ONSET OF SUMMER SURFACE COOLING IN THE GULF OF GUINEA DURING GATE

Ph. Hisard* and J. Merle**

(received 22 August 1979; revised 28 October 1979)

Abstract--Observations in the Gulf of Guinea during the summer of 1974 provide new information about the onset of summer surface cooling in the eastern equatorial Atlantic. Dramatic variations observed in the hydrological structure of the upper layer during summer are described. The seasonal SST signal is interpreted in terms of an annual component superimposed on an almost permanent El Niño-like phenomenon in the eastern equatorial Atlantic. This interpretation of the observations is supported by recent theoretical considerations which demonstrate the possibility of an eastern tropical Atlantic response to remote atmospheric forcing on a seasonal time scale.

* CRO-ORSTOM, BP V18, Abidjan, Ivory Coast.

** Antenne ORSTOM-COB, BP 337, 29273 Brest, France.

+ CIMAS, 4600 Rickenbacker Causeway, Miami, Florida 33149, USA.

INTRODUCTION

The GATE observations in the eastern equatorial Atlantic Ocean (Gulf of Guinea) have focused attention on a sharp decrease of sea surface temperature at 0°–10°W, during the first days of July, 1974 (R/V PASSAT data). This phenomenon appeared to precede a similar event noticed some days later along the northern coast of the Gulf of Guinea. Research on the link between these two SST decreases has provoked intensive theoretical discussions (Moore et al., 1978; Adamec and O'Brien, 1978; Philander, 1979).

A large amount of GATE-independent data was collected during 1974 as part of the routine activities of the Oceanographic Research Centers or Fisheries Research Unit in Ivory Coast, Ghana and Congo Republics. Moreover, a special experiment was conducted by them on the Ghana continental margin during summertime (Houghton, 1976). It included monthly cruises across the Congo Republic's continental margin, an annual tuna fishery survey between Sao Tome Island and the Gabon Coast, the participation of an airplane conducting infrared radiometer surveys (ART) and a cruise of the R/V CAPRICORNE (ORSTOM-CNEXO) in June–July, 1974 (Fig. 1). These data described well the principal hydrological features of the Gulf of Guinea during the GATE study and shed new light on the so-called summer upwelling.

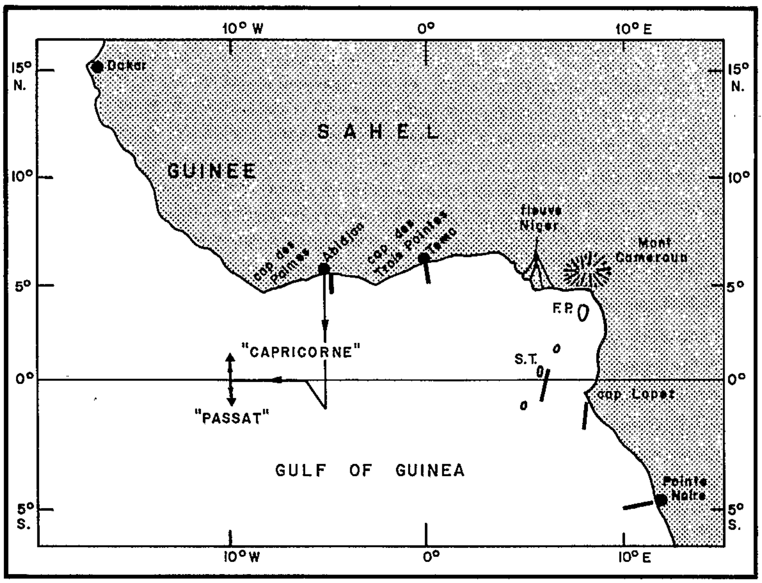

Fig. 1. Chart of the Gulf of Guinea with locations of the oceanographic surveys conducted during summer 1974 (GATE).

OCEANIC CIRCULATION IN THE UPPER LAYER OF THE GULF OF GUINEA

Bounded by land to the north (at 5°N) and to the east (at 10–12°E) the eastern equatorial Atlantic, the Gulf of Guinea, is open to the South Atlantic Ocean. As a consequence, the observed summertime surface cooling was at first accounted for in terms of southern winter influences. Southeasterly trades, which prevail over the basin, south of the equator, become southerly near the equator and southwesterly as they approach the African continent. Thus the winds could, in principle, induce a coastal upwelling. However, in spite of the northward migration of the ITCZ during summertime, and the wind field intensification over the equatorial Gulf, winds remain quite weak along the coastal region (see Fig. 3 in Philander, 1978) and cannot induce significant upwelling.

The Guinea Current is a coastal current which transports low-saline, warm waters toward the east from its western Atlantic origin. It is an extension of the North Equatorial Countercurrent (NECC). It has been demonstrated that the NECC, previously thought to be a seasonal current, is in fact a permanent feature (Hisard, Citeau and Morliere, 1976). Only the surface signal of the NECC is seasonal, this being brought about by the seasonal surfacing of the deeper current, mainly during summer, when the ITCZ migrates northward (Khanaichenko, 1974). In May–June the salinity of the Guinea Current is further decreased by the run-off from intensive precipitation over the mountainous region of Guinea. This is distinct from the two permanent areas of extreme low saline conditions which exist in the eastern Gulf of Guinea, one in the Biafra Bight (due to Cameroon Mountain and Niger flood influences), and one off the Congo River estuary.

The Guinea Current runs above an undercurrent which is thought to be a westward flowing extension of the northern branch of the Equatorial Undercurrent which is split into two branches after impinging upon the African continent at Sao Tome Island (Lemasson and Rebert, 1973a). Because the Equatorial Undercurrent carries cool, highly saline water, the thermocline beneath the Guinea Current is particularly intense.

The other important surface flow in the Gulf of Guinea is the South Equatorial Current (SEC) which is separated from the Guinea Current by the northern tropical convergence along 3°N (Dubravin, 1970; Hisard, 1975). At the equator, the thickness of the SEC sharply decreases due to the presence of the Equatorial Undercurrent (EUC). Hisard (1973) has previously described the seasonal variations of the EUC in the Gulf of Guinea. Near 4°30'S, the third branch of the equatorial countercurrent system is encountered. It has a velocity core of order 50 cm^{-1} s near the 150 m depth level (Khanaichenko, 1974; Hisard *et al.*, 1976).

Along the Gabon and Congo coasts, to the south of Cape Lopez, a thin surface current flows to the north, but the main transport in the upper 200 meters is southward. It is mainly the southern branch of the EUC (Rinkel *et al.*, 1966; Morliere *et al.*, 1974; Hisard *et al.*, 1975). The EUC continues to be important at 5°S (Pointe-Noire) where it opposes the northward continuation of the Benguela Current waters, whose mainstream is moreover deflected westward near $15^{o}S$, at Cabo Frio.

A general description of the atmospheric and oceanic fields in the Gulf of Guinea may be found in three recent atlases by Neumann et al., (1975), Hastenrath and Lamb (1977) and Merle (1978). The upper layer oceanic conditions in the Gulf of Guinea are characterized by a strong seasonal signal which accounts for an alternation between the effects of advection of warm, low salinity water and the summertime surface cooling (Merle, Fieux and Hisard, 1978). It has been demonstrated that this seasonal signal is larger in subsurface than in surface layers, and that advection by the equatorial countercurrent system may play a major role in its development (Merle, 1977).

OBSERVATIONS IN THE GULF OF GUINEA DURING GATE

A detailed data set was acquired at 0^{o}, $10^{o}W$, the western edge of the Gulf of Guinea during all three Phases of GATE by the R/V PASSAT (USSR) and during Phase II by R/V CAPRICORNE (France). These data demonstrated a narrow link between the onset of the summer surface cooling at the equator (the so-called equatorial upwelling) and the shoaling of the EUC (Fig. 2). The direct influence of the EUC upon cooling and enrichment processes of the upper layers at 0^{o}–$10^{o}W$ has been discussed by Hisard et al. (1977). The subsurface maximum salinity core progressively shoals (from 70 to 30 m depth) and simultaneously decreases, from 36.4% in May [data collected in May 1968 by R/V JEAN CHARCOT (Lemasson et al., 1969)] to 35.9% in August, a phenomenon associated with the shoaling of the EUC which increases the mixing with low salinity surface water. As a consequence the equatorial surface cooling precedes the actual surfacing of the Undercurrent.

The sharp decrease of SST observed at 0^{o}–$10^{o}W$, on July 7th to 10th, has been previously discussed and attributed to an oceanic response to remote wind forcing brought about by the intensification of the trades in the central Atlantic during May–June (Katz et al., 1977; Moore et al., 1978; Adamec and O'Brien, 1978). However, until now, no emphasis has been devoted to the increase of SST during the first week of September developed as rapidly as the July decrease. As shown in the following sections, very similar events occurred at nearly the same time along the northern and eastern coasts of the Gulf of Guinea (Fig. 3).

The Easternmost Equatorial Part of the Gulf of Guinea During Phase I of GATE

Each year in mid-June an important tropical tuna fishery exists between Sao Tome Island ($6^{o}30'E$) and Cape Lopez (Gabon coast, $9^{o}E$); it pursues large concentrations of tuna, closely associated with a sharp surface frontal zone. This frontal zone is a boundary between warm, low salinity waters from Biafra Bight, in the north ($28^{o}C$; $33.0^{o}/oo$) and cold, high salinity waters ($22^{o}C$; $36.0^{o}/oo$) which surface slightly to the south of the

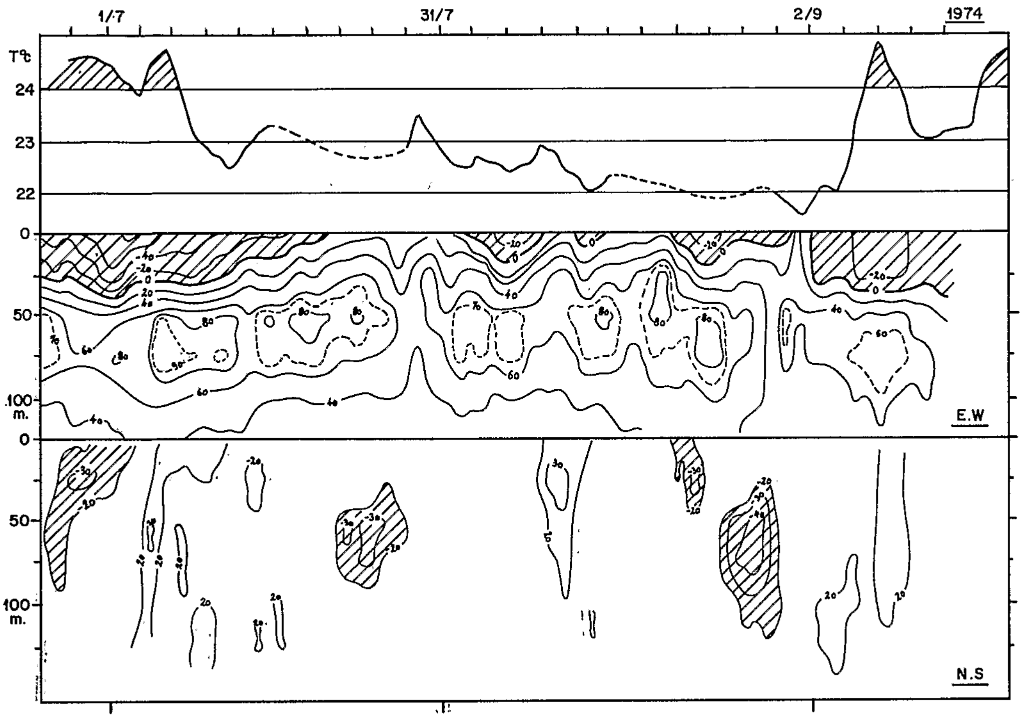

Fig. 2. Upper panel: SST variations at 0°–10°W during the three Phases of GATE. Lower panels: E-W and N-S components of the current, from mooring at 0°–10°W, in cm/sec, as calculated by Düing (pers. comm.) from R/V PASSAT data. Shaded areas: temperature greater than 24°C, west and south components.

equator and spread out along the coast, south of Cape Lopez. These cold, high salinity waters are part of the southern branch of the EUC which runs along the continental margin (Hisard et al., 1975).

ART survey from June–July, 1974 shows that as early as June 14th SST was lowered to less than 23°C, just off Cape Lopez, but there was large variability. In fact, the frontal zone was characterized by waves, and seemingly periodic outbreak of cold water patches has been previously described as a north-south migration of the frontal zone (Stretta, 1977).

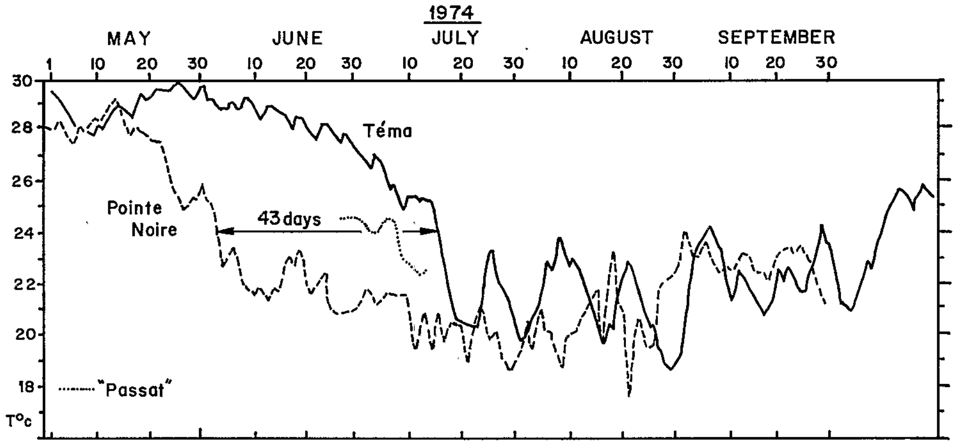

Fig. 3. SST variations during GATE, at three locations in the Gulf of Guinea: thick line is SST variations at Tema (Ghana), dotted line, at 0^{o}–10^{o}W (R/V PASSAT) and dashed line at Pointe Noire (Congo). See locations on Figure 1.

The oceanographic study made during the same period by the R/V CAPRICORNE is not interpretable as synoptic due to the high variability mentioned above. Nevertheless the sea surface salinity chart for this cruise demonstrates high saline patches surrounded by a low saline water mass of northern origin (Fig. 4). The surface high salinity core to the east of Sao Tome Island (35.9%) was observed on July 1st, associated with an SST of 22.2^{o}C. This low temperature was observed at 10^{o}W on July 12th. These observations support the conclusion based on historical data in the open ocean and at the coast that the summertime cooling of surface waters appears to move from east to west along the equator (Merle, Fieux and Hisard, 1978).

The vertical distributions of temperature and salinity (Fig. 5) in the Cape Lopez region in June–July, 1974 are in agreement with the cold high salinity waters observed at the surface, coming from the EUC as suggested by EQUALANT III observations (Rinkel et al., 1966) and a study of the so-called Cape Lopez Upwelling (Hisard et al., 1975).

Hydrological Variations Across the Continental Shelf Off the Congo During 1974

South of the previous region, at 5^{o}S, two sets of data were acquired during GATE along the coast. The first one (Figs. 6a and b) consists of monthly hydrological sections

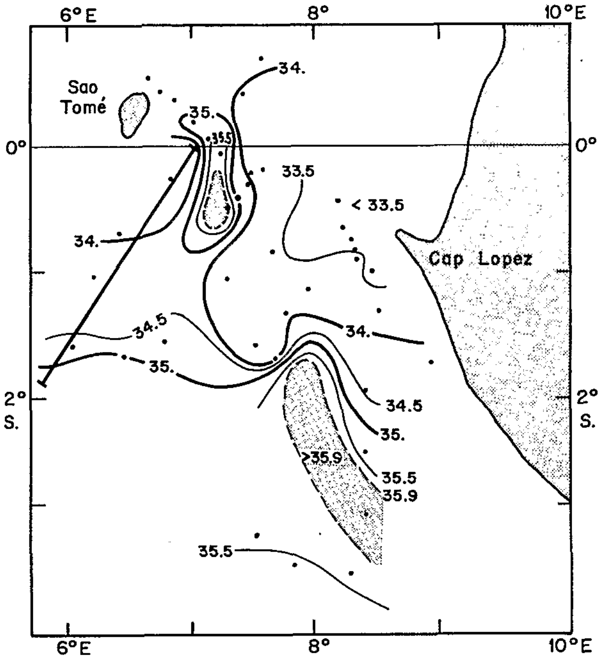

Fig. 4. Surface salinity distribution between Sao Tome Island and Cape Lopez (Gabon) during GATE (Phase I), as observed during a cruise made by R/V CAPRICORNE. Dots represent hydrological stations; shaded oceanic areas underscore water patches with salinity values greater than 35.9^{0}/oo. The thick line south of Sao Tome Island shows the position of the section in Figure 5.

across the continental shelf together with anchored current meter stations. The second (Fig. 7) is the daily surface T-S series at the Pointe-Noire coastal station which is part of a 10-year time series.

In April and May, 1974, the vertical distribution of salinity (Fig. 6a) demonstrates the intensification of the southern branch of the EUC. The subsurface salinity maximum flowed southward near 50 m depth, below a thin layer of low salinity, warm water which flowed northward along the coast probably due to the trade wind forcing. In June, the subsurface salinity core shoaled. As a consequence, the surface salinity increased and a surface cooling occurred but with exceptionally low values of salinity (Fig. 6b); consequently this cooling is attributed to the influence of the northward extension of the Congo River outflow plume.

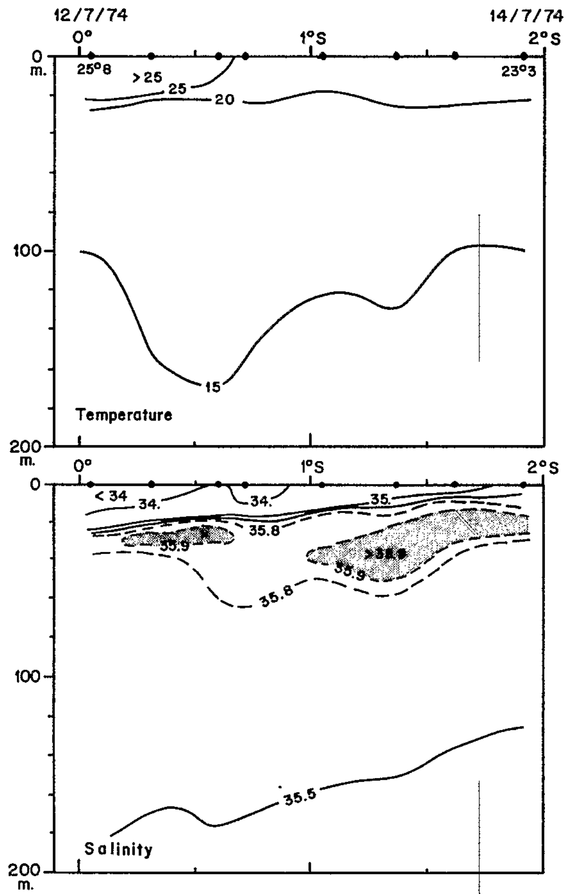

Fig. 5. Vertical transects of temperature (upper panel) and salinity (lower panel), along a section to the south of Sao Tome Island (see location on Fig. 4), on July 12-14th, 1974. Salinity values greater than 35.9°/oo are shaded.

The influences of this variation upon the Pointe Noire coastal station record are dramatic (Fig. 7). As early as May 20th, SST decreases sharply at 17 m depth and the salinity greatly increases to about 35.8°/oo. Spectral analysis of the 10-year time series revealed an energy peak at around 14 days (Picaut and Verstraete, 1975) in the same way as off Cape Lopez and along the equator.

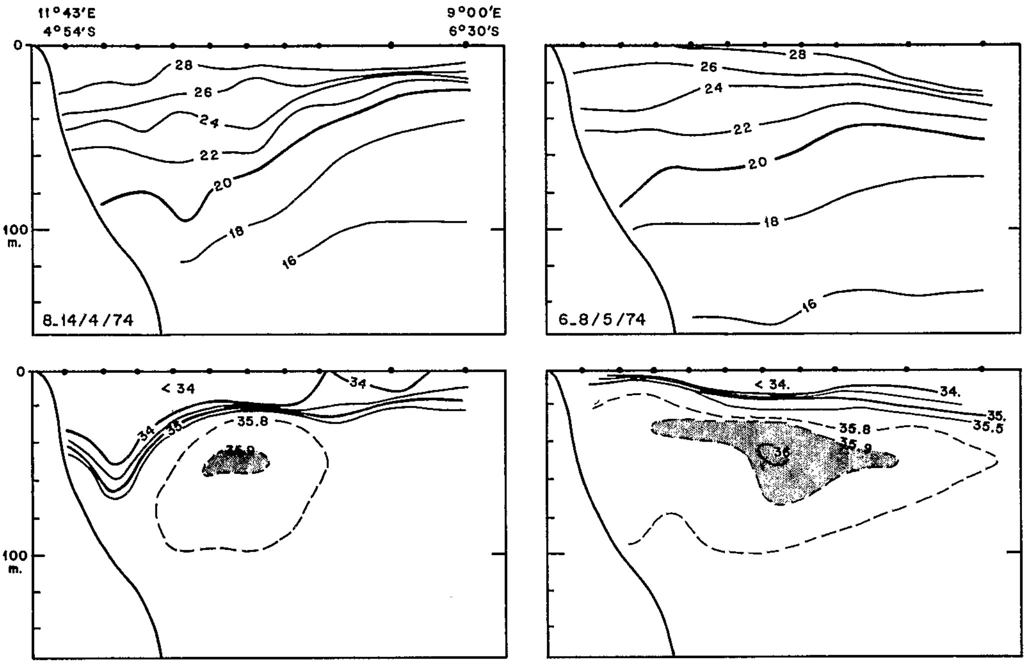

Fig. 6a. Vertical transects of temperature (upper panels) and salinity (lower panels) across the Congo Republic continental margin, off Pointe Noire, during April (left) and May (right) 1974. Salinity values greater than 35.9°/oo are shaded.

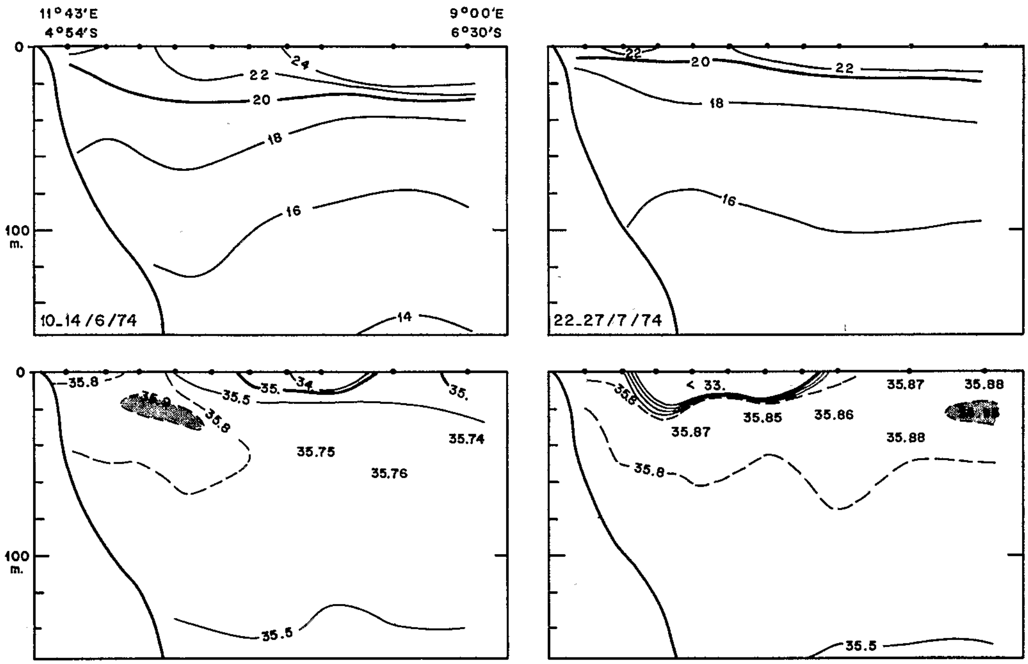

Fig. 6b. Same as Figure 6a but for June and July, 1974.

It has not been possible to correlate the observed surface cooling in May–June with local wind variations (Berrit, 1976). Tentative explanations of the cooling by influences of the Benguela Current appear to be irrelevant. Based on the characteristics of the upwelled (cool, saline) waters, these waters are advected southward in a branch of the EUC. This interpretation is supported by current meters measurements made during 1977.

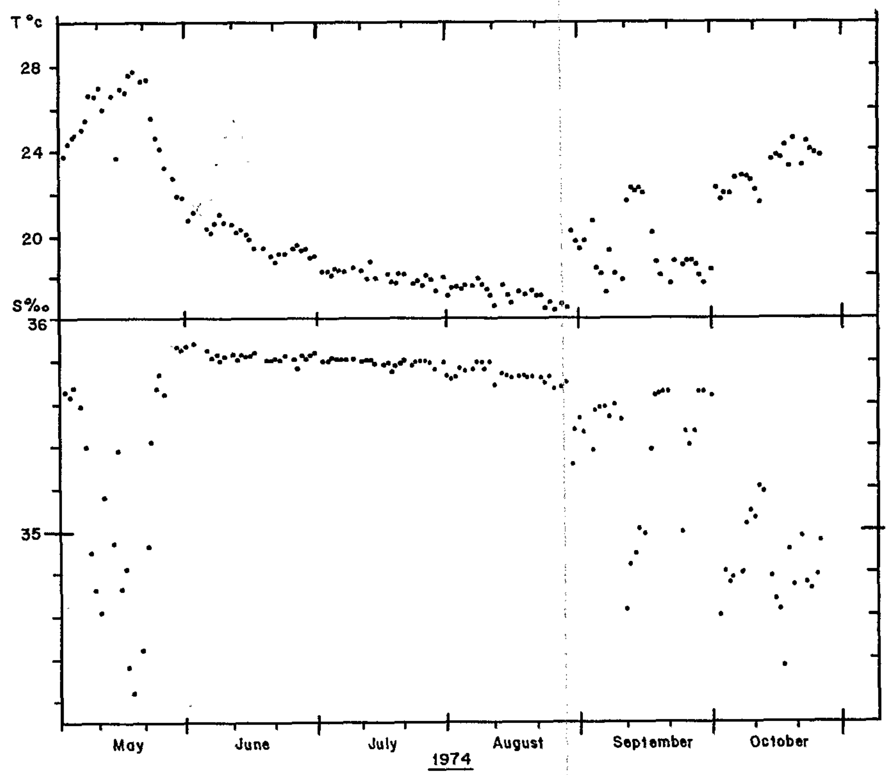

Fig. 7. Time series of daily measurements of temperature and salinity at 17 m depth, on the continental margin, off Pointe Noire (5°S–$11^{\circ}50'$E) during GATE. Data from ORSTOM-Oceanographic Research Center.

Very special conditions can develop when a massive southward extension of the northern waters from the Biafra Bight occurs and inhibits the summertime surface cooling along the Congo and Angola coasts as far south as Cabo Frio (15°S) where it opposes the flow of the Benguela Current. Such a situation has been described by Dhonneur (1974), as cited in Wauthy (1977) during the year 1925. He hypothesized that the north-south ITCZ pattern over central Africa was anomalously deflected offshore, over the ocean, a situation which would favor northerly coastal winds and a corresponding El Niño-like phenomenon along the Congo and Angola coasts.

Hydrological Variations Along the Northern Coast of the Gulf of Guinea During 1974

At the coastal stations off Ghana, SST decreased rapidly on about July 15th, 1974. The summer surface cooling which lasted until the first week of October (when a rapid SST increase took place), was characterized by a well-delineated oscillation with a period of about 14.5 days (Fig. 8). There is some evidence that the 14.5-day wave propagated westward (Houghton and Beer, 1976; Picaut and Verstraete, 1975). Thus, this oscillation appeared to be a general feature in the Gulf of Guinea along the E-W and N-S continental margin to the north and to the south of the equator, as well as along the equator.

The hydrological variations which accompanied the onset of the summer cooling in 1974 were described by Houghton (1976) using weekly hydrological surveys across the continental margin plus data from moored current meters. These observations confirm the conclusions from the Oceanographic Research Center (CRO-ORSTOM) in Abidjan (Ivory Coast) that the onset of the surface cooling is induced by the shoaling of the sharp thermocline and the subsequent surfacing of the cold, high salinity waters of the westward undercurrent (Morliere, 1970; Lemasson and Rebert, 1973b). The shoaling of the thermocline is consistent with geostrophic adjustment of the north-south slope of isotherms when the Guinea Current intensifies (Bakun, 1978; Philander, 1978a) a phenomenon which is enhanced off Cape Palmas and Three Points Cape. Philander (1978) suggests that the Guinea Current is induced by cross-equatorial winds that are intense at the equator but weak at the coast. However, from Bakun (1978) there is a lack of coincidence between locations of maximum offshore transport in the Guinea Current and SST minimum, and there is a lag of at least one month between the maximum current, observed in July, and the SST minimum in August-September.

Warm and low salinity water is advected eastward in the western and central Atlantic and flows eastward in the NECC. GATE data have shown that the eastward advection by the NECC had been previously underestimated. During summertime and also during February and March to a lesser extent, a second water mass dominates. This colder (less than 25^{o}C) and more saline (greater than 35.5^{o}/oo) water mass is advected westward from the northern branch of the EUC (Lemasson and Rebert, 1973a; Hisard and Morliere, 1973).

The period of transition between these water masses is generally rapid; both the SST decrease in July and the SST increase in July and the SST increase in October are sharp. There is a coincidence between those events and the seasonal north-south migration of the ITCZ (Fig. 9). The high rate of the precipitation which is associated with the ITCZ induces twice a year (in May-June and in November) a dramatic lowering of the salinity values in the upper layer.

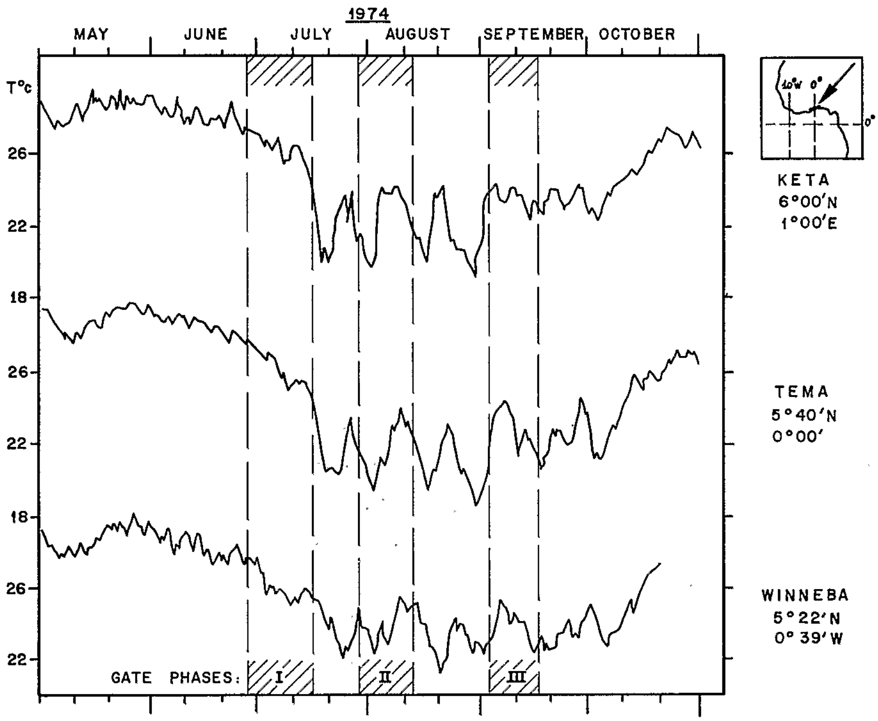

Fig. 8. — Time series of daily measurements of temperature at three coastal stations along the Ghana coast, during GATE. Date provided from the Fishery Research Unit (Tema).

During some years, as for instance during 1968, the summer cooling was nearly absent due apparently to an exceptional advection of warm, low salinity water by the Guinea Current. As a consequence of this anomalous warming, heavy rains occurred during the normally dry months of August and September (Bakun, 1978; Lamb, 1978). This anomalous situation was related to the northward migration of the ITCZ which did not proceed far enough during June, 1968 (Sadler, 1975;Lamb, 1978), a situation which would favor a more intensive advection of western Atlantic waters. Historical data analysis by Lamb (1978) and by Merle et al. (1978) underscored the existence of a widespread positive SST anomaly during the 1968 spring and summer in the entire equatorial region. Such a situation was also observed during 1958 and during 1963 (EQUALANT experiment). These situations are suggestive of an El Niño-like phenomenon which begs a comparison of the eastern equatorial Atlantic with the eastern equatorial Pacific. The biological consequences of the 1968 El Niño in the Atlantic was of a great importance. A large decrease in Sardinella aurita catches greatly damaged the local fishing industry in Ghana (Bakun, 1978) and the recruitment of the 1968 year class for tropical tuna was at a minimum (Fonteneau, personal communication). Moreover, due to heavy rains, catastrophic floods occurred in Ghana which induced exceptional damage.

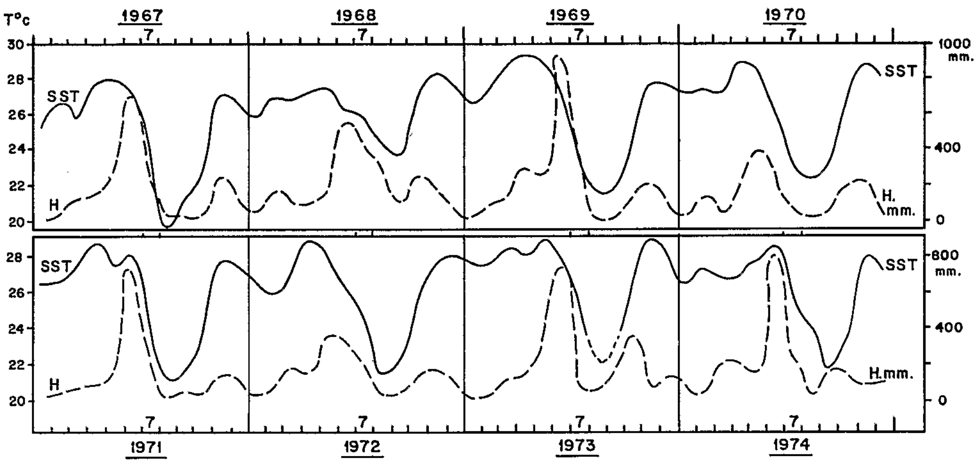

Fig. 9. SST and rainfall variations in Abidjan (Ivory Coast) during eight years, from 1967 to 1974. Note the weak summer surface coooling in 1968, and the rapid variations of SST between the "warm" and "cold season."

It has not been possible to satisfactorily explain the onset of the so-called summer coastal upwelling either in terms of local wind-driven upwelling or current-induced upwelling. As underlined by Houghton (1976), the 1968 summer wind was more intensive than normal and should have induced a more intensive coastal upwelling. Tentative explanations which invoke remote atmospheric forcing due either to an increase of the E-W stress of the wind (Moore et al., 1978; Adamec and O'Brien, 1978) or to an increase of the N-S stress (Philander, 1978) were proposed.

DISCUSSION

The preceding description of hydrological variations during the 1974 summer in three different locations in the Gulf of Guinea highlights a feature common to these events: the summer surface cooling proceeds through high salinity water from the EUC, either directly as along the equator, or indirectly, via the southern and northern branches of the EUC, west of Sao Tome Island. Until now these three coolings were considered independently and they were described in terms of either equatorial or coastal upwelling, regardless of the difficulties in relating them to familiar mechanisms of upwelling. The hypothesis of an oceanic response to a remote westward atmospheric forcing in the western equatorial Atlantic is not consistent with the surface cooling at Cape Lopez and along the Congo coast, which occurred prior to the cooling at 0^{o}–10^{o}W and along the northern coast of the Gulf of Guinea. These intriguing results led some authors to consider the possibility of an underestimated influence of cold water advection from the Benguela Current whose mainflow is apparently westward deflected at Cabo Frio (15^{o}S).

Little attention has been devoted to the long "warm" season which was mainly suggested to be of local origin. It appears that this "warm" season is mainly due to an eastward advection along with the Guinea Current. The intense local rain which parallels this season can be considered as a consequence of this warm advection creating a positive feedback. The extreme situations observed some years (1958, 1963, 1968) confirm this point of view. Hence, the normal situation in the eastern Atlantic would be an almost permanent annual "El Niño" interrupted only three to four months in summer and one to two months in winter. In contrast, even if a weak "warm" season occurs annually around Christmas time in the eastern Pacific ("Originally the name El Niño was applied to a weak coastal current flowing southward along the coast of Equador around Christmas time. As such it is an annual event . . ."; Wyrtki, 1975), the normal situation there is an almost permanent surfacing of cold waters. Extreme situations of El Niño occur when the "warm" season extends over several months as in 1972-1973. It is the consequence of a large eastward advection of warm, low salinity water in the NECC due to a relaxation of the trades and a subsequent intensification of the countercurrent system (Wyrtki, 1975).

Hence, we can consider that the eastern equatorial regions of the Pacific and Atlantic Oceans are similar in the structure of the processes affecting the seasonal and interannual variability but different by the magnitude of the induced effects. Both oceans have a "warm season," normally short in the Pacific Ocean and long in the Atlantic. The abnormal situation occurs when this "warm season" becomes longer in the Pacific, and so long in the Atlantic that the summer cold season does not even appear. The annual variation and the interannual variability of the SST of these equatorial oceans are modulated by the more or less extension of the "warm season." We claim that the warm surface water, associated with the "warm season" is due, in the Atlantic Ocean, to an eastward warm advection and to its local consequence: rain and run-off. Thus, the budget of warm, low salinity water in the eastern equatorial oceans appears to be the leading factor in determining the SST variability on the seasonal and interannual time scales, independent of the dynamic processes producing advection of these warm surface waters (atmospheric remote forcing and equatorial waves). That this budget appears more variable on an interannual time-scale in the Pacific and, in contrast, more regular and larger in the Atlantic, can be related to the size of the basins. The smaller Atlantic basin can react on an annual time scale and with a large amplitude to the seasonal variation of the atmospheric forcing; in the larger Pacific basin, a similar phenomenon, "El Niño," can only occur on an interannual time scale (Philander, 1979)).

Acknowledgments--For the second author, this study is partially supported by NOAA Contract No. 03-7-022-35199.

REFERENCES

ADAMEC D. and J.J. O'BRIEN (1978) The seasonal upwelling in the Gulf of Guinea due to remote forcing. Journal of Physical Oceanography, 8, 1050-1060.

BAKUN A. (1978) The Guinea Current upwelling. Nature, 271, 147-150.

BERRIT G.R. (1976) Les eaux froides côtières du Gabon a l'Angola sont-elles dues a un upwelling d'Ekman? Cahiers ORSTOM Séries Océanographique, XIV, 4, 273-278.

DHONNEUR G. (1974) Nouvelle approche des réalites méteorologiques de l'Afrique Occidentale et Centrale. Université de Dakar, Faculté des Sciences, Rpt. n°3.

DUBRAVIN V.F. (1970) Observations sur les courants de Golfe de Guinée. Proc.-Verb. Atlantic NIRO, XXVII, 27, 150-172. In Russian.

DÜING W., PH. HISARD, E. KATZ, J. MEINCKE, L. MILLER, V. MOROSHKIN, G. PHILANDER, A.A. RYBNIKOV, K. VOIGT and R. WEISBERG (1975) Meanders and long waves in the Equatorial Atlantic. Nature, 257, 5525, 280-284.

HASTENRATH S. and P.J. LAMB (1977) Climatic atlas of the tropical Atlantic and Eastern Pacific Oceans. The University of Wisconsin Press, Madison, 112 pp.

HISARD PH. (1973) Variations saisonnières a l'équateur dans le Golfe de Guinée. Cahiers ORSTOM Séries Océanographique, XI, 3, 349-358.

HISARD PH. (1975) La circulation superficielle dans la partie occidentale du Golfe de Guinee. Documents Scientifiques CRO Adidjan, VI, 2, 41-57.

HISARD PH. and A. MORLIERE (1973) La terminaison du Contre Courant Equatorial Subsuperficiel Atlantique (Courant de Lomonosov) dans de Golfe de Guinée. Cahiers ORSTOM Séries Océanographique, XI, 4, 455-464.

HISARD PH., J. CITEAU and A. MORLIERE (1975) Le Courant de Lomonosov et la formation de la zone frontale du Cap Lopez (Baie de Biafra, Golfe de Guinée). Cahiers ORSTOM Séries Océanographique, XIII, 2, 107-116.

HISARD PH., J. CITEAU and A. MORLIERE (1976) Le systeme des contre courants equatoriaux subsuperficiels; permanence et extension de la branche sud dans l'océan Atlantique. Cahiers ORSTOM Séries Océanographique, XIV, 3, 209-220.

HISARD PH., J. CITEAU and B. VOITURIEZ (1977) Equatorial Undercurrent influences on enrichment processes of upper waters in the Atlantic Ocean (as illustrated through GATE data). Lecture given to the Miami GATE Workshop, March 1977.

HOUGHTON R.W. (1976) Circulation and hydrographic structure over the Ghana continental shelf during the 1974 upwelling. Journal of Physical Oceanography, 6(6), 910-924.

HOUGHTON R.W. and T. BEER (1976) Wave propagation during the Ghana upwelling. Journal of Geophysical Research, 81(24), 4423-4429.

KATZ E.J. and Collaborators (1977) Zonal pressure gradient along the equatorial Atlantic. Journal of Marine Research, 35(2), 293-307.

KHANAICHENKO N.K. (1974) Le système des contre courants equatoriaux dans l'ocean. Ed. Guidrometeoizdat. Leningrad, 159 pp. (in Russian). French translation by Ph. Hisard and H. Rotschi.

LAMB P.J. (1978) Case studies of tropical Atlantic surface circulation patterns during recent Subsaharan weather anomalies: 1967 and 1968. Monthly Weather Review, 106, 482-491.

LEMASSON L., J. NOEL and J.P. REBERT 1969) "Guinée 1": Croisière du navire océanographique JEAN CHARCOT. Travaux et Documents ORSTOM, 3, 87 pp.

LEMASSON L. and J.P. REBERT (1973a) Circulation dans le Golfe de Guinée; étude de la région d'origine du sous courant ivoirien. Cahiers ORSTOM Séries Océanographique, 11(3), 303-316.

LEMASSON L. and J.P. REBERT (1973b) Les courants marins dans le Golfe Ivoirien. Cahiers ORSTOM Séries Océanographique, 11(1), 67-95.

MERLE J. (1977) Seasonal variations of temperature and circulation in the upper layer of the equatorial Atlantic Ocean. Miami GATE Workshop, March 1977, Abst. 1.87-1.88.

MERLE J. (1978) Atlas hydrologique saisonnier de l'océan Atlantique intertropical. Travaux et Documents ORSTOM, 82, 184 pp.

MERLE J., M. FIEUX and PH. HISARD (1978) Annual signal and interannual anomalies of sea surface temperature in the Eastern Equatorial Atlantic Ocean. Deep-Sea Research, GATE Supplement II to V. 26, 77-102.

MOORE D., PH. HISARD, J. MC CREARY, J. MERLE, J. O'BRIEN, J. PICAUT, J.M. VERSTRAETE and C. WUNSCH (1978) Equatorial adjustment in the Eastern Atlantic. Geophysical Research Letters, 5, 637-640.

MORLIERE A. (1970) Les saisons marines devant Abidjan. Documents Scientifiques CRO Abidjan, 1(2), 1-15.

MORLIERE A., PH. HISARD and J. CITEAU (1974) Le courant de Lomonosov dans le fond du Golfe de Guinée en mai 1973. Documents Scientifiques CRO Abidjan, 5(1-2), 85-102.

NEUMANN G. (1966) The Equatorial Undercurrent in the Tropical Atlantic. Actes Symposium Oceanographique Ressources Halieut Tropical Atlantic. Abidjan, UNESCO, 33-44.

NEUMANN G., W.H. BEATTY, III and E.C. ESCOWITZ (1975) Seasonal changes of oceanographic and marine climatological conditions in the Equatorial Atlantic. Department of Earth and Planetary Sciences, City College of CUNY and CUNY Institute of Marine and Atmospheric Science, 211 pp.

PHILANDER S.G.H. (1978) Upwelling in the Gulf of Guinea. Journal of Marine Research, 37, 23-33.

PHILANDER S.G.H. (1979) Variability of the tropical oceans. Dynamics of Atmospheres and Oceans, 3, 81-82.

PICAUT J. and J.M. VERSTRAETE (1975) Low frequency oscillations of temperature and sea level along the coasts of the Gulf of Guinea. Paper presented at the IUGG Symposium, Grenoble, August, 25, 1975.

RINKEL M.O., P. SUND and G. NEUMANN (1966) The location of the termination area of the Equatorial Undercurrent in the Gulf of Guinea based on observations during EQUALANT III. Journal of Geophysical Research, 71(16), 3893-3901.

SADLER J.C. (1975) The Monsoon circulation and cloudiness over the GATE area. Monthly Weather Review, 103, 5, 369-387.

STRETTA J.M. (1977) Température de surface et pêche thonière dans la zone frontale du Cap Lopez (Atlantique tropical oriental) en juin et juillet 1972, 1974 et 1975. Cahiers ORSTOM Séries Océanographique, XV, 2, 163-180.

WAUTHY B. (1977) Revision de la classification des eaux de surface du Golfe de Guinée (Berrit, 1961). Cahiers ORSTOM Séries Océanographique, XV, 3, 279-295.

WYRTKI K. (1975) El Niño - The dynamic response of the Equatorial Pacific Ocean to atmospheric forcing. Journal of Physical Oceanography, 5(4), 577-584.

Global Atmospheric Research Program Atlantic Tropical Expiriment (GATE)

GATE-2

EQUATORIAL AND A-SCALE OCEANOGRAPHY

Editor

WALTER DÜING

PERGAMON PRESS OXFORD and NEW YORK 1980