26
24
22
20
0
−500
−1000
−1500
Depth (m),γ
27
27.5
27.8
27.875
11
12
13
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15
16
17
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Latitude
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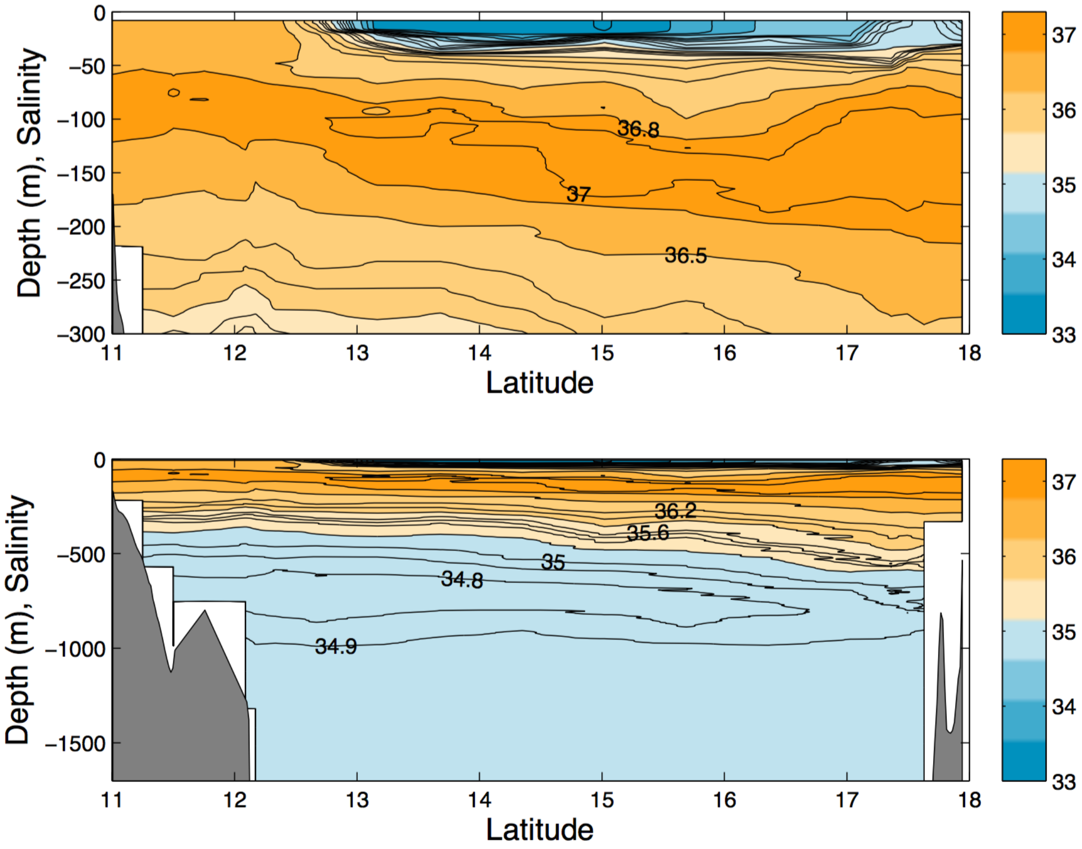
28
26
24
22
20

b)


Depth (m), Salinity
0
−50
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−150
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Latitude
36.8
37
36.5
37
36
35
34
33
Depth (m), Salinity
0
−500
−1000
−1500
11
12
13
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c)

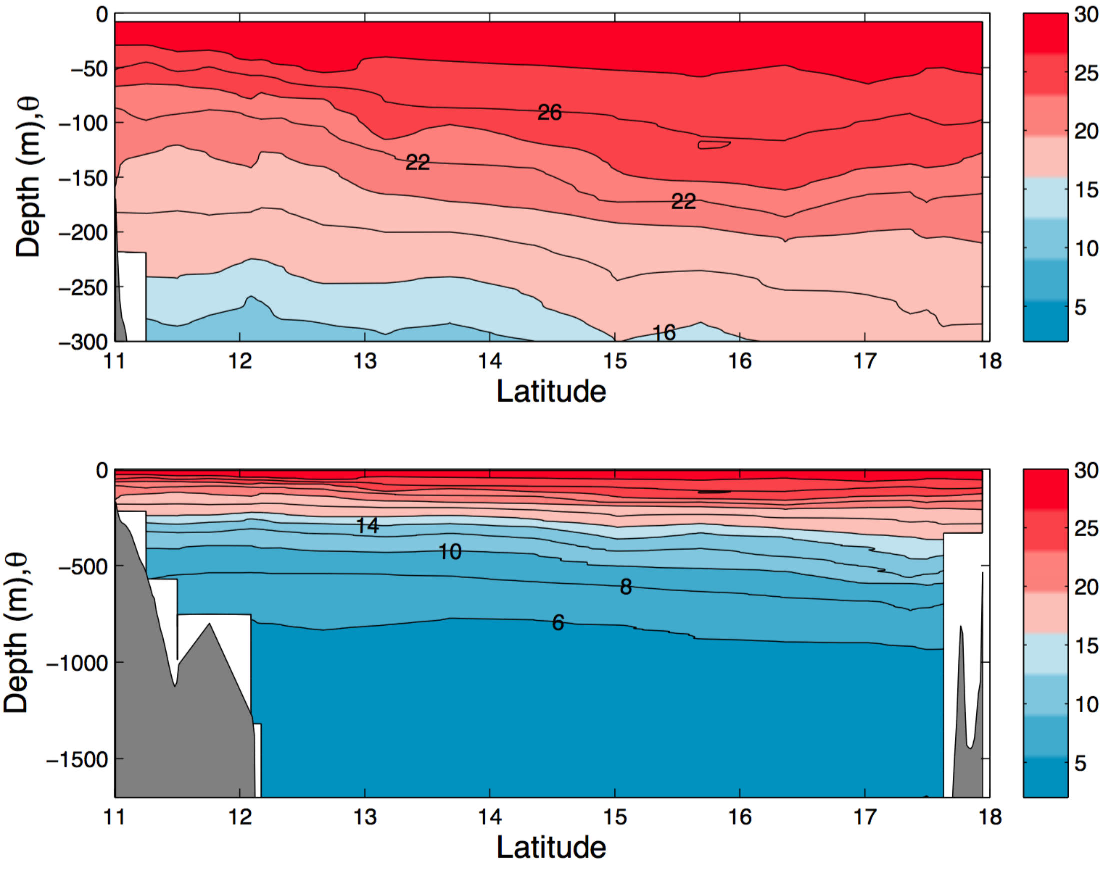

Figure 5: Section of a) density, b) salinity, c) potential temperature for the surface waters (<300m) and study area at 1700 m for the Caribbean.

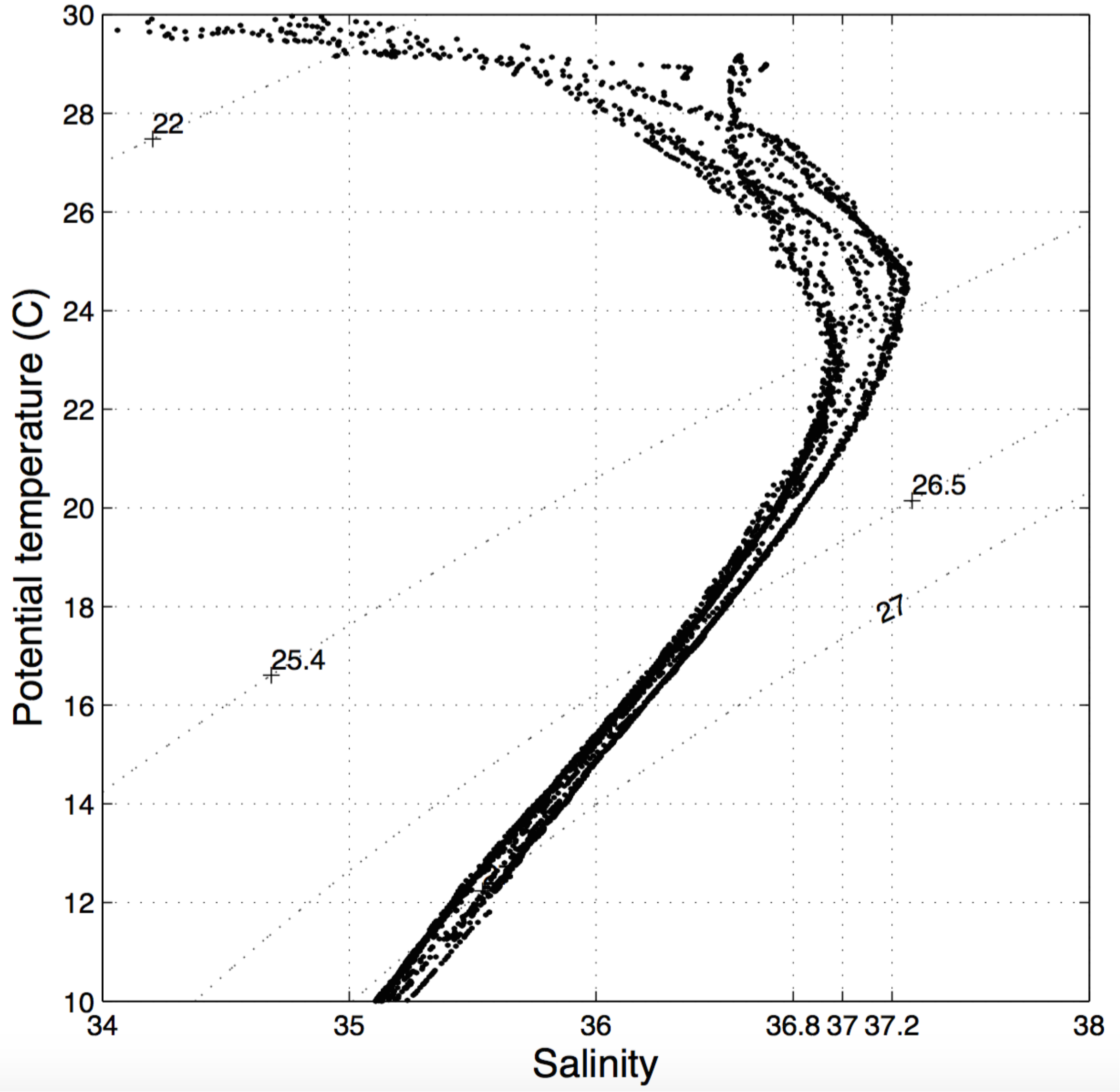

Figure 6: Potential temperature /salinity diagram for the surface waters (<300 m) of the Caribbean.

Surface current

Velocity from SADCP is shown in figure 7, figure 8 and figure 9. Velocity at 20 m (figure 7), is compared to the figure show is Hernandez-Guerra, 2000 (figure 8). Figure 9 shows the averaged velocity over nearly 790 m depth, that is the maximum range reached by the SADCP.

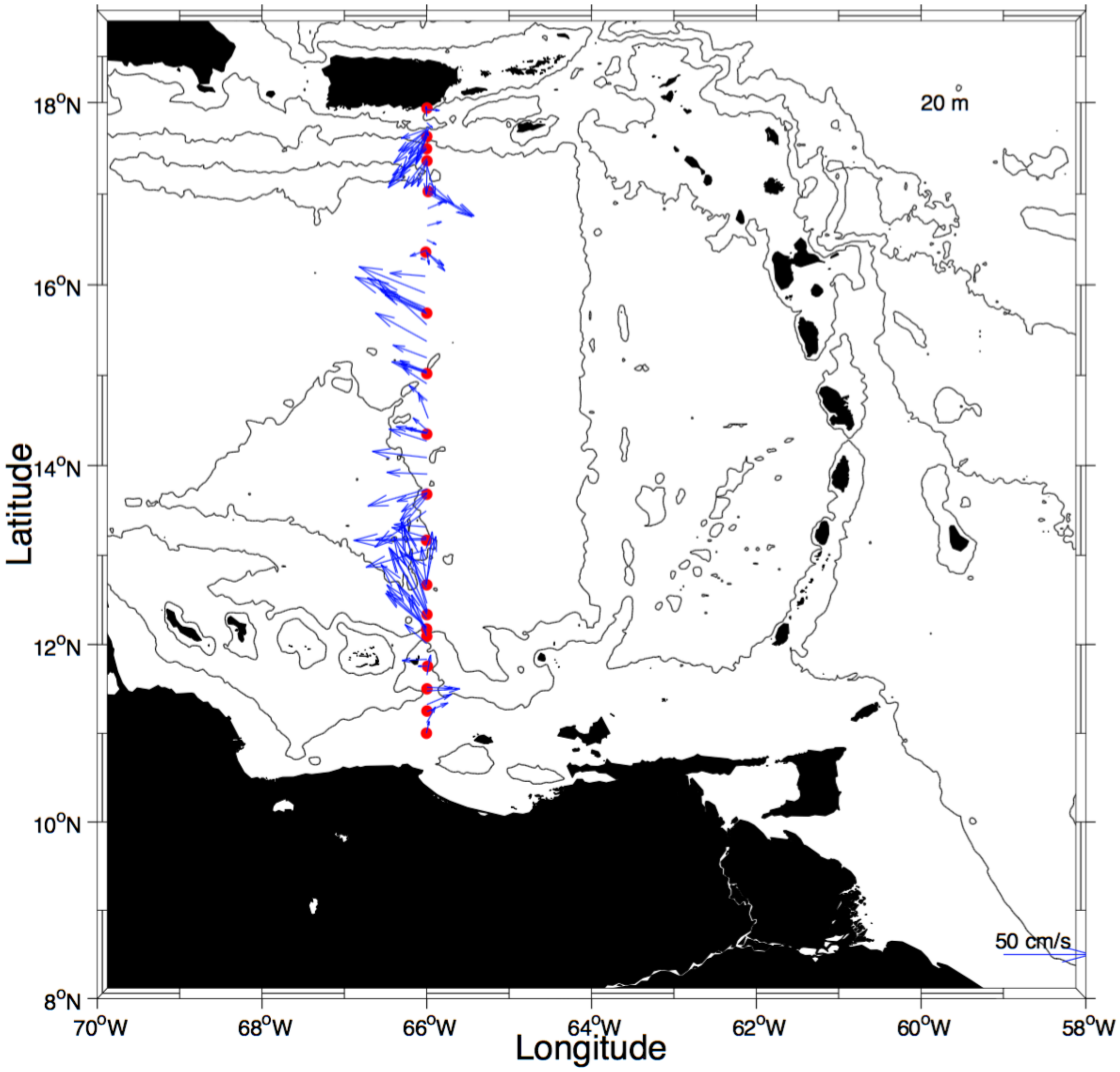

Figure 7: Surface velocities from the SADCP at 20 m depth (2003). For reference, locations of the CTD stations and main isobaths are shown.

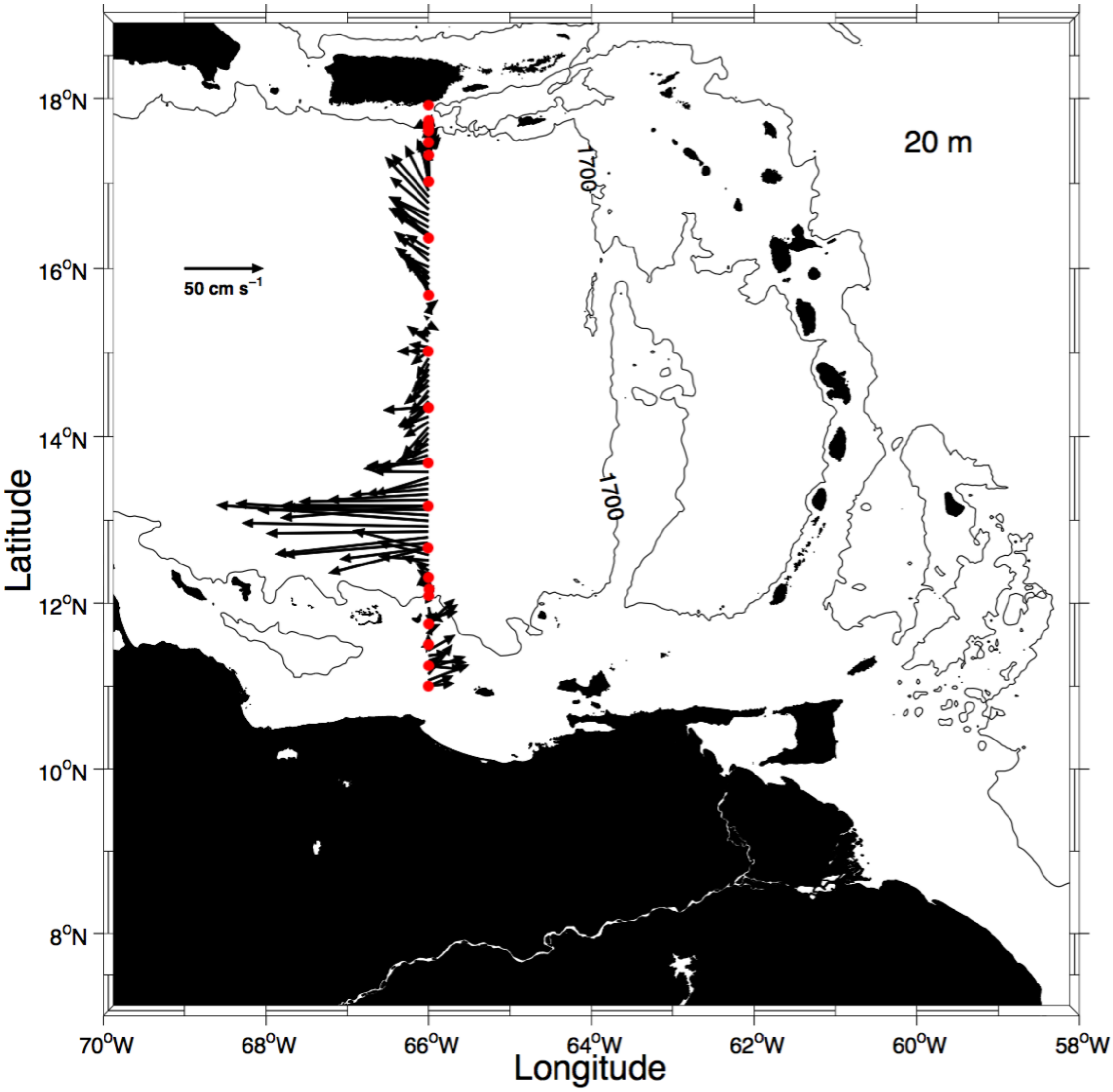

Figure 8: Surface velocities from the SADCP at 20 m depth (1997). For reference, locations of the CTD stations and main isobaths are shown. Taken from Hernández-Guerra et al., (2000).

In figure 8, a the narrow and strong jet with velocities of 130 cm s^{-1} at approximately 13ºN is clearly seen. Nevertheless, any jet is observed in figure 7. The two figures (Figure 7 and figure 8) show an input of water masses from the Atlantic Ocean to the Caribbean at different speeds. Figure 9 shows the average speed at which the water mass enters to the Caribbean.

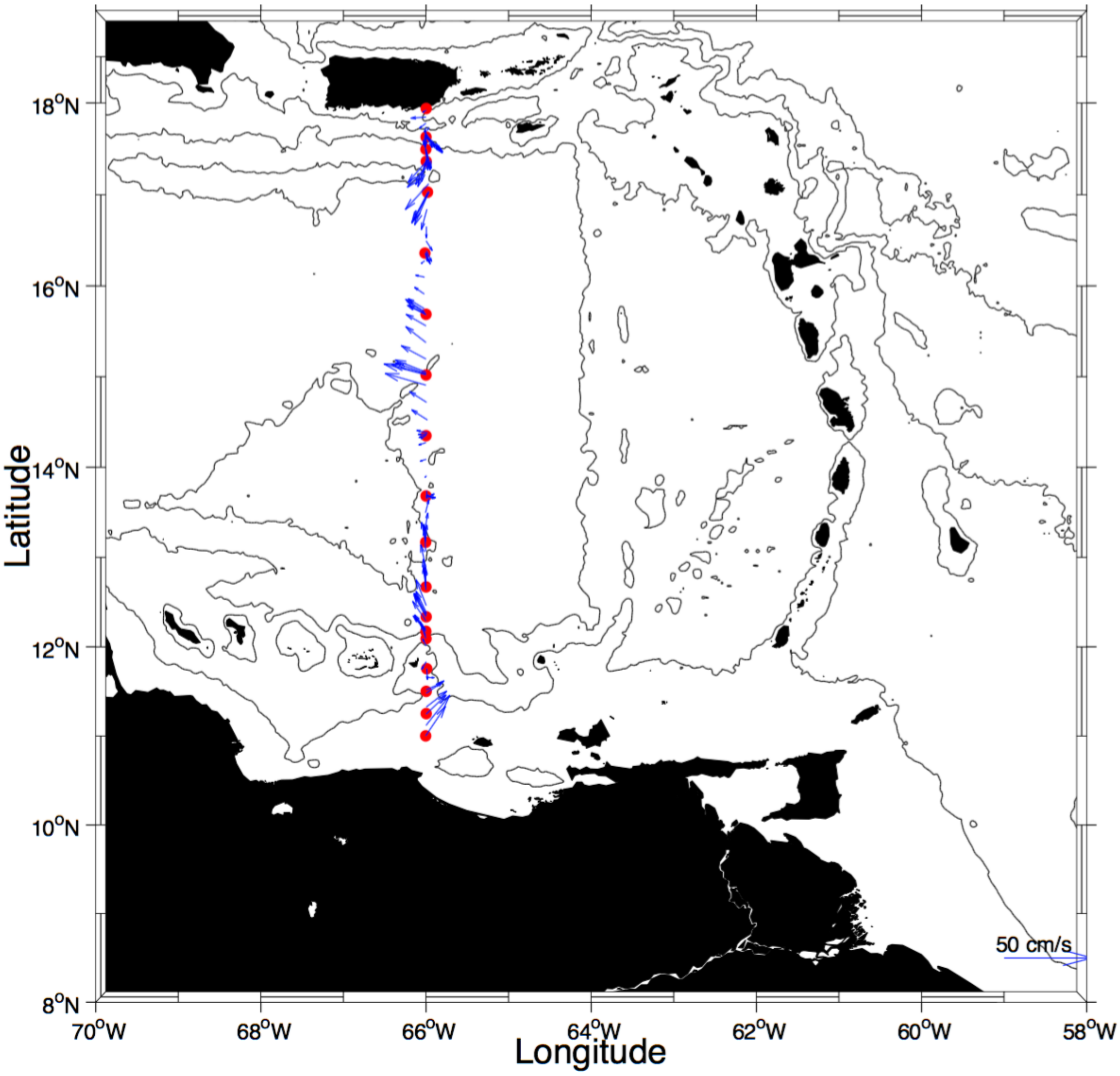

Figure 9: Full-depth averaged velocities from the SADCP (2003). For reference, locations of the CTD stations and main isobaths are shown.

Figure 10 shows the chlorophyll *a* image on October 28, 2003. A chlorophyll plume starting at the Orinoco river outflow is clearly seen. The plume formed at the Orinoco River is present during August through November every year. It is over 100 km wide and flows into the Caribbean Sea drifting northwest across the Caribbean, reaching Puerto Rico around October. On this occasion, the Orinoco plume passes through our section. It seems that the inflow transporting the Orinoco Plume from its source converges with the eastward outflow of the Caribbean. This carries the Orinoco plume to the north until the region where the prevailing westward flow is found [Hernández-Guerra et al., 2000].

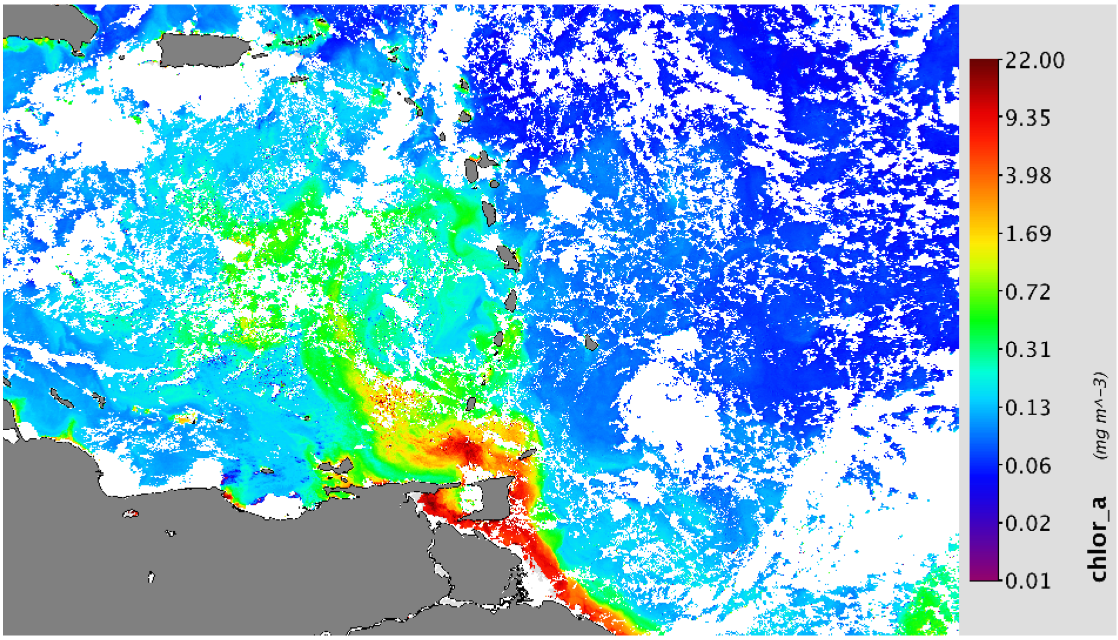

Figure 10: Phytoplankton pigment image for the Caribbean region from October 27, 2003.

The sea surface temperature (Figure 11) of Caribbean is around 27-30ºC. The temperature near the coast of Venezuela is colder than in the rest of the section. This colder water on the coast corresponds to the chlorophyll *a* plume that comes from the Orinoco river (Figure 10).

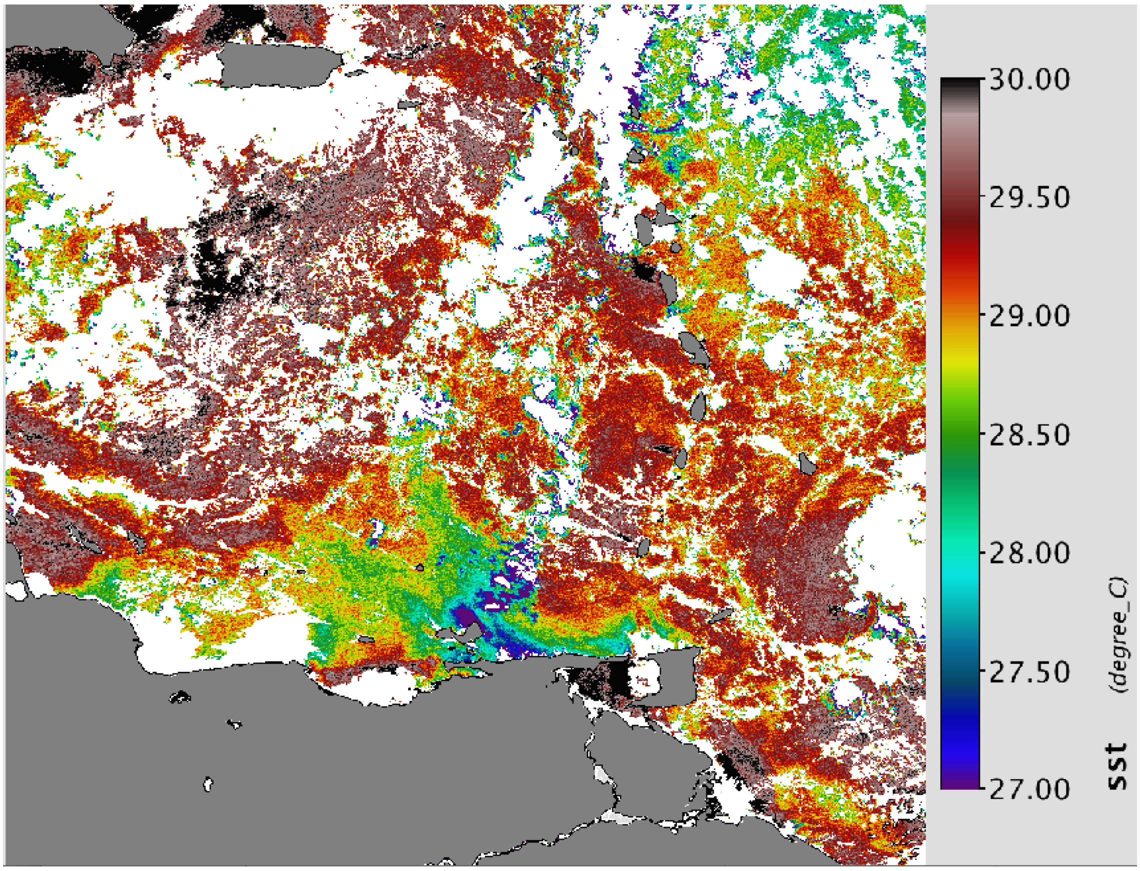

Figure 11: Sea surface temperature (SST) image for the Caribbean region from October 27, 2003.

Mass transport

Mass transports corresponding to geostrophic and ADCP-referenced sections are shown in this section. In figure 12 and figure 13, solid lines stand for the initial geostrophic calculations, while dashed lines represent the ADCP-referenced mass transport, that includes the velocity in the reference layer [Comas Rodríguez, 2011].

We have divided the water column up into 12 layers (Figure 11), but we study the first 10 layers (< 1700 m), shown as a dashed line in figure 12. Figure 12 shows the vertical structure of the zonal mass transport at 66ºW by layers, and shows that the reference velocity doesn't affect the first 6 layers, but it does to the deep layers.

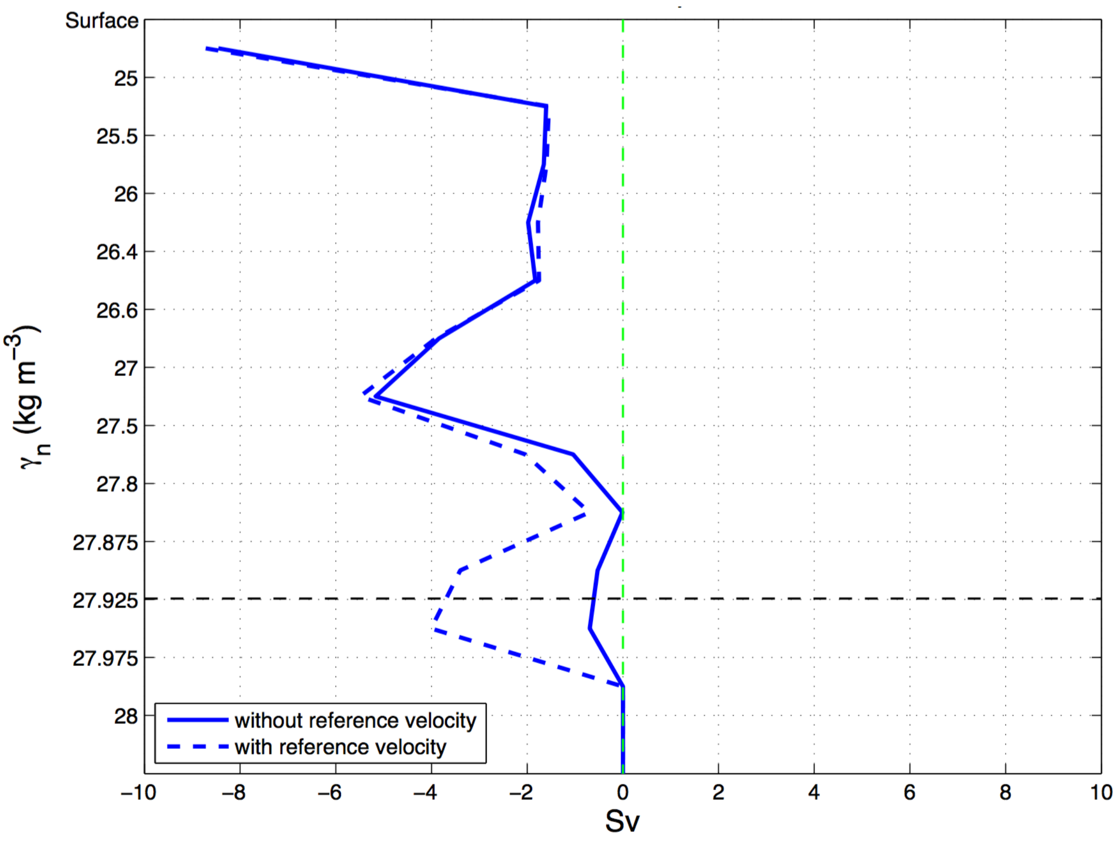

Figure 12: Mass transport for layers. Our section it goes north/south.

Figure 12 shows basin-wide mass transports (our section from north/south in figure 11), with a net westward inflow into the Caribbean. Figure 13 shows that, with the exception of the coastal flow north of Venezuela, flow in the upper layers of the Caribbean is everywhere westward, with indication of alternating bands of eastward flow (Figure 12 and figure 13) [Joyce et al., 2001].

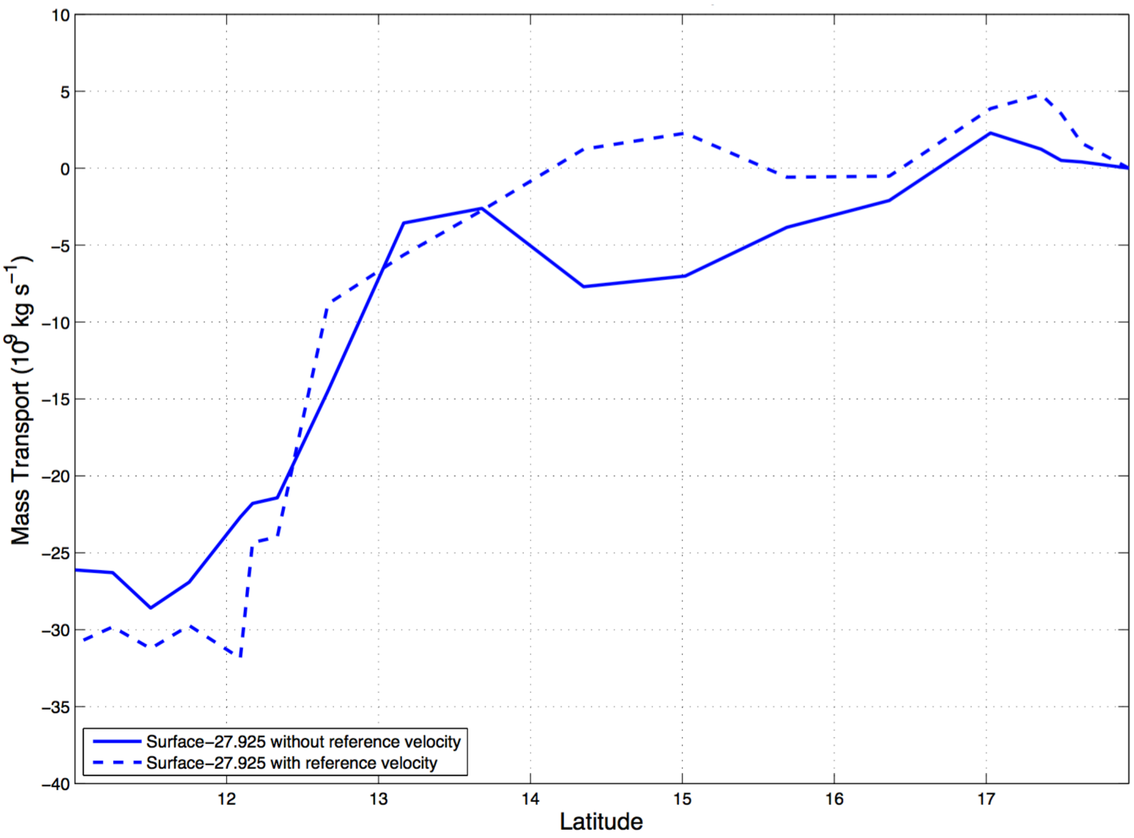

Figure 13: Accumulated mass transport (10^9kg s^{-1}) from surface to 1700 m depth. Dashed lines stand for mass transport without LADCP and solid lines represent the estimates corrected through LADCP data. Our section it goes south/north.

4. Conclusions

The main purpose of this study has been to study the oceanographic conditions in the Caribbean Sea in the A22 cruise in 2003. This cruise was carried out from 24 to 28 October carrying out, a hydrographic section at 66ºW from Venezuela to Puerto Rico.

The data from 19 oceanographic stations were processed with matlab software. θ/S diagram, station maps, potential temperature and salinity graph were made from salinity and temperature data from CTD. Velocity data from SADCP and LADCP were also processed with the matlab software.

Geostrophic velocity is calculated from the thermal wind equation. The geostrophic velocity, SADCP and LADCP velocities is used to calculate the reference velocity.

The water masses are determined with the vertical sections of neutral density, salinity, potential temperature and potential temperature/salinity diagram. A subsurface salinity maximum (≥37) is identified as Subtropical Underwater (SUW). Its origin is in the high evaporation regions of the subtropics. Caribbean Surface Water appears with salinity values less than 35.5. The minimum salinity water (< 34.5) are originated by the Orinoco river.

In 2003, it does not appear any jet in contrast to 1997 which is clearly appreciated. The plume of chlorophyll formed at the Orinoco River outflow passes through our section. The inflow transporting the Orinoco Plume from its source converges with the eastward outflow of the Caribbean.

The mass transport of the first 10 layers (< 1700 m) is studied in this work. We have checked that the referenced velocity estimated by the LADCP doesn’t affect in the first 6 layers, but it affects to the deep layers.

The Caribbean Current is a major current that transports North Atlantic Subtropical Gyre and South Atlantic waters through the Caribbean and into the Florida Current (-30 Sv) and the Gulf Stream.

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Descripción detallada de las actividades desarrolladas durante la realización del TFG

A partir de los datos de la campaña que me ha facilitado el profesor, he comenzado con averiguar las estaciones que corresponden con mi zona de estudio, todo ello con la herramienta Matlab. Una vez tengo mis estaciones de estudio he tenido que hacer un mapa de estaciones donde aparece mi zona de estudio marcando las estaciones donde se ha llevado a cabo la recogida de datos.

Después de esto, seguimos con diagramas T/S, son diagramas donde se grafica la temperatura potencial y la salinidad, secciones verticales de temperatura potencial, salinidad y densidad. Con la densidad averigüé la capa de no movimiento que era un dato importante para seguir con el resto del trabajo.

A partir de una base de datos facilitada por el profesor, me descargué datos de SADCP y LADCP de la campaña en formato 'netCDF'. Tras unas pautas que me indicaron para saber descargar y manejar los datos de este tipo de fichero, y saber exactamente los datos que necesitaba, tuve que seleccionar los datos de mis estaciones y prescindir del resto. Una vez supe los datos necesarios tuve que calcular la velocidad en superficie y una media en profundidad, y graficarlo. Con los datos de LADCP genero un fichero de la marea de la zona y calculé las velocidades de 'u' y 'v' de marea.

Con los ficheros de SADCP, LADCP y velocidades geostrófica generé el fichero de velocidad de referencia, y se graficó las tres velocidades por par de estaciones. Además de la velocidad de referencia.

También calculé el transporte acumulado y el transporte por capa de la zona, y se graficó, a partir de la velocidad de referencia generada con anterioridad.

Hice un procesado de datos de satélite con el programa 'SeaDas', traté los datos de clorofila y temperatura superficial del mar (SST), previamente descargados de la base de datos de 'Ocean Color Nasa', de un día de la campaña en la zona de estudio, ya que al ser datos de satélites hay que elegir un día donde se pueda apreciar con claridad la temperatura superficial del mar y la clorofila *a* sin la presencia de nubes en la zona de muestreo.

Finalmente, con todos los datos y gráficas obtenidas con el Matlab y con la búsqueda de bibliografía he redactado el TFG.

Formación recibida

He recibido unas pequeñas clases de Matlab, para refrescar lo que he dado a lo largo de estos años de estudio con este programa. Además de cosas nueva que me han enseñando para poder realizar el trabajo necesario para mi trabajo final.

Nivel de integración e implicación dentro del departamento y relación con el personal

El nivel de integración ha sido muy bueno. Ha habido buenas relaciones con el personal del grupo de investigación.

Aspectos positivos y negativos más significativos relacionados con el desarrollo del TFG

Cuando me han surgido dudas, se han interesado por ellas y me ha facilitado documentación y orientación para resolverlas. En ocasiones he tenido que resolver problemas por mis propios medios. Valoro como aspecto positivo haber aprendido a hacerlo aunque a veces resultaba complicado encontrar la solución adecuada.

Valoración personal del aprendizaje conseguido a lo largo del TFG

Considero valioso el aprendizaje logrado con el TFG. Ha sido la primera vez que he tenido una experiencia directa de investigación y las dificultades que tiene trabajar con datos reales que pueden traer consigo muchos problemas y tienes que saber solucionarlo de la mejor manera. Además he ampliado mis conocimientos sobre el trabajo y la redacción de artículo científicos.