Surface currents in the tropical Atlantic across high density XBT line AX08

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[1] Three temperature sections that cross the tropical Atlantic obtained from high density XBT transects are used to identify the major surface currents and to compute their water mass transports. The dynamic heights are computed using XBT temperature profiles with salinity derived from historical T-S relationships. The values of dynamic height estimated from altimeter data used in conjunction with climatological dynamic height fields are within 3 cm of the XBT-derived values. The error in XBT-derived dynamic height introduced by using historical T-S relationships instead of actual salinity values are estimated to be of the order of 1.5 cm. Dynamic height estimates using the actual salinity values underestimate those obtained using historical T-S relationships. The structure exhibited in the dynamic height and altimeter-derived sea height fields do not reveal all the upper ocean currents, making these temperature sections presented here critical for computing transports and identifying currents in this region. *INDEX TERMS:* 4512 Oceanography: Physical: Currents; 4536 Oceanography: Physical: Hydrography; 4532 Oceanography: Physical: General circulation; 4283 Oceanography: General: Water masses. **Citation:** Goni, G. J., and M. O. Baringer, Surface currents in the tropical Atlantic across high density XBT line AX08, *Geophys. Res. Lett.*, *29*(24), 2218, doi:10.1029/2002GL015873, 2002.

1. Introduction

[2] In support of the PIRATA project and US CLIVAR, which focus on the ocean-atmospheric interactions in the tropical Atlantic, the high density XBT line designated AX08 has been funded by NOAA in order to improve the current observing system by measuring long term spatial-temporal variability of mesoscale oceanic features, including surface currents. The XBT line AX08 crosses the tropical Atlantic in a NW-SE direction between North America and South Africa. Historical data along AX08 and other temperature observations in the tropics exhibit decadal and multi-decadal signals [*Enfield and Mayer*, 1997]. It has been hypothesized that this decadal signal may have a cause and effect relationship between atmospheric and oceanic signals. Given the importance of the tropical Atlantic in climate variability, and the scarcity of observations in this region, data obtained from the measurements along this line are key to improving the climate forecast by increasing the subsurface temperature coverage. Within the CLIVAR Atlantic program, NOAA/AOML has carried out the first three realizations of this line in its high-density mode, deploying XBTs approximately every 30 km, between 20°N and 20°S in December 2000, September 2001 and January 2002 (Figure 1). This transect will be repeated four times per year, one during each season, for the next five years.

[3] The upper ocean dynamics in the equatorial Atlantic is dominated by the presence of westward currents, eastward countercurrents and westward undercurrents. Their seasonal cycle is highly related to the seasonally varying wind field, including the migration of the Intertropical Convergence Zone. The South Equatorial Current (SEC) has been described to have up to four main branches, the south SEC (sSEC), the central SEC (cSEC), the north SEC (nSEC) [*Molinari*, 1982], and the equatorial SEC (eSEC) [*Stramma and Schott*, 1999]. The South Equatorial Undercurrent (SEUC) flows between 3°S and 5°S typically between 100–500 meters depth and is usually found between the nSEC from the cSEC [*Molinari et al*, 1981]. The South Equatorial Countercurrent (SECC) flows between 7°S and 9°S [*Stramma*, 1991], between the cSEC and the sSEC and is believed to be formed in part by recirculation of waters from the cSEC and sSEC. The cSEC lies between the SEUC and the SECC. The sSEC, characterized as a broad and slow moving current between 10 and 25°S [*Stramma and Schott*, 1999], lies to the south of the SECC and bifurcates off the coast of Brazil at approximately 10°S, with its waters contributing to the formation of the North Brazil Current (NBC) to the north and the Brazil Current to the south. The North Equatorial countercurrent (NECC), which lies between the NEC and nSEC, is the southern limit of the North Atlantic subtropical gyre. In the western tropical Atlantic, this current becomes very week during the boreal spring, even reversing the direction of its flow towards the west [*Garzoli and Katz*, 1983]. However, further to the east and closer to the AX08 section, the NECC can be seen as a persistent feature throughout the year [*Peterson and Stramma*, 1991].

[4] This study uses temperature profile data from the three available XBT sections along AX08. The objective of this work is to provide additional information on the spatial and temporal variability of the above currents by estimating their location and geostrophic transport. The relationship between the altimeter-derived and the hydrographically-derived dynamic height fields are explored in this work. Salinity profiles are derived from historical monthly T-S relationships to estimate the geostrophic transport of each of these currents. Additionally, salinity profiles obtained from 14 profiling floats deployed during the December 2000 transect are used to investigate the uncertainty of the

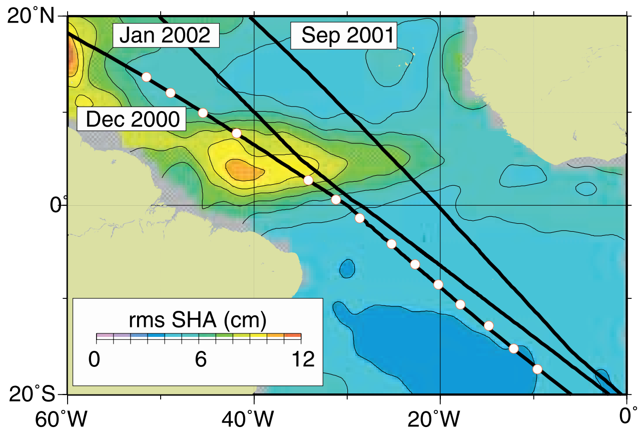


Figure 1. Sea surface height variability in the tropical Atlantic. The location of the XBT sections (black lines) and profiling float deployments (circles) are superimposed.

dynamic height estimates caused by using salinity obtained from historical T-S relationships.

2. Region of Study and Data Collected

[5] The mean dynamic topography of the tropical Atlantic is characterized by a series of zonal troughs and crests superimposed to an east-west slope. Some indication of the variability of the surface currents in this region can be evaluated from the rms of SHA derived from TOPEX/POSEIDON data (Figure 1). The variability is up to three times lower in the southern hemisphere indicating either very weak spatial and temporal variability of the currents, a combination of compensating effects in the water column, which may mask changes in the sea level [*Mayer et al.*, 2001], or both. In the northern hemisphere, the variability is higher between the equator and 10°N west of 30°W, with a peak value of rms of SHA of more than 10 cm. This region is also characterized by having the largest temperature variability between 100 and 200 m depth [*Mayer et al.*, 2001]. The northern portion of the three AX08 sections crosses the region of higher rms variability.

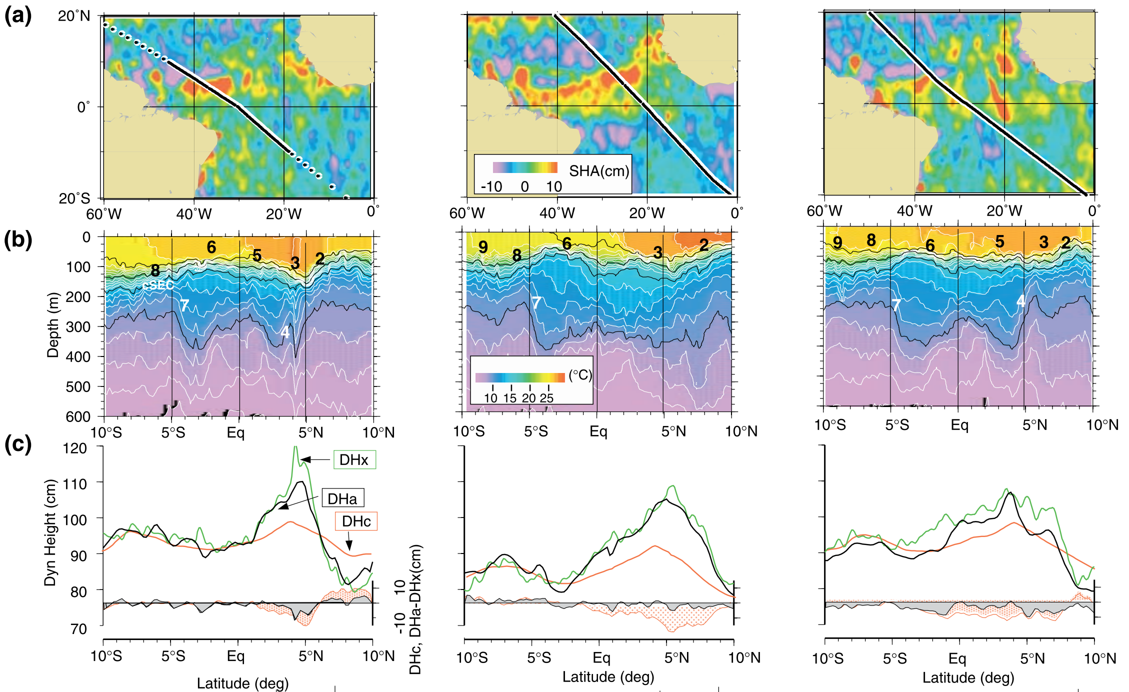
[6] A total of 500 deep blue XBTs were deployed during the first three transects between 20°N and 20°S. The thermal structures observed during these sections depict the mesoscale features present in the region (extending to over 800 meters depth), as given by the slope of the isotherms (Figure 2b), with each of these sections showing a larger mean slope in temperature in the northern hemisphere. All sections show the characteristic deepening and shoaling of isotherms indicative of the geostrophic currents: NEC, NECC, NEUC, SECC, SEUC and SEC.

[7] Along-track sea height anomaly data derived from a blended product of three altimeters (TOPEX/POSEIDON, ERS-2 and GFO), was extracted along each of the XBT sections (Figure 2a). The blended sea height anomaly (SHA) fields are generated using a Gaussian interpolator with a radius of 0.5 degrees for a ten-day period centered about the day when each XBT section crossed the equator. These SHA fields reflect some of the main features associated with the surface and undercurrents. Higher SHA anomaly values, of more than 10 cm, between the equator and 10°N are found in the northern hemisphere and associated with the nSEC, the NEUC and the NECC. Unfortunately, the three XBT sections do not cross areas of very low or high SHA values in the southern hemisphere.

3. Analysis and Results

[8] Dynamic heights referenced to 500 m (Figure 2c) and transports (Table 1) were computed from the XBT data by using the monthly temperature-salinity relationships from the *Conkright et al.* [1998] climatology and matching potential temperatures to infer the salinity. The along-section altimeter-derived sea height anomaly added to the mean dynamic height [*Conkright et al.*, 1998] produces values that have a mean 3 cm (December 2000), 3 cm (September 2001) and 2 cm (January 2002) rms difference with the computed XBT-derived dynamic heights (Figure 2c). These estimates are approximately 20% better than using TOPEX/POSEIDON altimeter data alone, denoting the advantage of utilizing a blended altimeter product. These rms differences appear to be larger in the northern hemisphere, with the NECC consistently exhibiting the largest differences. Differences between the XBT and altimeter estimates of dynamic height are because the altimeter-derived values include a barotropic and steric component and because the XBT-derived dynamic height is referenced to 500 m, while altimetry integrates the effects of the entire water column. Although altimeter estimates are usually lower than the dynamic height estimates using XBT data by 1 to 4 cm (Figure 2c), the main features are still reproduced. Given the overall fairly good agreement between the dynamic height derived from XBTs and the altimeter-derived height, the surface geostrophic transport derived from them should also be in reasonable agreement as well. A comparison between the XBT-derived and monthly climatological values of dynamic heights (Figure 2c) shows that climatological values are inadequate to identify the dynamic height features characteristic of the currents, particularly in the northern hemisphere. The rms values of these differences (red panels of tables in Figure 2c) are of up to 9 cm in the northern hemisphere, approximately 5 cm larger than the differences obtained using altimetry estimates.

[9] As part of another NOAA/OGP-funded CLIVAR project a total of 14 profiling floats were deployed during the first transect (Figure 1). The salinity profiles obtained from the profiling floats show higher surface salinity in the southern hemisphere than the Levitus climatology (Figure 3). Over the entire section (10°N to 10°S) water is saltier at the surface (to 150 m deep) by approximately 0.4 psu. At deeper levels, considerably lower values of salinity of up to 0.3 psu between 150 and 500 m deep are found. These differences between measured and climatological salinity are not negligible. Our results indicate that the dynamic height computed from the historical T-S relationship were consistently higher than the dynamic height from float-derived salinity by approximately 1.5 cm (Figure 3). This difference can be thought of as a measure of the error in dynamic height when salinity information is missing. This uncertainty in salinity is probably the largest contribution to dynamic height error. Furthermore, the error appears substantially dependent upon geographic location, with differences as large as 5 cm. Although the estimates of dynamic height using salinity data derived from profiling



	10°S-10°N	SH	NH
mean dif (cm)	-1	-1	0
rms dif (cm)	3	2	3
mean dif (cm)	-1	-1	-1
rms dif (cm)	6	1	9

	10°S-10°N	SH	NH
mean dif (cm)	-1	1	-2
rms dif (cm)	3	2	3
mean dif (cm)	-1	4	-7
rms dif (cm)	6	2	5

	10°S-10°N	SH	NH
mean dif (cm)	-4	-3	-4
rms dif (cm)	2	2	2
mean dif (cm)	-4	-3	-6
rms dif (cm)	4	3	5

Figure 2. AX08 sections from December 2000 (left), September 2001 (center), and January 2002 (right) showing (a) the station locations (black line) overlaid on the corresponding altimeter-derived sea height anomaly map, (b) the XBT temperature sections. The 25, 20, 15 and 10°C contours are highlighted in black. The numbers correspond to the main currents as shown in Table 1, and (c) the dynamic height derived from XBTs using historical T-S relationships (DHx, green lines), from altimetry using climatological dynamic height (DHc, red lines). The differences between the XBT and the altimeter and climatological estimates are also indicated below (in red and gray shades). The tables list the mean differences for the altimeter (gray) and climatological (red) estimates for the entire section and the northern (NH) and southern (SH) hemispheres.

floats emphasizes the importance of knowing the correct values of salinity at mesoscale resolution, we use the historical relationships to compare the transport of water mass for the three sections, because salinity from floats is only available during the first realization.

[10] The transport and location of each of the geostrophic currents were estimated from the temperature sections and from geostrophic transports computed using a zero reference velocity at 800 m depth (Table 1). The locations of the currents were determined from examination of inflection points in the cumulative transport (not shown). Transports were computed to 800 m depth. While most of the currents can be identified in all three sections within similar latitude ranges, the computed transports vary substantially. Perhaps the most unusual finding in these transport estimates is the relatively barotropic nature of the currents outside of ±3°

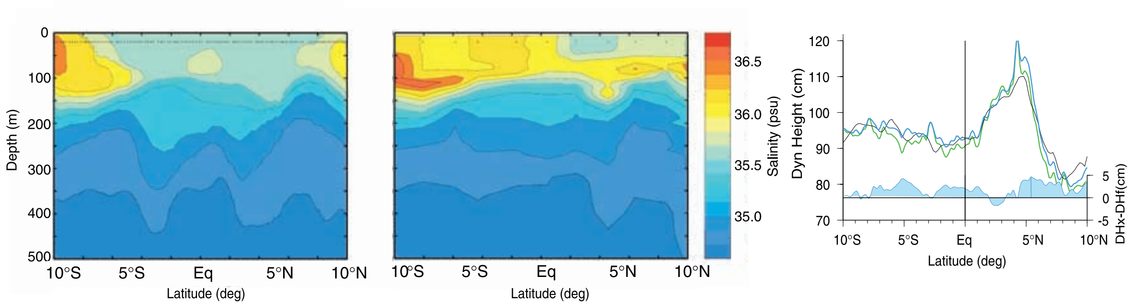


Figure 3. Salinity sections during December 2000 using monthly T-S relationships (left) and profiling floats salinities (center). (right) Difference (blue line and shading below) between the dynamic height derived from the XBT section and salinity from monthly T-S relationship (green line) and from the XBT section and the salinity obtained from the profiling floats (blue line). This difference shows the overestimation of dynamic height when using historical T-S data. The altimeter-derived dynamic height is superimposed (black line).

Table 1. Locations and Transports for Each of the Currents Identified Along AX08

Current	December 2000		September 2001		January 2002	
	Location	Sv	Location	Sv	Location	Sv
1. NEC	19.7–9.7°N	−23	19–13.1°N	−15	19.8–11.1°N	−22
2. NECC	7.2–4.9°N	25	9.7–5.6°N	22	9.3–7°N	16
3. nSEC	4.9–3.7°N	−20	5.6–3.2°N	−20	7–5.5°N	−14
4. NEUC	3.7–3.0°N	14	–	–	5.5–3.9°N	18
5. nSEC	3.0–1.7°N	−37	–	–	3.9–2.2°N	−30
6. eSEC	1.5–3.6°S	−36	1.7–4.3°S	−5	1.8–4.2°S	−13
7. SEUC	3.6–5.2°S	17	4.3–5.4°S	11	4.2–4.7°S	14
8. cSEC	5.2–6.8°S	−13	5.4–6.9°S	−11	4.7–8.0°S	−6
9. SECC	10–12.9°S	6	6.7–9.5°S	11	8.0–9.3°S	7
10. sSEC	12.9–19.9°S	−7	9.5–15.3°S	−10	9.3–20°S	−8

Negative values indicate transports towards the west. All transports are integrals to 800 m of geostrophic velocities assuming a level of no motion at 800 m, the deepest level of XBT temperature observations.

from the equator. For example, the SECC and SEUC were found to include surface currents with substantial transport above 100 m, while historical estimates suggest these currents are primarily subsurface [*Peterson and Stramma*, 1991; *Molinari et al.*, 1981]. It is clear from the temperature sections that the SEUC has reverse shear in the surface layer that tends to reduce the near surface flow (Figure 2b). However, it is not enough to counteract the subsurface shear. Similarly, the SECC is surface intensified. Another important finding here is that dynamic height estimates (Figure 2c) indicate that the NECC, NEUC and nSEC are the features with the strongest surface signature in the northern hemisphere. The SECC and the SEUC appear to be the most identifiable currents in the southern hemisphere from the surface dynamic height values, although there exists only a weak signature in the December 2000 section. The rest of the currents must be identified using the temperature profiles because surface dynamic height or altimeter data alone cannot adequately detect them.

[11] Transport values computed here generally fall within previous estimates. However, given the different methodologies and locations used in their computation, direct comparisons are not straightforward. Our results show the NECC located between the NEC and the nSEC with larger transport values, between 22 and 25 Sv (1 Sv = 10^6 m^3/s) during September and December, respectively, marginally reflecting the strengthening of this current due to the northern migration of the ITCZ [*Garzoli and Katz*, 1983]. The NEUC was not identified in the December 2001 section, but contains almost identical transport values in the other two sections. The core of this current is found here to be between 100 and 300 m deep between 3 and 5.5°N. This region is characterized by larger values of rms of sea height (Figure 1) as well as by large temperature variability between 100 and 200 m [*Mayer et al.*, 2001, their Figure 3]. Between 3–5°N, this subsurface current appears to impact the sea surface height variability seen in altimetry. The NEUC lies between two westward branches of the nSEC during December 2000 and between the NECC and the nSEC during January 2002. This current was not observed during September 2001. The nSEC is found here up to 7°N (January 2002) and with somewhat larger transport values than previously reported [*Stramma and Schott*, 1999]. The SEUC is concentrated between 100 and 550 m deep, with its core found between 4 and 5°S in all three sections.

[12] Transports obtained from the three sections do not show a more noticeable range of values in the northern hemisphere, despite the large SHA rms. Although the transports of the currents in both hemispheres show a similar range of fluctuations, the weaker SHA variability field in the southern hemisphere may be probably due to weaker spatial variability of the currents in the region. While blended altimetry data with improved spatial and temporal resolution may lead to more accurate SHA fields, results obtained here suggest that there are substantial tropical upper ocean currents with very weak surface signature and spatial variability that cannot be resolved from surface topographic fields alone. It is hoped that future XBT sections will aid in establishing a relationship between each current and their characteristic sea height signature to establish a monitoring system to investigate their spatial and temporal variability in more detail.

[13] **Acknowledgments.** XBT and profiling float deployments were funded by NOAA/OGP. The blended altimeter data is provided by ONR through Navoceano. Special thanks goes to the crew or the M/V SAFMARINE NOLIZWE and the M/V MAERSK CALIFORNIA for accommodating these measurements and to our science personnel Robert Roddy and James Farrington for obtaining the XBT data. The authors would like to thank two anonymous reviewers and Dr. C. Schmid for her suggestions and careful reading of the manuscript.

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