GEOPHYSICAL RESEARCH LETTERS, VOL. 11, NO. 8, PAGES 802-804, AUGUST 1984

SIMULATION OF THE SEASONAL CYCLE IN THE TROPICAL ATLANTIC OCEAN

S .G. H. Philander and R. C. Pacanowski

Geophysical Fluid Dynamics Laboratory, Princeton University

Abstract. Simulation of the seasonal cycle in the tropical Atlantic Ocean with a multi-level primitive equation numerical model yields remarkably realistic results including the separation of the Brazilian Current from the coast and the reversal of the Countercurrent.

Introduction

Simulation of the various striking phenomena associated with the seasonal cycle in the tropical Atlantic Ocean is a stringent test for any model. These phenomena include the separation of the intense Brazilian Coastal Current from the coast during certain months of the year; the seasonal reversal of the North Equatorial Countercurrent in the western side of the basin; the penetration of the Equatorial Undercurrent into the Gulf of Guinea where the zonal pressure gradient opposes the Undercurrent; and the seasonal coastal upwelling in the Gulf of Guinea in regions when the local winds do not vary seasonally. This report describes results from a numerical model that attempts to simulate these phenomena.

The Model

The model extends from 28°S to 50°N in the Atlantic Ocean and takes the topography of the seafloor into account except that islands do not rise above 150m, the coastal shelf not above 50m. There are 27 layers in the vertical, the resolution is 10m in the upper 100m, the longitudinal grid-spacing is 1° and the latitudinal grid-spacing is 1/3° between 10°S and 10°N. Poleward of these latitudes it increases gradually and is 1.5° at 20°N.

The forcing function is the monthly mean surface winds as described by Hellerman and Rosenstein (1983). To calculate the heat flux at the ocean surface the seasonally varying air temperature at sea level is specified and the radiation and relative humidity are assigned constant values. The only important terms in the heat budget are the incoming radiation and the evaporation from the ocean surface.

The primitive equation model is that described by Bryan (1969). The Richardson number dependent mixing coefficients have been discussed by Pacanowski and Philander (1981). Mixing caused by high frequency wind fluctuations is taken into account by assigning the eddy viscosity a value of 10 cm^2/sec in the upper 10m of the ocean. In the expression for evaporation it is assumed that wind fluctuations exert a minimum stress of .25 $dyne/cm^2$. In the absence of this minimum sea surface temperatures increase to unacceptably high values in regions where the monthly mean windstress is weak.

The initial temperature field corresponds to climatological January conditions as described by Levitus (1982). There are no currents initially. Equilibrium conditions are attained within a matter of months, between 15°N and 15°S and in the upper 300m of the ocean at least, because March of the second year differs little from March of the first year. The results shown here are from the third year of the calculations.

Results

Figures 1 and 2 show the velocity vectors at 5m and the temperature at 55m on 15 February and 15 August. These months correspond to the extremes of the seasonal cycle over much of the basin.

The Brazilian Coastal Current is seen to flow all along the coast in February, but to have turned offshore near 5°N by August. It starts to veer offshore in April already and continues to do so until November. At subsurface levels, however, an anticyclonic eddy is evident, especially in the temperature field, as late as February. This is consistent with the measurements described by Bruce (1984).

The curl of the wind is one factor that determines the behaviour of the Brazilian Coastal Current. It also determines the North Equatorial Countercurrent which is intense and eastward between May and December. In the density field the intense eastward Countercurrent is associated with a trough in the thermocline along 3°N approximately. This trough starts to deepen rapidly in May, especially in the western side of the basin. From July onwards it shoals. Between January and April this trough practically disappears, while the surface flow reverses direction west of 30°W. These results are in excellent agreement with the observations of Garzoli and Katz (1983), Katz and Garzoli (this issue), Richardson and McKee (1984) and Richardson (this issue).

The westward surface flow at the equator is most intense in August (when the southeast trades are most intense) and is very weak in March and April. During the boreal summer the strong latitudinal shear between the equator and 5°N results in unstable waves with a period of three weeks and a wavelength of 1000km. These waves are very inhomogeneous in space - they are most energetic to the west of 25°W - and they are nonstationary in time, appearing abruptly in June and petering out by October. Though this phase propagation is westward, packets of waves are observed to move eastward. Weisbergs's measurements (this issue) reveal waves with the same properties.

The Equatorial Undercurrent is most intense in September and October when the zonal slope of the thermocline to the west of 10°W is a maximum and

Paper number 4L6114.

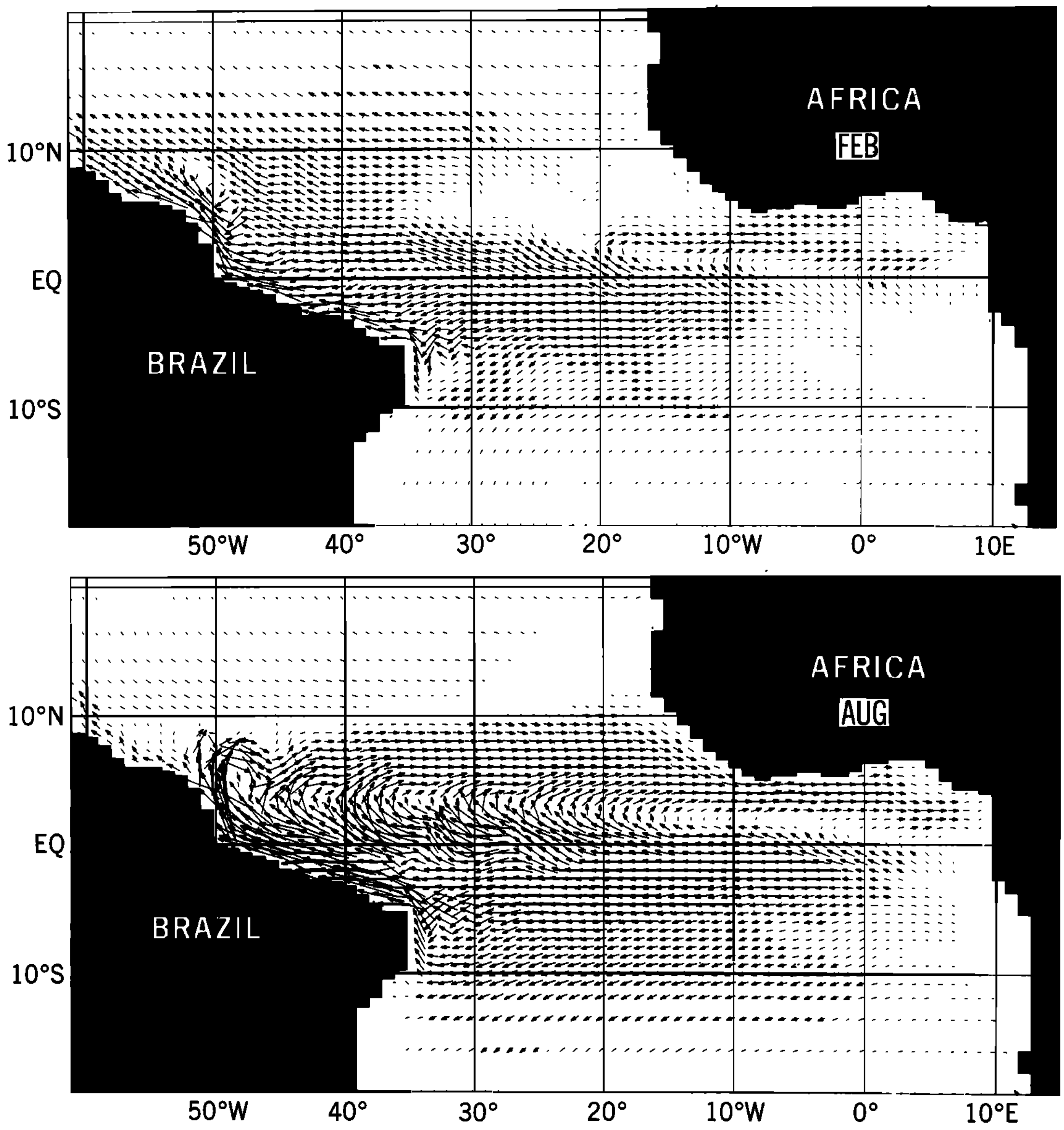

Fig. 1. Map of the horizontal currents at a depth of 5m on 15 February and 15 August.

when the trades are intense. It is weak in March and April. This current penetrates to the African coast between October and February. Along the Greenwich Meridian the maximum speed of 40 cm/sec is attained in October when there is an eastward pressure force as far east as 0°. This suggests that inertial overshoot is a factor in the penetration of the Undercurent further east where the pressure force is westward. Measurements for a quantitative check of these results are not available yet.

In the Gulf of Guinea there is a substantial

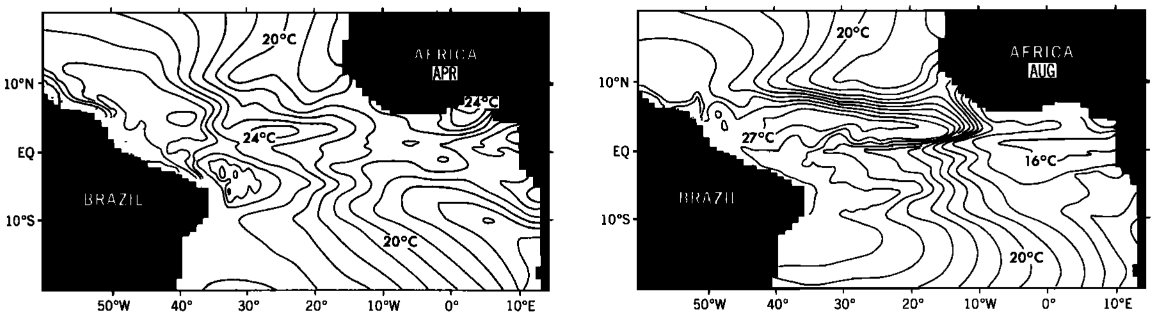

Fig. 2. As for 1 but temperature at a depth of 55m.

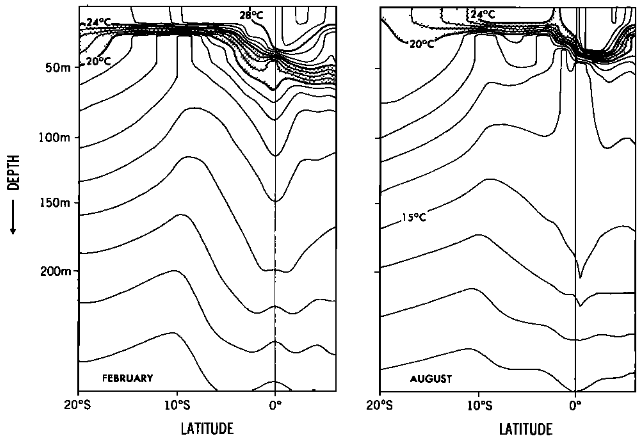

Fig. 3. Meridional section along 0°W of the temperature on 15 February and 15 August.

seasonal change in the latitudinal density gradients (Figure 3). The coastal upwelling during the boreal summer is seen to have a considerable latitudinal scale and not to be a local coastal phenomenon. The simulated changes are in agreement with the observations (Houghton - this issue).

Further analysis of the model results and additional calculations in which simplifying assumptions are made, should elucidate the physics of the various phenomena mentioned here.

References

Bruce J., Comparison of eddies off the North Brazilian and Somali Coasts, *J. Phys. Oceanogr,* In press, 1984.

Bryan K., A numerical method for the study of the world ocean, *J. Comp. Phys. 4,* 347-376, 1969.

Garzoli, S.L., and E.J. Katz, The forced annual reversal of the Atlantic North Equatorial Countercurrent, *J. Phys. Oceanogr., 13,* 2082-2090, 1983.

Hellerman, S., and M. Rosenstein, Normal Monthly Stress over the World Ocean with Error Estimates, *J. Phys. Oceanogr. 13,* 1093-1104, 1983

Levitus, S., Climatological Atlas of the World Ocean, *NOAA Professional Paper 13,* 188pp.,1982.

Pacanowski, R.C. and S.G.H. Philander, Parameterization of vertical mixing in numerical models of tropical oceans, *J. Phys. Oceanogr. 11,* 1443-1451, 1981.

Richardson, P.L. and T.K. McKee, Average seasonal variation of the Atlantic North Equatorial Countercurrent from ship drift data, *J. Phys. Oceanogr.,* In press, 1984.

R.C. Pacanowski and S.G.H. Philander, Geophysical Fluid Dynamics Laboratory, Princeton University, P. O. Box 308, Princeton, New Jersey 08542.

(Received March 12, 1984;
revised May 28, 1984;
accepted May 30, 1984.)