The Atlantic North Equatorial Countercurrent Inferred From Dynamic Height and Thermocline Depth

From a given temperature profile, three basic oceanographic parameters are usually derived: the dynamic height *Dh* (through a mean T-S curve), the heat content *Ht*, and the thermocline depth *Th*, the latter being frequently defined as the depth of a fixed isotherm or of the maximum temperature gradient. Any relations among these parameters should be useful for ocean-monitoring or interpretations of the results of numerical models. Therefore, I document here the reltionships among these three parameters in the tropical Atlantic Ocean and then analyze, as an example, the impact of using specific parameters (*Th* and *Dh*) to estimate the annual cycle of the western part of the Atlantic North Equatorial Countercurrent (NECC). The basic data used in this note have been gathered by the FOCAL program and are described by Merle and Delcroix (1984) and Merle and Arnault (1985).

The three parameters referred to above, *Dh, Ht,* and *Th,* are first compared through linear regression analysis. Correlation coefficients r were calculated from temperature profiles collected over 4° longitude by 2 ° latitude rectangles, including at least 20 observations running from the surface to 300 m.

The correlations between the depth of the 20°C isotherm and the heat content, defined as the mean temperature of the upper 300 m, first appear to be very useful west of 20°W and between 10°S and 20°N (Figure 1). In fact, in the latter region, the correlations are always > +0.8, *i.e.,* more than 65% of the heat-content variability can be attributed to its linear relation with the depth of the 20°C isotherm. Nevertheless, the heat content can be determined from the depth of the 20°C isotherm, with a standard error of about 0.2°C (4°S-10°N) to 0.4°C (10°S-4°S and 10°N-20°N). In the 4°S-10°N band, this is an order of magnitude smaller than the mean annual cycle of heat storage (Merle, 1983) and in the ratio of 1 in the 10°S-4°S and 10°N-20°N bands. The correlations are thus only interesting in the first latitudinal band, west of 20°W. East of 20°W, 35% of the heat content variability (r= +0.6) can be associated with the vertical displacements of the 20°C isotherm, moving from 30 to 80 m (Merle and Delcroix, 1984). The thermal variability should thus be considered in this area.

The correlations between depth of the 20°C isotherm and the dynamic height (0/300 dbar) are presented (Figure 2). A glance at their spatial variations suggests that the depth of the 20°C isotherm can be used as a proxy for the dynamic height,

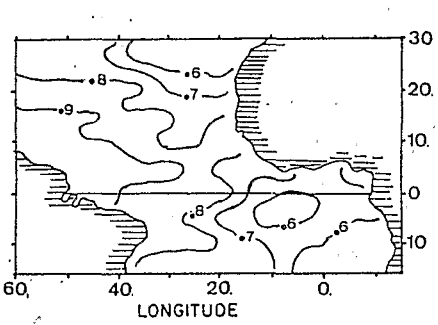

FIGURE 1 (*Delcroix*)
Correlation coefficients, between the 20°C isotherm depth and the heat content (0-300 m).

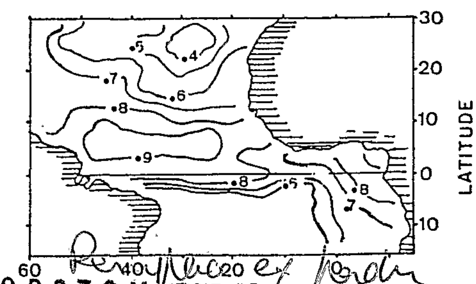

FIGURE 2 (*Delcroix*)
Correlation coefficients between the depth of the 20°C isotherm and the surface dynamic height relative to 300 dbar.

mainly between 4°S-10°N and west of 15°W and in a small part of the Gulf of Guinea (r +0.8). Nevertheless, in these regions, the dynamic height can be inferred from the depth of the 20°C isotherm with a mean standard error of 0.35 m^2s^{-2} (3.5 dyn cm). Such a value is half the amplitude of the annual component of the surface dynamic height relative to 500 dbar (Merle and Arnault, 1985), which is close to the 300-dbar reference level. Therefore, using the depth of the 20°C isotherm to deduce quantitatively the surface dynamic height relative to 300 dbar appears to be quite imprecise for use in the whole basin.

The correlations between heat content and dynamic height are not presented here since they were always > +0.9 in the whole basin, with no significant spatial variations.

The second part of this note illustrates the differences obtained in the mean annual cycle of the western part of the Atlantic NECC, *i.e.,* the region of 4°N-10°N; 35°W-45°W, inferred from the slope of the thermocline (depth of the 20°C isotherm and maximum temperature gradient) and from dynamic height gradients. This latter region was chosen because it is an area of maximum correlation among the three parameters referred to above. Although some previous investigations (Merle and Delcroix, 1984; Merle and Arnault, 1985; Garzoli and Katz, 1983) already noted disagreements when monitoring different parameters in the NECC, they could be attributed to their own raw data management. To prevent such possibilities, we made similar treatments for the parameters (average over 2° latitude by 10° longitude boxes, weighted interpolation, and extrapolation by imposing an annual sinusoidal cycle).

Two estimates of the annual cycle of the western Atlantic NECC, from the meridional slopes of the depths of the 20°C iostherm the maximum temperature gradient between the 2°N-4°N/35°W-45°W and 10°N-12°N/35°W-45°W rectangles, are presented (Figure 3). They are quite consistent with what has been observed (Merle and Delcroix, 1984; Garzoli and Katz, 1983) using different data processing. The zonal velocity components of the NECC, deduced from each slope, agree well in phase, whereas they are almost in the ratio of 2 throughout the year. This is because the 20°C isotherm is generally deeper (+ 10 m) than the depth of the maximum temperature gradient in the northern rectangle and shallower (-5 m) in the southern rectangle. Calculation of the meridional slopes increases these differences. This illustrates quite well the impact of using a given definition of thermocline depth.

In a two-layer ocean model, the slope of the thermocline is proportional to the geostrophic velocity U in the upper layer:

$$U = -(g'/f)\cdot(dTh/dy),$$

where g' is the reduced gravity and f the Coriolis parameter, whereas the meridional gradient of the dynamic height at a given level is proportional to the geostrophic velocity u at this level:

$$u = -(1/f)\cdot(dDh/dy),$$

assuming a level of no motion. Therefore, a third estimate of the annual cycle in the NECC was performed looking at the meridional gradients of dynamic height at different levels. This is presented (Figure 4) for the 0, 30, 60, and 90 dbar relative to the 300-dbar reference level. As previously deduced from the thermocline depth gradients, this third estimate clearly shows that the average zonal velocity over a 100-m depth (*i.e.,* the mean annual depth of the maximum temperature gradient in the area) changes sign from March/April to June. Zonal geostrophic velocities u, deduced from dynamic height gradients, reverse only in May in the first 30 m, in contrast to the 3-month period of the westward current occurring between 60 and 90 m. Using slopes of the thermocline has masked this vertical heterogeneity during the period of reversal. In the investigated area, variations in the meridional gradients of the surface dynamic height can not account for those of the zonal surface velocity deduced from shipdrifts (Richardson and McKee, 1984). Ekman flow should thus be considered.

In conclusion, a given oceanographic parameter (*Dh, Th,* or *Ht*), calculated in the tropical Atlantic Ocean, can not be reliably used to deduce quantitatively the remaining ones through linear relations, except for the depth of the 20°C isotherm and the heat content (0-300 m) west of 20°W and between 4°S-10°N. It was then shown, using 3 different estimates of the annual cycle of the western part of the NECC, that the choice of specific parameters (*Dh* and *Th*), even in regions where they are strongly correlated, is crucial.

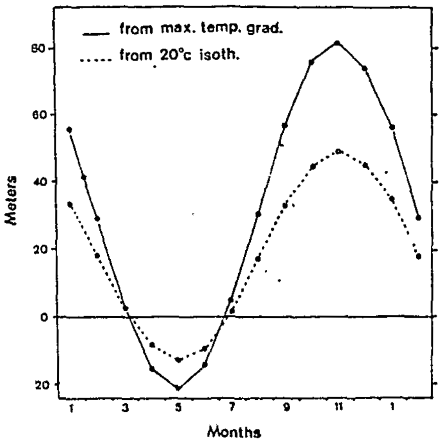

FIGURE 3 (*Delcroix*)
Thermocline depth differences defined as the 20°C isotherm depth and the depth of the maximum temperature gradient between the rectangles 2°N-4°N/35°W-45°W and 10°N-12°N/35°W-45°W.

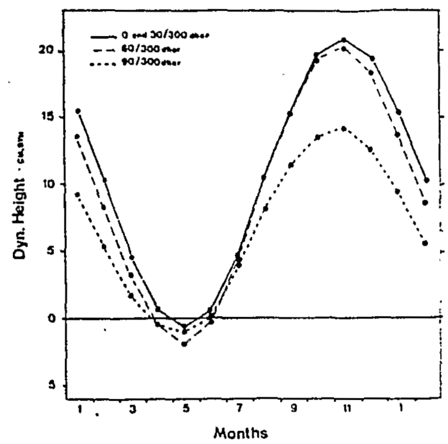

FIGURE 4 (*Delcroix*)
Dynamic height differences at 0, 30, 60 and 90 dbar relative to the 300-dba reference level, between the rectangles 2°N 4°N/35°W-45°W and 10°N-12°N/35°W 45°W.

References

Merle J. and T. Delcroix (1984). Seasonal variability of the thermocline topography in the tropical Atlantic Ocean. (Submitted to the *J. phys. Oceanogr.*).

Merle J. and S. Arnault (1985). Seasonal variability of the surface dynamic topography in the tropical Atlantic Ocean. *J. mar. Res., 43,* 267-288.

Merle J. 1983. Seasonal variability of subsur face thermal structure in the tropical At lantic Ocean. *Hydrodynamics of th Equatorial Ocean.* J. Nihoul, ed., Elsevie pp. 31-50.

Garzoli S. and E. Katz (1983). The force annual reversal of the Atlantic Nort Equatorial Countercurrent. *J. phy Oceanogr., 13,* 2082-2090.

Richardson, P. and T. McKee (1984). Averag seasonal variations of the Atlantic Equ torial currents from historical shipdrift *J. phys. Oceanogr., 14,* 1226-1238.

Thierry Delcroi
ORSTOM
B. P. 35
29273 Brest Cede.
Franc