More on the zonal pressure gradients in the equatorial Atlantic

Equatorial Atlantic
FGGE
Zonal pressure gradient
Wind stress
Atlantique équatorial
PEMG (ou PGGE)
Gradient zonal de pression
Tension de vent

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ABSTRACT

During FGGE in February 1979 the NOAA Ship R/V "Researcher" collected CTD observations along the 27.5, 25, 20, 18, 14.5 and 11°W meridians across the equator. The data were analyzed and the zonal pressure gradient calculated. The data is compared with a study by Katz *et al.* (1977) using historical and GATE data. Our data set supports the Katz *et al.* (1977) conclusion that the zonal pressure gradient associated with the Equatorial Undercurrent is strongly dependent on the zonal component of the wind-stress.

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RÉSUMÉ

Nouveaux résultats sur le gradient zonal de pression dans l'Atlantique équatorial

Durant la PEMG, en février 1979, le NO « Researcher » de la NOAA a effectué des mesures avec une sonde CTD le long des méridiens 27,5, 25, 20, 18, 14,5 et 11°W au niveau de l'équateur. Les données correspondantes sont comparées aux données historiques et de GATE utilisées dans l'étude de Katz *et al.* (1977). Elles permettent de corroborer les conclusions de Katz *et al.* (1977), à savoir que le gradient zonal de pression au niveau du sous-courant équatorial est fortement dépendant de la composante zonale de la tension du vent.

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INTRODUCTION

The establishment of a zonal pressure gradient along the equator, balancing the zonal westward wind stress plays an important role in theories of Equatorial Undercurrents (EUC) (Philander, 1980). Associated with this pressure gradient, the main thermocline along the equator slopes upward from West to East resulting in much greater heat storage in the mixed layer on the western side of the ocean basin when compared with the eastern side (see for example Düing *et al.*, 1981, Fig. 8). Any relaxation of the zonal wind stress, seasonal or interannual, should also relax the pressure gradient and consequently redistribute the zonal heat storage. Because of its importance to the development of equatorial dynamics and implications in climate research, studies of zonal pressure gradients and the relationship to zonal windstress along the equator have recently drawn considerable attention (Katz *et al.*, 1977). This paper, based on recent FGGE data set, has the purpose to extend the previous work by Katz *et al.* (1977).

THE ZONAL PRESSURE GRADIENT

The main result of the study by Katz *et al.* (1977) suggests a strong seasonal dependence of the zonal pressure gradient between 30 and 10°W in accordance with the seasonality of the wind stress. This result is based primarily on the Gate data set collected between

June and September 1974, with additional data from Equalant II in August and September 1963 and a zonal section by Crawford during IGY in November 1958. All of these data were obtained during the high wind stress season. The only data available for the light wind stress season are the Equalant I observations from February to April 1963. And, indeed, the pressure gradients from Equalant I showed significantly lower values.

The FGGE data set were collected between January 1979 and March 1980. In the following, a detailed analysis will be presented using only the "Researcher" data, between 1.5°S and 1.5°N (in most cases 11 CTD casts) and from 27.5, 20, 18, 14.5 and 11°W (a more comprehensive analysis of all FGGE data is in preparation by Lass *et al.*). Since the core of the EUC is meandering about the equator between 1°S and 1°N (Düing *et al.*, 1975), Katz *et al.* (1977) considered associated density variations as "noise" on the zonal mean large scale field and attempted to reduce it by averaging the data between the corresponding latitudes.

Figure 1 shows the zonal dynamic height distribution for 10, 50 and 100 dbar level relative to 500 dbar. The values are averages of nine stations between 1°S and 1°N. The standard deviation of the entire data-set is .006 dyn.m. The salinity maximum of each longitude section is given in Table 1, indicating the approximate location of the core of the EUC (Düing *et al.*, 1975). It can also be seen from the table that in general the magnitude of the salinity maximum decreases from West to East and an increase in density.

The core of the EUC is found south as well as north of the equator (Table 1). If only stations are used which exhibit the highest salinity maximum values for the calculation of the pressure gradient (see Fig. 2), then a close correspondence is found between the meridionally averaged data and these single station data. The largest difference between the section mean and the station with highest salinity is found at 25°W and amounts to 2 dyn.cm, which could imply that even 15 nm sampling spacing may not be sufficient.

From Figure 1, for the 50-500 dbar pressure gradient a value of $2.3 \pm 0.4 \; 10^{-5}$ dynes/g was found, somewhat higher than that of Equalant I (Katz *et al.*, 1977) of 0.4×10^{-5} dynes/g. The difference may be related to the respective windstress magnitudes. The Equalant I data was obtained under near zero conditions of the zonal averaged windstress (Katz *et al.*, 1977). During February and March 1963, the ITCZ was located at the equator and south of it, at least west of 25°W (Kolesnikov, 1973). During the first 2 weeks in February 1979, however, the Intertropical Convergence Zone (ITCZ) was located near 5°N (climatological mean about 4°N) resulting in relatively high winds at the equator. Table 2 lists the wind stress calculated from wind data obtained on the Researcher between 27.5 and 11°W and from the Meteor at 22.5°W (Spaeth, private comm.). The wind stress was calculated from meteorological observations obtained on board the research vessels and at St. Peter and St. Paul Rocks using the wind speed squared law with a value of $\rho_a C_D = 1.3 \times 10^{-6}$. In view of the uncertainty in the wind data this parameterization seems adequate enough for the purpose of this study. If the zonal pressure gradient is indeed strongly

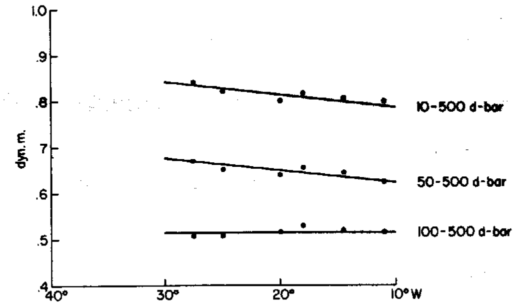

Figure 1
Zonal pressure gradient for the 10-, 50- and 100-dbar surfaces relative to 500-dbar.

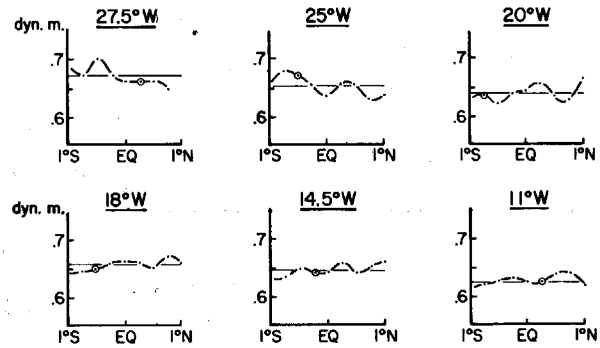

Figure 2
Meridional dynamic height distribution (50-500 dbar) between 1°S and 1°N at 6 different longitudes. Horizontal lines indicate meridional average, points station distribution, and the circle locates the station with the largest subsurface salinity maximum.

Table 1
Location of salinity maximum along the equator.

Section Longitude	Latitude of S.Max	Date 1979	Depth (M)	T (°C)	S (Max. ‰)	δ_t	Sta (N°)
27.5°W	0.5°N	Jan. 31	70	24.70	36.547	24.63	35
25.0°W	0.5°S	Feb. 3	76	25.33	36.523	24.42	43
20.0°W	0.75°S	Feb. 6	50	24.31	36.424	24.65	52
18.0°W	0.5°S	Feb. 7	50	23.35	36.380	24.90	63
14.5°W	0.25°S	Feb. 10	52	23.28	36.350	24.90	75
11.0°W	0.25°N	Feb. 12	50	22.31	36.230	25.09	88

Table 2
Windstress distribution along the equator during FGGE SOP 1 period (31 January -12 February, 1979).

Longitude	T_x	T_y	
30.0°W	−0.39	+0.14	St. Peter and St. Paul Rocks (*)
27.5°W	−0.69	+0.69	Researcher
25.0°W	−0.38	+0.50	Researcher
22.0°W	−0.42	+0.42	Meteor (Spaeth, private comm.)
20.0°W	−0.40	+0.41	Researcher
18.0°W	−0.32	+0.65	Researcher
14.5°W	+0.04	+0.20	Researcher
11.0°W	−0.02	+0.36	Researcher
Mean	−0.32	+0.42	
Climatol.	−0.29	+0.17	Katz *et. al.* (1977)

(*) Average for February 3-10, 1979, data courtesy of E. Katz.

correlated with the wind stress distribution, then a better method of presenting the data would be to sort the data according to the strength of the wind distribution with an appropriate time lag rather than seasonally, thereby possibly reducing the variance, and year to year climatic variability.

It is important for the calculation of the pressure gradient to obtain statistically meaningful data, either in time or in space. According to Katz *et al.*, (1977) and the above, five to nine stations along a meridian between 1°S and 1°N seem to suffice, whereas, pure zonal sections such as the Crawford IGY transect may require averaging over some five longitude degree, in view of the meandering nature of the EUC.

DISCUSSION

In order to place our measurements in a broader perspective, Figure 3 shows them in a seasonal grouping irrespective of year of observation. Katz *et al.* (1977) plotted the pressure gradient of the 50-dbar level relative to the 500-dbar surface for various expeditions: IGY Crawford section from November 1958, Equalant I data obtained in February-March 1963, Equalant II from August-October 1963, and GATE from June-July 1974. We have added our data from January-February 1979 to the diagram (circle). Although larger than the only other winter observation, the winter 1979 value is less than all the summer values. All gradients were taken west of 10°W. It seems that east of 10°W the pressure gradient relaxes at least for the Crawford data to zero (Katz *et al.*, 1977) or reverses sign toward the African Coast (see Neumann *et al.*, 1975; Merle, 1978). The gradients east of 10°W show strong seasonality with maxima in summer during the upwelling in the Gulf of Guinea.

In general, local wind forcing has been excluded for initiating the surfacing of the thermocline and the EUC during summer east of 10°W (Moore *et al.*, 1978), but rather remote forcing in the western Atlantic has been invoked to generate eastward travelling equatorially trapped Kelvin waves. It should also be noted that between 10°W and 0° the magnitude of the zonal wind stress component drops to zero in all seasons, while the meridional component is present in all seasons, except for seasonal changes in magnitude (Hellerman, 1980). For these reasons, all pressure gradients were calculated from the data west of 10°W.

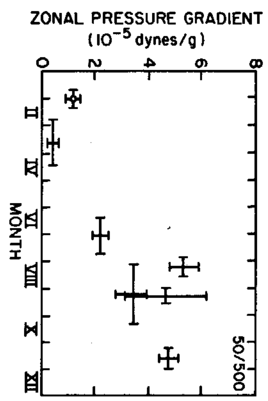

Figure 3

Zonal equatorial pressure gradient in the Atlantic at 50-dbar surface relative to 500-dbar west of 10° W, composite from IGY, Equalant, Gate (Katz et al., 1975*) and FGGE January-February* 1979 *data (circle). The horizontal lines span observational period, the vertical bars indicate the standard error of the regression coefficient.*

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