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On the existence of an El Niño-type phenomenon in the Benguela System

by L. V. Shannon[1], A. J. Boyd[1], G. B. Brundrit[2] and J. Taunton-Clark[1]

ABSTRACT

Since the early 1950s, although there have been several warm and cool periods in the Benguela region off southwestern Africa, e.g. the warm event in the southern part of the system during the austral summer of 1982/83, only two events which approximate to an *El Niño*-type situation have occurred, viz in 1963 and in 1984. During the 1963 event temperatures 2–4°C and salinities 0.1–0.2 × 10^{-3} above normal were recorded in the upper 50 m off Namibia up to at least 150 km offshore. The pressure adjusted sea level during 1963 was on average 4 cm above the mean. During early 1984 an intrusion of equatorial water moved southward along the coast of northern and central Namibia to 25S. This most recent Benguela *Niño* was preceded by an extended period of vigorous upwelling during 1982 and 1983. Higher than average pressure adjusted sea levels were recorded at Walvis Bay between October 1983 and September 1984 with maximum positive monthly anomalies of 7 cm during March and August 1984. Equatorward windstress was above average during both the 1963 and 1984 events. Although long time series in the Benguela are few, historic records indicate that in March 1950 the 27°C isotherm in the eastern Atlantic lay 600 km further south than normal, while there is evidence that a major *El Niño*-like event occurred here between February and August 1934, with sea temperatures 2–3°C above the long term average from March to July 1934. During the 1934 perturbation there was a reported slackening and reversal of the usual equatorward surface flow of the Benguela current and abnormally high rainfall occurred which resulted in extensive flooding of Namib Desert rivers. High rainfall over the Namib was recorded in 1950 and 1963 while some flooding occurred in 1984. Conditions were clearly anomalous in low latitudes in the Atlantic in 1934 and 1963, while there was a major perturbation in the equatorial Atlantic in 1984. This strongly suggests a nonlocal cause of the Benguela anomalies. It is suggested that there is a South Atlantic equivalent of the Pacific *El Niño*, but that in the Benguela region these events are less pronounced and less frequent. Their causal mechanism may also be different. The effect of these events on the southern Benguela is minimal.

1. Introduction

The term *El Niño* originally referred to an annual event in the eastern Pacific commencing around Christmas and lasting for about three months. During this period there is a cessation or relaxation of upwelling or alternatively a depression of the seasonal thermocline so that local equatorward winds do not bring cool nutrient rich

1. Sea Fisheries Research Institute, Private Bag X2, Rogge Bay, 8012, Cape Town, South Africa.
2. Department of Physical Oceanography, University of Cape Town, Rondebosch, 7700, South Africa.

water to the surface, and a southward flow of warm water occurs along the coasts of Ecuador and Peru. In some years anomalously warm water covers much of the Pacific and the abnormally high sea temperatures encountered along the South American coast persist into the next upwelling season. It is these major events which are now referred to as *El Niño* or ENSO in view of their association with the Southern Oscillation. The periodicity of ENSO events varies between 2 and 10 years (Rasmusson and Carpenter, 1982), with an average period of 3 years (Philander, 1983). The climatological and biological consequences of *El Niño* are well known (e.g. Walsh, 1978).

Probably the earliest reference to a similar occurrence in the tropical eastern Atlantic is that of Schott (1931) who, in his pioneering account of the 1891 and 1925 Pacific *El Niño* events, speculated about *Niño* periods at the west African coast. Schott drew attention to the similarity in shape of the Gulf of Guinea-Cameroon Bight and the area of Galapagos-Gulf of Panama, and also the correspondence between the Peruvian and Benguela upwelling regimes. Citing earlier work he pointed out that southward flows along the African coast between the equator and 14S were common (frequency of occurrence 20–38%), both in summer and in winter. He considered that the principal difference between the Atlantic and Pacific events was that off Peru anomalous conditions only arise on rare occasions when the trade winds are disturbed, whereas off west Africa the frequently changing winds make the southerly warm currents a normal event.

Mechanisms of atmospheric forcing and hydrospheric response in the equatorial-tropical Atlantic, analogous to the Pacific ENSO have been suggested by Hisard (1980), Merle (1980), Merle *et al.* (1980) and others. The seasonal zonal tilt of the thermocline in the equatorial Atlantic, similar to that in the Pacific, was demonstrated by Merle (*op. cit.*), while Merle and Delcroix (1983) noted that there was evidence of the existence of an annual meridional oscillation as well, and suggested a possible link between this and the position of the Inter Tropical Convergence Zone (ITCZ). Lahuec (1984), Citeau *et al.* (1984), Servain (1985) and others have shown that the ITCZ lies further south during "warm" years in the Gulf of Guinea (e.g. 1979, 1980, 1981, 1984) and further north during "cold" years (1978, 1982, 1983). That there is a relation between the zonal wind stress in the western equatorial Atlantic and positive anomalies in the Gulf of Guinea appears certain (Servain *et. al.*, 1985), although Philander and Pacanowski (1981) pointed out that variations in the intensity of meridional winds in the eastern equatorial Atlantic can contribute significantly to the variability of SST in the region in the same way as in the Pacific. A point of comparison between the Atlantic and the Pacific, however, is that the seasonal signal in the Atlantic is stronger than the interannual, whilst the reverse is true in the Pacific.

Although major positive SST anomalies occurred in the Gulf of Guinea in 1947 and 1968, (e.g. Servain *et al.*, 1985; Picaut *et al.*, 1985; CCCO Panel, 1984) the best documented anomaly occurred during 1984. Early in 1984 the zonal pressure gradient in the equatorial Atlantic east of 1E was extreme and dynamic heights were anomalously high (Hisard and Henin, 1985). General eastward drift in the equatorial region was reported by Henin and Hisard (1985) and P. Hisard (pers. commn.) views the large surface South Equatorial Countercurrent as the most surprising feature of the Atlantic in 1984. Reverdin and McPhaden (1986) showed from their analysis of FOCAL buoy tracks that there was near zero westward flow in the Gulf of Guinea, where there was a positive SST anomaly of about 2°C during the second and third quarters of 1984. Piton and Wacongne (1985) recorded unusually high quantities of very high salinity subsurface water ($>36.5 \times 10^{-3}$) in the Gulf in May 1984.

A clear seasonal warming-upwelling signal is evident in the SST in the Gulf of Guinea (e.g. Gouriou, 1984; Reverdin, 1985). Moore *et al.* (1978) attributed the upwelling, in part, to an internal Kelvin wave generated by increased easterly winds off northern Brazil and propagating along the equator and subsequently reflecting poleward at the African coast. A comparable warm pulse moving poleward from the equator can possibly be inferred from the work of Mazeika (1968), Berrit (1976) and McLain *et al.*, 1985 as well as the recently published FOCAL Climatic Atlas of the Tropical Atlantic (Picaut *et al.*, 1985). Verstraete (1985a,b) provided further evidence of the poleward propagation of the mean seasonal coastal upwelling in the region and noted that the annual changes of the heat content depended largely on the changes of the thickness of South Atlantic Central Water, which are related to changes in sea level. He concluded that the equatorial countercurrents play a major role in the advection of heat through the eastern tropical Atlantic.

Hirst and Hastenrath (1983) regarded the Angola littoral as the obvious corollary to the *El Niño* region of the South American west coast and showed that the anomalous seasonal relaxation of wind stress in the western equatorial Atlantic accounted for 23% of the SST variance off Angola, while the local wind forcing contributed only 9%. [Their work suggests a definite link between the relaxation of the wind stress off northern Brazil and the Angolan rainy season (March–April).] However, as the *northern extent* of the main coastal upwelling area off western Africa south of the equator lies around 15S (Shannon, 1985) i.e., close to the border between Angola and Namibia, it may be more appropriate to look at the Benguela region *south* of 15S for evidence of the Atlantic equivalent of the Peruvian *Niño.*

The main upwelling period in the Benguela north of 25S extends from about March to November, peaking around August (see Shannon, 1985). Some upwelling takes place throughout the year, however. Upwelling in the northern Benguela is somewhat out of phase with that south of 30S where the season extends between September and March, with very little upwelling taking place during the winter (June–August). In the central Benguela and also at Cape Frio upwelling is continuous throughout the year (Shannon, 1985). The significance of the phase lag is that the upwelling in the northern Benguela is in phase with the seasonal insolation cycle (which makes it difficult to separate out the interannual signal), whereas in the southern Benguela it is not. The

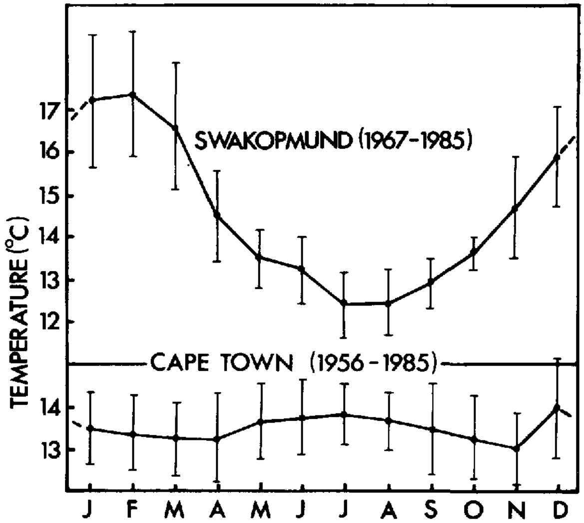

Figure 1. Seasonal SST cycles at Swakopmund (23S) and Cape Town (34S). Error bars are standard deviations of the monthly means.

result is that there is a pronounced seasonal cycle in SST in the north while in the south there is no clear SST cycle. This difference is illustrated in Figure 1. The seasonal SST cycle in the northern Benguela is in fact very similar to the seasonal cycle at 4W between 1N and 1S portrayed by Reverdin (1985) and the coherency between the warming and upwelling in the two areas suggests that they may be linked.

The seasonal warming during late summer off northern and central Namibia is a regular occurrence and is due to the intrusion of warmer higher salinity water of Angolan origin into the region (O'Toole, 1980; Shannon, 1985).It is not merely a surface phenomenon and can be detected at a depth of 50 m and deeper. Aspects of the intrusion resemble the annual event off Peru, *cf* the original meaning of the term *El Niño.* The distribution of temperature at 20 m off central Namibia between March and May 1957 (Fig. 2) illustrates the structure of the intrusion and its subsequent disappearance (1957 was not a "warm" year in the northern Benguela. If anything it was cooler than normal—see Figure 4, also Stander, 1963).

Notwithstanding the lack of reliable long time series for the Benguela, there have been a number of warm and cool periods documented in the northern and southern Benguela (e.g. Stander and De Decker, 1969; Walker *et al.*,1984; Shannot *et al.*, 1984; Boyd and Thomas, 1984; Shelton *et al.*, 1985; McLain *et al.*, 1985). Only on three occasions (1934, 1963, 1984) have *major* warm water intrusions into the system been documented, although there was also an indication of abnormally warm water in the extreme north of the system in March 1950. In this paper we shall take a look at these major events in the Benguela and shall discuss possible connections with processes in the equatorial Atlantic. We shall not, however, attempt to address the causes of the

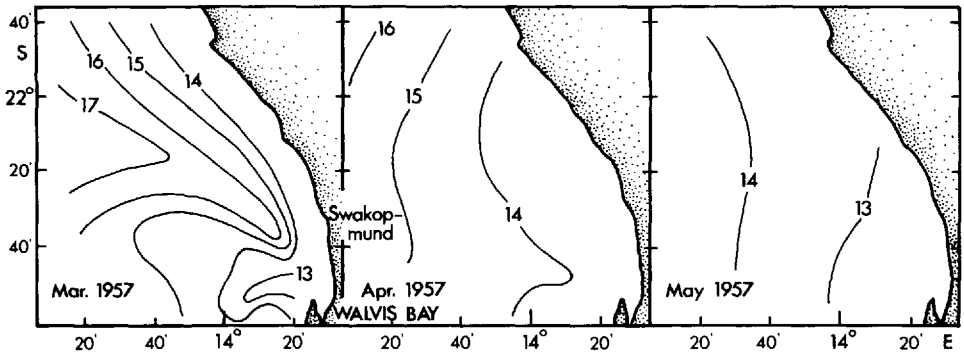

Figure 2. Distribution of temperature (°C) at 20 m off central Namibia, late summer–autumn 1957 (redrawn from Stander, 1962).

perturbations in the low latitudes of the Atlantic, as this is beyond the scope of the present paper.

2. Data

a. Temperature and salinity. Data were obtained from a variety of sources, details of which follow. The monthly temperatures at Swakopmund reflected in Figures 1 and 9 were based on daily measurements in the upper 1 m taken between 09h00 and 10h00 on the lee side of an exposed groyne. Pre-World War II data (Fig. 3) are from Walter (1937). Temperatures during March 1950 are from Hart and Currie (1960). Those at Cape Town covering the period 1955 to 1985 (Fig. 8) were extracted from the continuous records of the ESCOM power station in Table Bay, which has a sea water intake at a depth of about 1–2 m. The sea surface temperatures in the Walvis Bay area (Fig. 4) are from discrete measurements made monthly in the upper 1 m by research

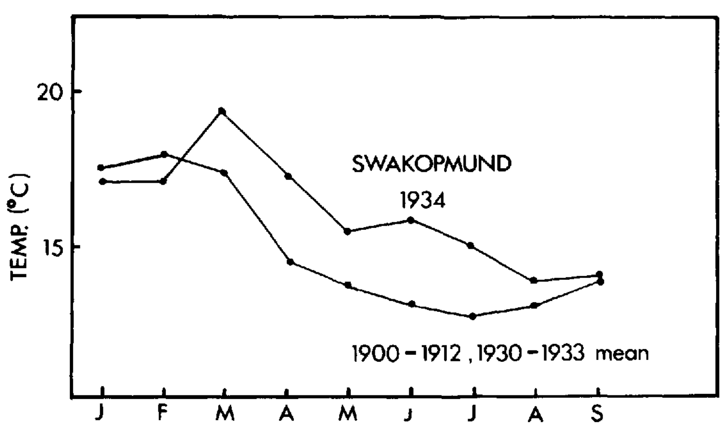

Figure 3. Monthly SST at Swakopmund during 1934 compared to 17 year mean values (after Walter, 1937).

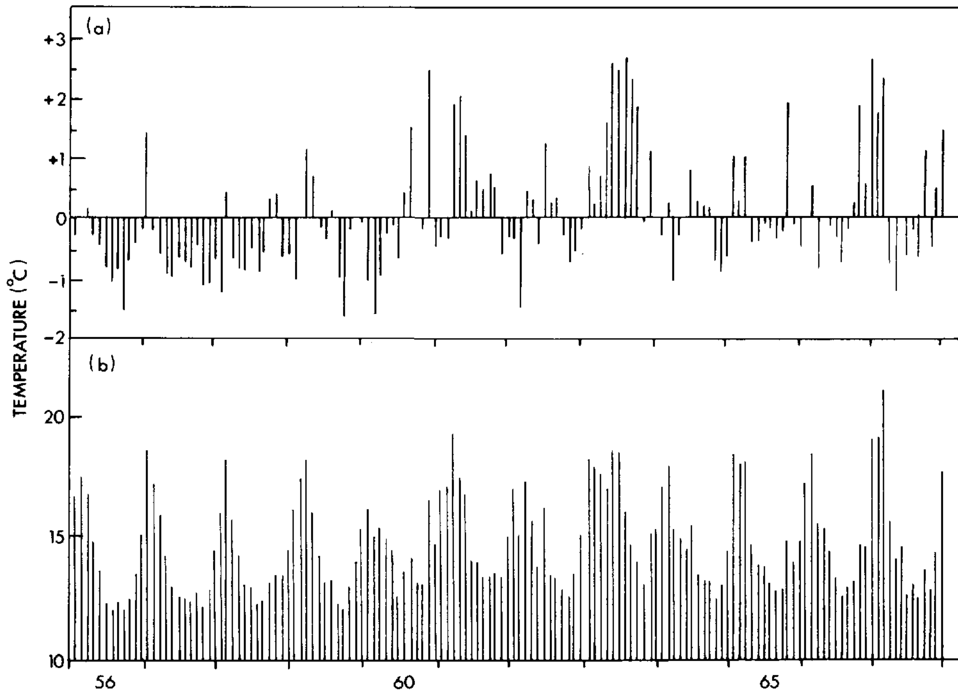

Figure 4. Normalized monthly temperature anomaly (a) and mean monthly SST (b) for the central Namibian area between 1956 and 1967.

ships at stations within a radius of 50 km of the town between 1956 and 1967. The monthly temperatures and salinities at 20 m given in Figure 5 are from Stander and De Decker (1969) and relate to the same group of stations around Walvis Bay. The positions of the 17°C surface isotherm and 34.4×10^{-3} surface isohaline have been extracted from research ship data cited in Stander and De Decker (*op. cit.*). The monthly temperature distributions portrayed in Figure 10 and also the summer-autumn (December–May) mean distribution in Figure 11 have been drawn from data provided by commercial shipping (upper 5 m) via the South African Weather Bureau. The surface isotherms and isohalines during March 1984 (Fig. 11) are from data collected by a research ship of the Sea Fisheries Research Institute. Error bars shown in Figure 1 are standard deviations, while in Figure 9 the normalized monthly anomalies were calculated by division of the monthly values by the standard deviations.

b. Sea level. Tide-gauge records of sea level at Walvis Bay (23S), Lüderitz (27S) and Port Nolloth (29S) were obtained from the Hydrographic Office of the South African

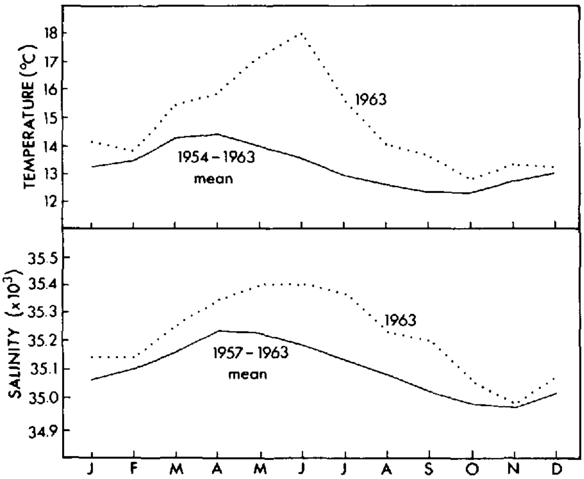

Figure 5. Monthly values of temperature and salinity at 20 m off central Namibia during 1963 compared with the seven year mean values (redrawn from Stander and De Decker, 1969).

Navy. The isostatic effect of air pressure was removed from the raw sea level data using atmospheric pressure data at sea level supplied by the South African Weather Bureau. Sea level referred to throughout this paper is thus pressure adjusted.

c. Winds. Wind data were obtained from two sites, viz. Pelican Point lighthouse near Walvis Bay and Cape Point lighthouse, some 50 km from Cape Town at the southern extremity of the Cape Peninsula. At both these sites wind speed and direction is measured once per hour.

d. Rainfall. Records of total annual rainfall at five sites in the Namib and adjacent areas (Windhoek, Swakopmund, Usakos, Okombahe, Fransfontein) from about the year 1900 as well as shorter records at three other sites (Kamanjab, Khorixas, and Gobabeb) were provided by the South West African Meteorological Service. Additional information was obtained from the South African Weather Bureau News Letters.

e. NOAA satellite imagery. Digital AVHRR data collected by NOAA 7 on 1 and 9 April 1984 (orbits 14305 and 14418 respectively) were obtained from the Satellite Data Service, Washington, D.C. Digital data of the level 1B format was calibrated to brightness temperatures with a thermal resolution of 0.25°C by using scan line specific calibration coefficients (Huh and Di Rosa, 1981) and then atmospherically corrected using the algorithm of Strong and McClain (1984). As existing software did not permit the inclusion of geocoordinates on the output products, the latitudes of key places have been inserted in parenthesis in Figures 12 and 13.

3. Anomalous conditions during 1934, 1950 and 1963

Probably the first documented account of a major climatic perturbation in the northern Benguela region was provided by Walter (1937) who cited observations of anomalously warm water, current reversals off Namibia and high rainfall over the interior of the Namib during the summer of 1933/34. Using data collected by Dr. G. Boss at Swakopmund, a small coastal town just north of Walvis Bay, Walter (*op. cit.*) showed that the mean monthly SSTs between March and July 1934 were 2–3°C above the 15 year monthly mean values (Fig. 3). This implies either reduced upwelling or increased southward advection of warm water over an extended period, or both. That there was enhanced poleward flow in the Benguela during 1934 seems to be confirmed by Walter's reference to the fact that the floodwaters from the Orange River, as characterized by high surface turbidity, flowed southward rather than northward which is more usual. In addition ship passages were reported as being shortened by 2 days between the Canary Islands and Cape Town, which in itself suggests that surface currents in the tropical eastern Atlantic were abnormal at the time. Also of significance is that the summer of 1933/34 was abnormally rainy over large parts of the interior (South African Weather Bureau data) and extensive flooding of Namib Desert rivers occurred, causing coastline modifications (Ward *et al.*, 1983). Northern and central Namibia received about three times its normal annual rainfall during 1934 and Walter (*op. cit.*) attributed this to the proximity of warm water and the possible southward displacement of the atmospheric circulation system. In the analysis of the zonal component of wind stress in the western equatorial Atlantic (5N–5S, 25–35W) covering the period 1923 to 1938 by Servain *et al.* (1982) it is clear that the most significant anomaly occurred in 1934 when the wind stress was well below average throughout the first nine months of the year. Their work also shows that the maximum positive SST anomaly during the 16 year period occurred in mid-1934 in the Gulf of Guinea. Although their data also indicated a positive SST anomaly in the central Benguela area (25–30S, 10–15E) in 1934, other larger anomalies were evident in this region in 1937 and 1938. (The central Benguela area is, however, not a good site for investigation of possible Benguela Niños as it also responds to changes in the southern Benguela which are not necessarily caused by events in the tropical Atlantic.) The 1934 warming in the Gulf of Guinea was also highlighted by Merle *et al.* (1980) whose time series suggest that it was the largest extended positive SST anomaly in the period 1921–1959. From the above it seems that an *El Niño* type of event did occur in the northern Benguela during 1934 and that the warm water intrusion persisted from late summer for about six months.

The rainfall records at all the Namibian sites examined (where these data exist—see Data) indicate that 1950 was an exceptionally wet year in central and northern Namibia. At Swakopmund and Okombahe the annual rainfall equalled the previous recorded maximum (1934) while at Kamanjab the 1934 figure was exceeded. Windhoek received 506 mm of rain during the first four months of 1950—almost double the long-term average for these months. The abnormal rainfall suggests that oceanographic conditions off northern Namibia may have been anomalous during the first part of 1950. Unfortunately no reliable serial records of SST or sea level are available to test this hypothesis. However, during March 1950 *R.R.S. William Scoresby* undertook her first survey of the Benguela Current (Hart and Currie, 1960) and it is appropriate to re-examine some of the data. Hart and Currie (*op. cit.*) reported that the position of the 27°C surface isotherm lay at latitude 16°13′S (just north of the Namibia—Angola border) with a sharp front poleward of this latitude. The occurrence of 27°C water so far south is unusual as data in Picaut *et al.* (1985) and McLain *et al.* (1985) show that its mean position during the month of March is close to 10S. During the major 1984 Benguela *Niño* (discussed later) the 27°C isotherm during March was only slightly further south (see Fig. 11) than in March 1950. Unfortunately Hart and Currie (*op. cit.*) did not record salinity north of 22S on their first survey. However, their bathythermograph measurements on the Möwe Point line (20S) indicate a fairly normal situation (for March), although at 100 m the water over the shelf may have been slightly warmer (by 0.5°C) than normal. Hart and Currie (1960) noted that their first cruise had been preceded by a lengthy period of calms and hinted that March 1950 was anomalous. Their ship's drift observations indicated generally northerly sets—i.e. a normal situation—while south of 22S their data show nothing unusual. It is conceivable that the 1950 "event" was the tail-end of the 1949 warming in the tropical Atlantic (see Merle *et al.*, 1980). Thus, while it is not possible to comment on the full extent and duration of the 1950 "anomaly"the available data do suggest that it was confined to the area north of 20S and that it may well have been caused by regional atmospheric influences. It was probably not a proper Benguela Niño.

In the 1950s the principal pelagic fishing areas in the Benguela were centered around Walvis Bay between 22 and 23S and around St Helena Bay (32–33S). Monthly monitoring of the southern region commenced in 1951 and three years later off central Namibia. The interannual trends deduced from the early records have been discussed by Clowes (1954), Buys (1957, 1959) and Stander (1962, 1963). The mean monthly SST for a group of 10 stations within a radius of 50 km of Walvis Bay, together with the corresponding normalized monthly temperature anomaly during the period 1956–1967 are illustrated in Figure 4. Seasonal effects and interannual variability, in particular an extended warm event during 1963, are evident in the record. Physical and biological aspects of the 1963 anomaly were comprehensively documented by Stander and De Decker (1969). However, as their report may not be readily accessible to

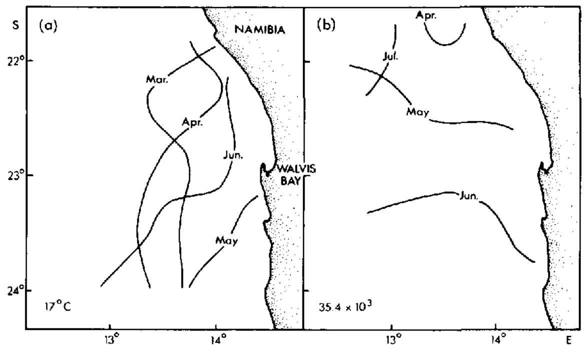

Figure 6. Positions of (a) 17°C surface isotherm and (b) 35.4 × 10^{-3} surface isohaline off Namibia during the 1963 Benguela Niño (data from Stander and De Decker 1969).

readers, we shall summarize their main findings. By April 1963 unusual hydrological conditions were noted off central Namibia. Instead of decreasing in accordance with the normal annual cycle, temperature and salinity in the upper 50 m remained high during the autumn of 1963 and reached maximum mean values during June when positive anomalies of 5°C and 0.2 × 10^{-3} respectively were recorded (Fig. 5). At 100 m during this month temperature and salinity values of 2°C and 0.2 × 10^{-3} above normal were reported by Stander and De Decker (*op. cit.*) which suggests that a marked depression of the thermocline occurred. Their horizontal sections together with the T-S analysis of water in the top 50 m and the zooplankton distributional data strongly suggest that the anomalous conditions were due to a major incursion of Angolan and oceanic water from the northwest into the northern Benguela system. Equatorward windstress during 1963 was about 25% higher on average than usual although calms were common. Standard and De Decker (*op. cit.*) concluded that the anomaly did not have a local origin. The lack of any significant upwelling response to the windstress is evidenced by the unusual positions of the 17°C isotherm and 35.4 × 10^{-3} isohaline off central Namibia between March and July 1963 (Fig. 6). Whereas the water in the upper layer originated from the north and the west, Stander and De Decker considered that equatorward movement was suggested by the dissolved oxygen and zooplankton data at depths deeper than 100 m (The few deep T-S curves which they portrayed do not seem to support this view, however.)

Further evidence of the magnitude and duration of the perturbation in the northern Benguela during 1963 is provided by the pressure adjusted monthly mean sea level anomaly for Walvis Bay for 1959–65 (Fig. 7a). The background seasonal variation (Fig. 7c) is for a maximum in late summer (February and March), falling sharply to a minimum in June. In 1963, this fall did not occur and a positive anomaly of 10 cm (amounting to 3 standard deviations) was recorded in May. It can be seen that the positive anomaly was sustained throughout 1963, following a sustained negative

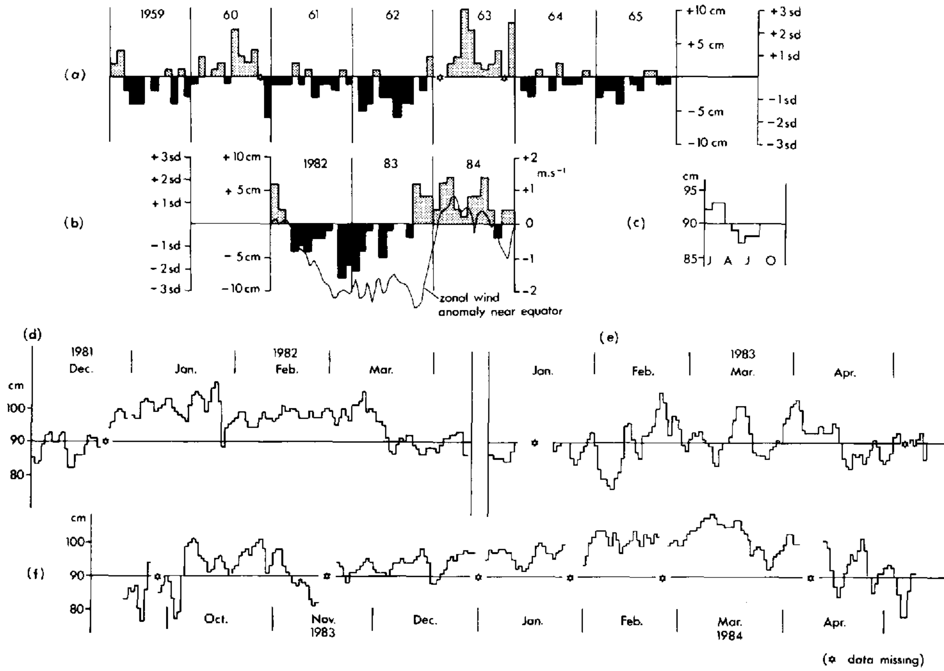

Figure 7. Changes in sea level at Walvis Bay: Anomalies in the pressure adjusted mean monthly sea level, (a) 1959–1965 and (b) 1982–1984 (also shown are the 850 mb wind zonal wind anomalies for the equatorial Atlantic according to Horel *et al.*, 1986,). (c) Pressure adjusted monthly mean sea level for ten years (1959–1965, 1982–1984); Daily changes in unadjusted sea level, (d) December 1981–March 1982, (e) January–April 1983 and (f) October 1983–May 1984.

anomaly throughout 1961 and 1962. A similar kind of anomaly was recorded at the two adjacent sites of Lüderitz (27S) and Port Nolloth (29S) and Brundrit (1984) has shown coherence in the interannual trend in sea level measured at various other west coast sites between 23S and 34S. During 1963, positive displacements were recorded at all sites, which suggests that the anomaly was not limited to northern and central Namibia.

As was the case in 1934 and in 1950 abnormally high rainfall occurred over much of the Namib desert and adjacent plateau region in 1963, with values typically double the average being recorded during the first four months of the year at Windhoek, Swakopmund and at most of the other recording sites (refer to Data). During January 1963 Namib Desert rivers were reported as flowing as strongly or even stronger than during the 1933/34 floods.

An examination of research ship SST data for the St Helena Bay area as well as the Cape Town record (Fig. 8) shows that a positive temperature anomaly of about 2°C occurred in late 1963 in the southern Benguela. Thus although the main effect of the

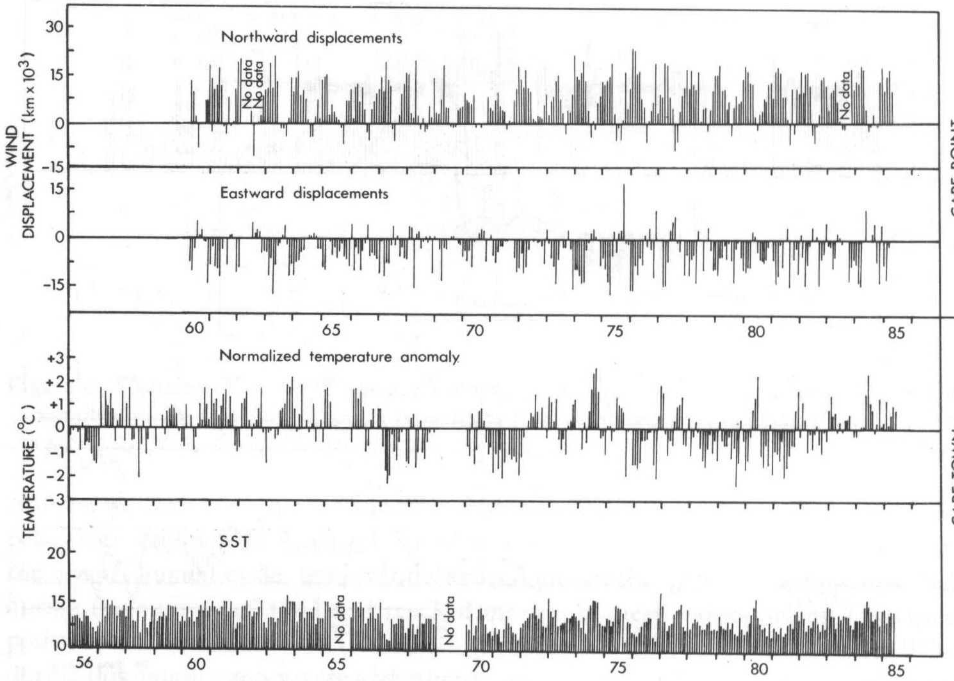

Figure 8. Monthly wind displacements at Cape Point (near Cape Town) between 1960 and 1985 and the mean monthly SST and normalized temperature anomaly at Cape Town from 1956 to 1985.

1963 event was limited to that part of the Benguela north of 24S, the signal was felt throughout the Benguela, so the event seems to have been a major one.

There is good evidence that conditions in the equatorial and tropical Atlantic were anomalous during 1963. Reid (1964a) commented that the maximum salinity value at the core of the Equatorial Undercurrent during the cruise of the *Argo* (July 1963) was significantly different from that in April 1961 while Reid (1964b) provided the first evidence of the existence of a South Equatorial Countercurrent in the Atlantic from his *Argo* data. Katz *et al.* (1977) have shown that the zonal pressure gradient in the equatorial Atlantic during the Equalant I observational period (February–April 1963) was nearly zero, while the Undercurrent was very much in evidence at the time (50–80 cm/s from drogue data). Katz *et al.* (*op. cit.*) also noted that the zonal component of the wind stress near the equator west of 10W was extremely low during Equalant I. (Evidently much of the Equalant' data suggest an unusual set of circumstances in 1963.) Merle *et al.* (1980) have shown that there was a positive SST anomaly of 1–2°C throughout 1963 in Marsden squares 300 and 371 (0–10S, 0–10W and 10–20S, 0–10E respectively). Their time series indicates that the 1963 anomaly was the most significant prolonged warm event in the eastern tropical Atlantic between

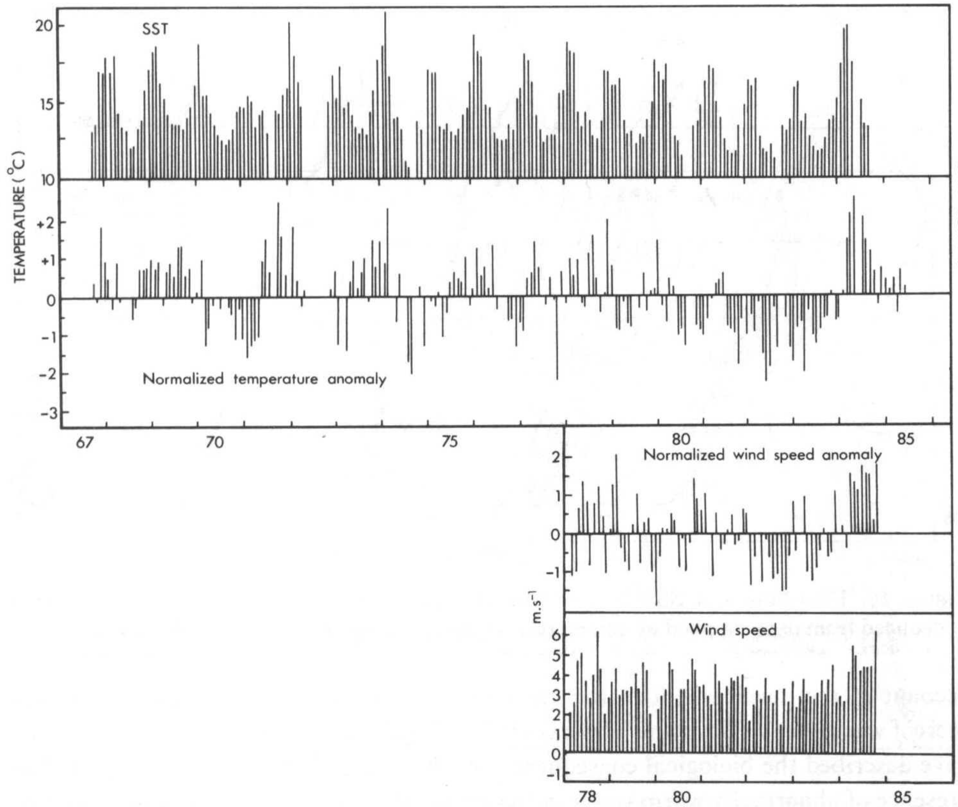

Figure 9. Mean monthly SST and normalized temperature anomaly at Swakopmund between 1967 and 1984 and mean monthly equatorward wind speed and normalized equatorward wind speed anomaly at Pelican Point (Walvis Bay) from 1978 to 1984.

1963 and 1975. Their fifty year time series for Marsden square 300 (1921–1970) indicates that the 1963 signal was even stronger and longer than that in 1934. The marked contrasts in the thermohaline structure in the western equatorial Atlantic between 1963 and 1980 were demonstrated by Lass *et al.* (1983), and they noted that the ITCZ appeared to be situated unusually far south in the early part of 1963. Voituriez (1983) has also discussed the extreme oceanographic features which characterized the tropical Atlantic during 1963.

From the above it is clear that the warm event in the northern Benguela in 1963, like in 1934, coincided with a major perturbation in the tropical Atlantic.

4. The 1984 Benguela event

In 1984 during the summer and autumn (February–May) a warm event similar in scale and intensity to the 1963 perturbation occurred in the northern Benguela. A brief

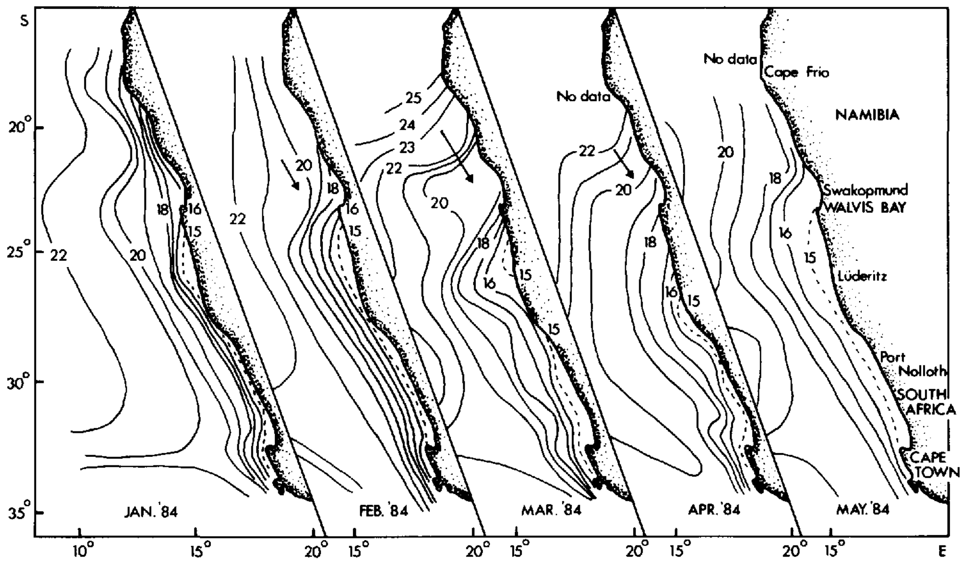

Figure 10. Distribution of SST in the Benguela region between January and May 1984 as deduced from data supplied by commercial shipping via the S.A. Weather Bureau.

account of the development of the anomaly and the initial biological consequences thereof was given by Boyd and Thomas (1984). Boyd *et al.* (1985), and Le Clus (1986) have described the biological consequences of the whole anomaly in more detail. The presence of abnormally warm water in the upper 50 m layer during 1984 followed two cooler than normal years in the northern Benguela. This is reflected in the Swakopmund SST record (Fig. 9) which indicates a positive normalized temperature anomaly of 1–2°C from February to August 1984 (and close to 3°C during April). Whereas upwelling-favorable winds during the cool years 1982 and 1983 were lighter than normal (Fig. 9), during 1984 the equatorward wind stress was nearly double the 1978–1985 average. This was in spite of the negative sea level pressure anomaly (approx. -1 mb) that was characteristic of the southeast Atlantic during the first 9 months of 1984.

The development and the extent of the warm intrusion is evident in Figure 10. During January the isotherms suggest a fairly normal situation, although there was a sign of warm (20–21°C) water within 100 km of the coast at 21S. By February the warm water had moved closer to Walvis Bay, although there was clear evidence of coastal upwelling continuing farther south. During March abnormally warm water was present over an extensive area off northern and central Namibia, which persisted through April apart from cooler water within 10–15 km of the coast and only showed signs of retreating in May. A more detailed representation of the March SST was provided by a research cruise between 8 and 23 March 1984 with sampling commencing in the north and this together with the surface salinity distribution is shown in Figure 11. Temperatures and salinities typically 6°C and 0.6×10^{-3} higher than

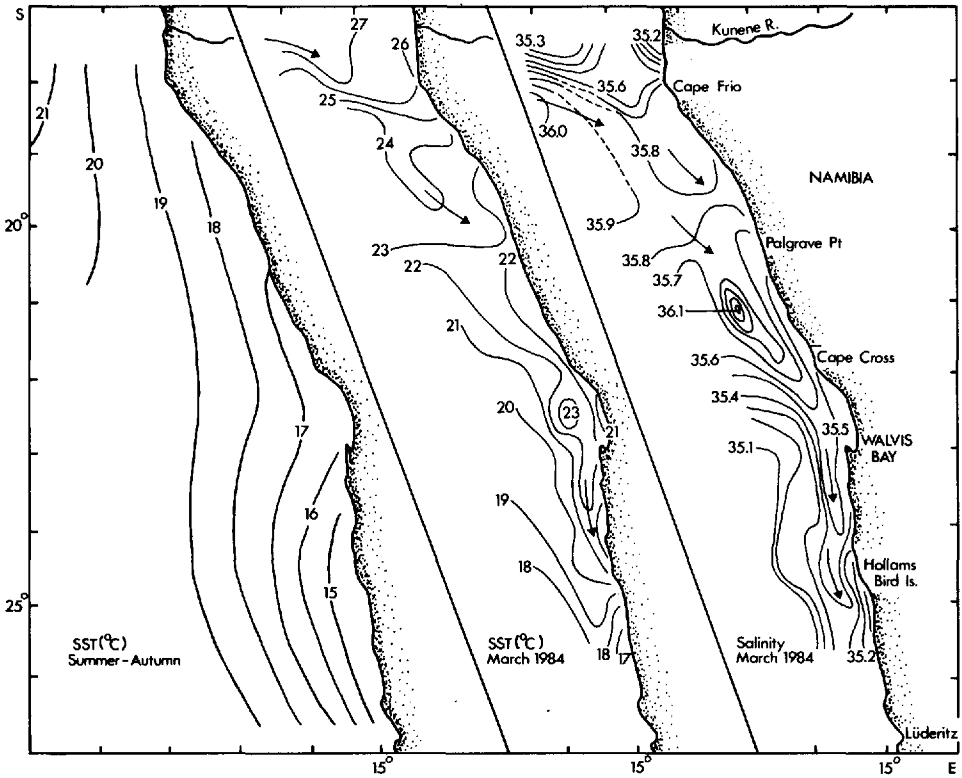

Figure 11. Mean positions of isotherms off northern and central Namibia during autumn and summer contrasted against the distribution of SST and surface salinity during March 1984.

normal for the month characterized much of the area north of 23S, and Figure 11 shows that warm saline Angolan water penetrated *at least* as far south as Hollams Bird Island (25S). A buoy with a drogue set at 10 m, released 40 km offshore at 21S, drifted polewards at 10 cm/s^{-1} which, according to Boyd and Thomas (1984), was the first time since 1981 (when buoy tracking commenced) that a southward movement of near-surface water had been observed. As was the case in 1963 the values of temperature and salinity at 50 m during those months in 1984 when surveys were undertaken were higher than normal,—typically by 2°C, 0.2 × 10^{-3}—while even at 100 m depth off Walvis Bay in March and April 1984 the temperature was 1–2°C warmer than normal, indicating a depression of the seasonal pycnocline.

Comparison of the data collected in 1984 with the T-S characteristics of the northern Benguela and southern Angolan surface water (see Shannon, 1985) suggests that very warm and highly saline water from the north or northwest penetrated about 5° of latitude farther south than normal during the late summer and autumn of 1984 and effectively suppressed upwelling of cool nutrient rich water in the northern Benguela, in spite of the stong equatorward winds. The southward progression of warm water into the northern Benguela which reached its maximum poleward extent in March 1984 before retreating is particularly clear in the graphical time series of monthly SST for the eastern Atlantic seaboard given by McLain *et al.* (1985). Their data show that the intrusion raised the temperature in the northern Benguela by at least 2°C above the mean shown by their three degree square analysis. Like during the 1934, 1950 and 1963 events high rainfall occurred over parts of northern and central Namibia during 1984 (e.g. Windhoek experienced the wettest April since 1963) which resulted in flooding of rivers for the first time since 1976.

Pressure adjusted sea level anomalies at Walvis Bay for 1982–84 (Fig. 7b) show a trend similar to the Swakopmund SST anomalies. Following lower than normal sea level during 1982 and the first 9 months of 1983, a positive displacement took place in October 1983 which persisted through 1984, with a temporary dip in April and May, which may have been a response to the abnormally strong equatorward wind stress (Fig. 9). The similarity of the variation in the sea level anomaly between 1961 and 1963 and between 1982 and 1984 is striking. As was the case in 1963 positive sea level anomalies were recorded during 1984 at Lüderitz (27S) and to a lesser extent also at Port Nolloth (29S).

It is possible to compare records of unadjusted daily mean sea level over the summer periods in the three years 1982–84, so as to highlight the 1984 event (Figure 7d–f). These daily mean sea level records show sea level fluctuating over several days (synoptic events) against a background trend. In the second half of December 1981, the background trend of the synoptic events increased from 87 cm to 100 cm (Fig. 7d). This trend was sustained until mid March 1982 when a fall in sea level between 11 and 20 March 1982 brought the background trend back down to 87 cm for April 1982. The summer 1983 high sea level event was delayed, weak, and of short duration, fitting the negative anomaly picture (Fig. 7e). Only between mid-February 1983 and mid April 1983 did the background trend of the synoptic events rise above 87 cm and then only by a mere 5 cm.

The summer of 1983/84 raised sea level event was *early, long and strong* (Fig. 7f). Between 3 October 1983 and 10 October 1983 sea level rose sharply from a background trend of 85 cm up to a level of 94 cm. Apart from a brief decline in early November 1983, this background trend level was sustained until mid January 1984. For the next two months there was a slow consistent rise, culminating in sea level moving from 99 cm to 109 cm between 1 March 1984 and 10 March 1984. Following this peak sea level, there was a slow decline in the background trend which eventually fell below 90 cm at the end of April 1984. The raised sea level event lasted almost seven months from October 1983 to April 1984 with peak levels in March 1984 where the unadjusted monthly mean sea level was 102.1 cm (as compared with 94.2 cm in 1982 and 91.6 cm in 1983, both inside their raised sea level events).

The NOAA thermal infrared image of the southeast Atlantic south of 22S on 1 April 1984 (Fig. 12) illustrates an unusual situation. The warm (21–23°C) water near Walvis Bay is evident (light grey) as is a large warm patch offshore west of Lüderitz.

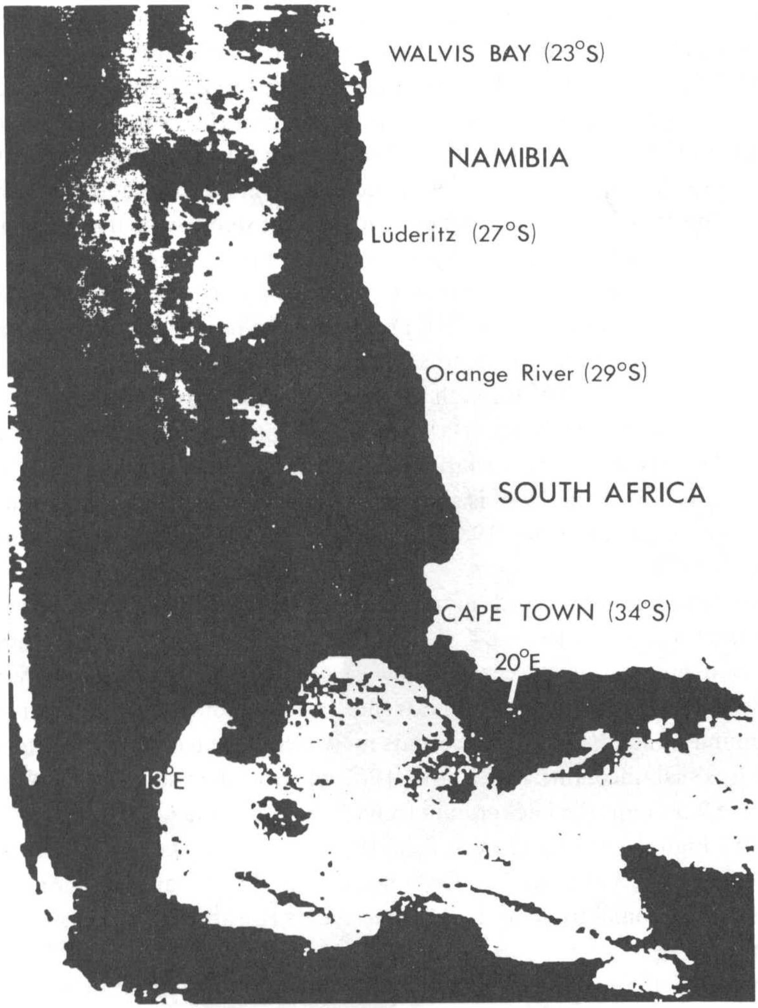

Figure 12. NOAA 7 thermal infrared image of eastern Atlantic south of 22S on 1 April 1984.

KEY: Black 11–17°C, Dark grey 18–20°C, light grey 21–23°C, white 23.5–25.5°C.

The absence of any substantial upwelling between Walvis Bay and just north of Lüderitz is shown, while at Lüderitz, the principal upwelling center in the Benguela system (Shannon, 1985), upwelling (black) was minimal. In the southern Benguela, within 200 km of the coast there is nothing unusual about the temperature distribution. However what is unusual in the south is the degree of penetration of the core of Agulhas Current (*circa* 24°C—white) into the Atlantic (as far as 13E), and the extensive upwelling along the south coast. Walker (1986) attributes these last two features to increased easterly wind stress and abnormally high atmospheric pressure south of Africa during the early part of 1984. Whether the local winds exerted such a

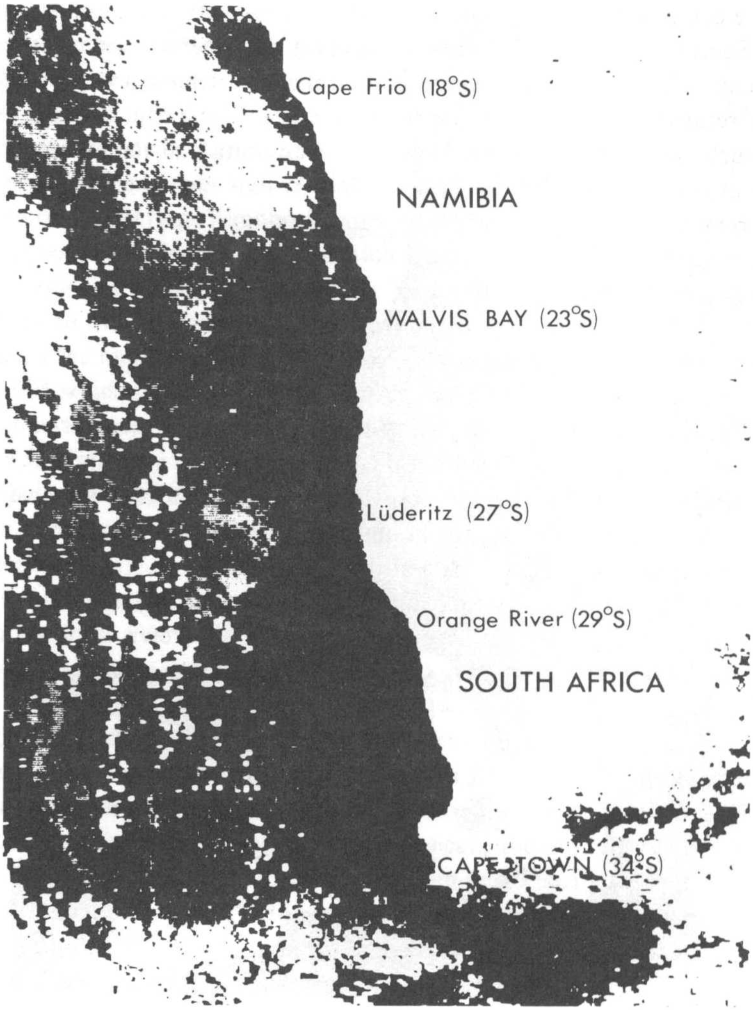

Figure 13. NOAA 7 thermal infrared image of Benguela region on 9 April 1984 (see Fig. 12 for key).

profound influence on the Agulhas Current or whether the westward displacement of the retroflection zone had a more distant cause (e.g. in the central Indian Ocean) is uncertain. The fact remains though that the intrusion of warm Angolan water into the northern Benguela region coincided with an enhanced flow of warm water farther south from the Indian into the Atlantic Oceans but which did not affect the coastal region of the southern Benguela. In Figure 13, a NOAA scene on 9 April 1984, the expansion of the area covered by upwelled water west and north of Lüderitz can be seen, with the upwelling zone (black) extending as far as Walvis Bay. In this figure the magnitude of the intrusion of warm water from the north can be seen; but if Figures 12 and 13 are compared, then the retreat of the intrusion between 1 and 9 April can be inferred. Some upwelling off Cape Frio is also evident. When viewed together with the sea level data, Figures 12 and 13 would suggest that the Benguela system south of 23S started to return to normal during April 1984, and that the effect on this area of the 1984 perturbation was short-lived. However, cruise data and the Swakopmund SST data indicate that this was not the case north of Walvis Bay where temperatures and salinities remained above their monthly mean values until August at least.

Considering the marked effect of the 1984 Benguela event on the region north of 25S and probably on the Lüderitz upwelling area also, the question arises as to how far south in the Benguela the effect of the warm water intrusion was felt. Reference to Figures 8 and 9 shows that there is some coherence in the inter-annual trends in SST between Swakopmund and Cape Town. (An obvious exception is the warming in 1983 at Cape Town which was a localized feature reflecting the partial failure of the southerly winds in the extreme south of the Benguela that year. This atmospherically caused warming coincided with the period of greatest anomalies in the Pacific and indicates a more rapid teleconnection at higher southern latitudes.) There was a small positive temperature anomaly ($< 1°C$) at the southernmost site during the first half of 1984, in spite of there being no significant change in the equatorward wind stress. How significant this change in what is an extremely noisy (refer to Shannon, 1985) southern Benguela regime is, and whether it was linked with the major perturbation off Namibia is not clear.

Some of the anomalous conditions in the tropical/equatorial Atlantic during 1984 have already been touched-on in the introduction. It should further be noted that dynamic height values in the Gulf of Guinea were unusually high in January–February 1984 but decreased sharply by April (Hisard and Henin, 1985). These authors suggested that this might account for the marked intrusion of warm water off Namibia. Although the pressures were nearly uniformly reduced across the Atlantic and zonal winds were weaker than average in the area 10–35W during 1984, (Horel *et al.*, 1986) the zonal winds do not appear to have been abnormally weak. What these authors considered to be striking, however, was the gradual build-up of the trade winds during mid 1982, their sustained intensity during most of 1983 which was followed by a rapid relaxation between November 1983 and January 1984. It is evidently the sudden *change* in the wind stress which perturbed the tropical Atlantic in 1984. The index of the 850 mb zonal wind in Figure 1b of Horel *et al.* (1986) is mirrored closely by our sea level data (Figure 7b).

So it seems that the 1984 Benguela event was, like in 1934 and 1963 symptomatic of a major perturbation in the tropical Atlantic.

5. Discussion

The seasonal temperature cycle in the northern Benguela is somewhat similar to that in the eastern equatorial Atlantic and the regular southward intrusion of warm water into the northern Benguela during (late) summer each year resembles the situation off Peru. It is only on rare occasions in the Benguela, however, that this intrusion develops into a major, persistent event analagous to the *El Niño* off Peru.

While there have been several warm periods in the Benguela, only during three years viz. 1934, 1963 and 1984 have *major* warm events been documented. There is, however, an indication that 1950 may also have been anomalous, while rainfall records suggest that lesser perturbations may have occurred in 1967 and in the mid 1970s. The three major warm events in the Benguela share a number of common features. In each case the warm water persisted for 6 months or longer, with anomalous conditions in 1963 spanning a full year. The 1963 and 1984 anomalies were associated with above average sea level, with positive anomalies persisting for at least 12 months. Positive sea level anomalies were also felt during these years at sites farther south along the west coast. A downward trend in sea level during the years preceding the 1963 and 1984 events seems to be suggested in Figure 7, with a marked upward adjustment taking place during or just prior to the two Benguela *"Niño"* years. This feature is remarkably similar to the classical *El Niño* situation in the Pacific and suggests that processes in the Atlantic may be analagous to those in the Pacific, but on a smaller scale. During both 1963 and 1984 equatorward windstress over the northern Benguela was stronger than normal, yet upwelling was suppressed by the southward progression of warm highly saline water from the Angolan region. The warm intrusions were accompanied by abnormally high rainfall (1934, 1950, 1963 and to a lesser extent 1984) and flooding of northern Namib Desert rivers. Both 1934 and 1984 were preceeded by major droughts in southern Africa. In all warm years, the origin of the warm water appeared to have been from the northwest and in 1963 and 1984 at least had a high salinity typical of lower latitudes in the eastern Atlantic. During 1963 and 1984 Angolan water penetrated at least as far south as 24–25S, while there is a strong indication from the surface drift in 1934 and the SST distribution in 1984 that the central part of the Benguela (24–30S) may also have been affected. Although there is evidence that a warm signal was felt in 1963 and 1984 in the southern Benguela, there is no evidence to suggest that a major perturbation during these years occurred there.

While minor warm perturbations have occurred in the southern Benguela on various other occasions as well, e.g. during austral summers of 1976/77 and 1982/83, these events have generally been confined to the extreme south of the system and may have been due, in part at least, to the failure locally of southerly winds. The possible association between these perturbations and Pacific ENSOs has recently been addressed in a suite of papers in the February 1984 issue of the *South African Journal of Science*. In this respect it should be noted that anomalous conditions were experienced during 1982/83 off southern Australia (Lennon, 1985) and in the northern spring of 1983 off Mauritania and Senegal there was only very weak upwelling (Michelchen, 1985; Hisard and Henin, 1983) suggesting an almost immediate coupling with the ENSO in the equatorial Pacific and processes at more distant locations at higher latitudes. However, the 1963 and 1984 events in the northern Benguela are clearly out of phase with major Pacific events. By early 1984 conditions off Peru had returned to normal (Miller, 1985). There is some suggestion, nevertheless, (e.g. Rasmusson *et al.*, 1985) that the warm cycle in the Pacific in 1982/83 progressed eastward reaching the Atlantic meridians a year or so later. The atmospheric conditions in the Atlantic during 1983 and 1984 have recently been described by Horel *et al.* (1986).

There seems to be an obvious link between the warming in the equatorial Atlantic in 1934, 1963 and 1984 and the intrusion of warm saline water from Angola into the northern Benguela, and this suggests that changes in wind stress off northern Brazil may at times cause (or at least be symptomatic of) a response over a major part of the South Atlantic. Interannual variability in monthly mean sea level possesses a comparable spatial and temporal structure along the eastern-boundary coast of the entire Pacific Ocean (Enfield and Allen, 1980), and this variability has been shown to be well correlated with ENSO events. Brundrit (1984) showed from an examination of temperature and sea level records between 1959 and 1964 that a similar mechanism may exist in the eastern Atlantic. Whether the event is a wave [analogous to Picaut's (1981) poleward propagating cool pulse with a phase velocity of 0.66 m.s.$^{-1}$] is not clear. It seems more probable that it is due to a change in the system of currents and countercurrents in low latitudes in the Atlantic. Recent observations by Verstraete (1985b), Piton and Wacongne (1985) and McLain *et al.* (1985) suggest that this was the case in 1984 at least. McLain *et al.* (*op cit.*) suggested that in 1984 the warm water in the southeastern Atlantic approached the coast *near Cape Frio* and then moved poleward *and equatorward.* There is obvious coherency between the warm pertubations throughout much of the tropical and equatorial eastern Atlantic. What is perhaps also significant is that the recent cool years in the equatorial Atlantic (viz. 1982 and 1983) when the ITCZ was farther north than normal were also cool years in the northern Benguela.

The three anomalously warm years in the northern Benguela coincided with periods of low or sharply reduced zonal wind stress in the western equatorial Atlantic, while equatorward winds in the northern Benguela were stronger than normal during at least two of the years. In 1963 and 1984 eastward flow in the system of equatorial currents and countercurrents in the Atlantic was enhanced, evidently in response to the relaxation of the zonal winds at low latitudes and the southward shift of the ITCZ. This would result in a rise in sea level in the eastern tropical Atlantic and enhanced compensatory southward flow along the African coast. It is conceivable that during these events the South Equatorial Countercurrent might short-circuit to the south of the Angolan Dome, rather than moving cyclonically around it as is more usual. Certainly this might explain the features noted by McLain *et al.* (1985). What is clear is that the major northern Benguela events are not related to changes in local wind stress but have their origin to the north or northwest of the system. Whereas the Pacific

ENSO is characterized by an east-west see-saw in atmospheric pressure, the events in the tropical Atlantic seem to be more closely related to the meridional shift of the ITCZ. Notwithstanding the essential differences apparent in the causal mechanism, the major warm anomalies in the northern Benguela do seem to occur as a response to changes in the atmospheric pressure in low latitudes. They possess many features similar to the Pacific *El Niño,* and it is our view that the use of the term *Benguela Niño* to describe these events would be justified.

Apart from 1934, 1963 and 1984, major warm events in the equatorial Atlantic evidently occurred in 1947 and 1968 (CCCO Panel, 1984). Benguela records are inadequate to permit a comparison to be made for 1947, but for 1968 there is no indication of any particularly abnormal situation in the region. The lack of a Benguela response in 1968 is to be expected as the abnormally warm water which was present in the Gulf of Guinea during that year (Picaut *et al.,* 1985) was somehow trapped or blocked and never reached the coast of Africa south of the equator (J. Picaut, pers. comm.)

We consider that it may be profitable for pre-1964 data for the tropical-equatorial Atlantic to be reprocessed to supplement the present FOCAL Atlas data set.

6. Conclusions

Although the southward intrusion of warm Angolan water into the northern Benguela is an annual occurrence during the first quarter of the year, major intrusions of warm highly saline tropical water have only been documented on a few occasions, the most recent being during 1984. During 1963 and 1984 the anomalous oceanographic conditions in the northern Benguela were characterized by increased local equatorward wind stress. The three *major* recorded perturbations (1934, 1963, 1984) were similar in their appearance in the Benguela to the Peruvian *El Niño,* and there is evidence that the three Benguela events were linked with anomalous situations in the equatorial Atlantic. Viewing the results presented in this paper in the light of current knowledge of the processes in the equatorial Atlantic, it can be concluded that *Benguela Niños* do occur but that they are less intense and less frequent than their counterparts in the eastern Pacific. This suggests that fish populations in the region may also be less well adapted ecologically to their occurrence.

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REFERENCES

Berrit, G. R. 1976. Les eaux froides côtières du Gabon à l'Angola sont-elles dues à un upwelling d'Ekman? Cah. O.R.S.T.O.M. Sér. Océanogr., *14*, 273–278.

Boyd, A. J., J. D. Hewitson, I. Kruger and F. le Clus. 1985. Temperature and salinity trends off Namibia from August 1982 to August 1984 and their relation to plankton abundance and the reproductive success of pelagic fish. Colln scient, Pap. int. Commn SE Atl. Fish., *12*, 53–60.

Boyd, A. J., and R. M. Thomas. 1984. A southward intrusion of equatorial water off northern and central Namibia in March 1984. Tropical Ocean—Atmos. Newsletter, *27*, 16–17.

Brundrit, G. B. 1984. Monthly mean sea level variability along the west coast of southern Africa. S. Afr. J. Mar. Sci., *2*, 195–203.

Buys, M. E. L. 1957. The South African pilchard (*Sardinops ocellata*): Temperature variations in the upper 50 meters in the St. Helena Bay area, September 1950–August 1954. Investl. Rep. Div. Fish. S. Afr., *27*, 114 pp.

—— 1959. The South African pilchard (*Sardinops ocellata*) and maasbanker (*Trachurus trachurus*): Hydrographical environment and the commercial catches, 1950–1957. Investl Rep. Div. Fish. S. Afr., *37*, 176 pp.

CCCO Panel. 1984. IOC/SCOR Committee on climatic changes and the ocean (CCCO) panel on tropical Atlantic Ocean climate studies. Third session, 1–2 March 1984, Paris. 19 pp.

Citeau, J., B. Guillot, R. Lae and M. Thepenier. 1984. Warm and cold oceanic events in the tropical Atlantic and their relationship with the Intertropical Convergence Zone. Tropical Ocean—Atmos. Newsletter, *23*, 19–20.

Clowes, A. J. 1954. The South African pilchard (*Sardinops ocellata*): The temperature, salinity and inorganic phosphate content of the surface layer near St. Helena Bay, 1950–52. Investl Rep. Div. Fish. S. Afr., *16*, 47 pp.

Enfield, D. B. and J. S. Allen. 1980. On the structure and dynamics of monthly mean sea level anomalies along the Pacific coast of North and South America. J. Phys. Oceanogr., *10*, 557–578.

Gouriou, Y. 1984. Evolution des temperatures de surface de la mer au voisinage de 0°, 10°W, en Atlantique. Veille Climatique Satellitaire. Bull. No. 2, 16–17.

Hart, T. J. and R. I. Currie. 1960. The Benguela Current. Discovery Rep., *31*, 123–298.

Henin, C. and P. Hisard. 1985. Permanence of an eastward surface flow near 2–3S in the equatorial Atlantic Ocean. Symposium on vertical motion in the equatorial upper ocean and its effects upon living resources and the atmosphere, April 1985, Paris (Preprint).

Hirst, A. C. and S. Hastenrath. 1983. Atmosphere-ocean mechanisms of climate anomalies in the Angola—tropical Atlantic sector. J. Phys. Oceanogr., 13, 1146–1157.

Hisard, P. 1980. Observation de résponse de type "El Niño" dans l'Atlantique tropical oriental—Golfe de Guinée. Ocean. Acta., *3*, 69–78.

Hisard, P. and C. Henin. 1983. The 1982–83 warm upwelling season in the Canary Current off Dakar. Tropical Ocean—Atmos. Newsletter, *19*, 12–13.

—— 1985. Zonal pressure gradient variability along the equatorial Atlantic from October 1982 to August 1984. Symposium on vertical motion in the equatorial upper ocean and its effects upon living resources and the atmosphere, April 1985, Paris. (Preprint).

Hisard P. and B. Piton. 1981. Interannual variability in the eastern tropical Atlantic during the last decades, *in* Recent Progress in Equatorial oceanography: A Report of the Final Meeting of SCOR Working Group 47, Venice, April 1981. J. P. McCreary, D. W. Moore and J. M. White, eds. Fort Lauderdale, FL, Nova University/NYIT Press, 297–306.

Horel, J. D., V. E. Kousky and M. T. Kagano, 1986. Atmospheric conditions in the Atlantic sector during 1983—1984. Nature, (in press).

Huh, O. K. and D. DiRosa. 1981. Analysis and interpretation of Tiros-N AVHRR infrared imagery, western Gulf of Mexico. Remote Sensing of Environment, *11*, 371–383.

Katz, E. J. and collaborators. 1977. Zonal pressure gradient along the equatorial Atlantic. J. Mar. Res., *35*, 293–307.

Lahuec, J. P. 1984. Convergence Intertropicale: L'intensité de la convection en janvier—mars 1984. Veille Climatique Satellitaire, Bull. No. 1, 7–8.

Lass, H. U., V. Bubnov, J. M. Huthnance, E. J. Katz, J. Meincke, A. de Mesquita, F. Ostapoff and B. Voituriez. 1983. Seasonal changes in the zonal pressure gradient in the equatorial Atlantic during the FGGE year. Oceanologica Acta, *6*, 3–11.

Le Clus, F. (1986). Aftermath of environmental perturbations off Namibia during 1972–1985 in relation to the anchovy stock. Colln scient. Pap. int. Commn SE Atl. Fish., *13*, (in press).

Lennon, G. W. 1985. Long period variations of sea level in Australia. IAMAP/IAPSO Joint Assembly, 5–16 August 1985, Honolulu, HI, Paper 04–06.

Mazeika, P. A. 1968. Eastward flow within the South Equatorial Current in the eastern South Atlantic. J. Geophys. Res., *73*, 5819–5828.

McLain, D. R., R. E. Brainard and J. G. Norton. 1985. Anomalous warm events in eastern boundary current systems. CalCOFI Rep., *26*, 51–64.

Merle, J. 1980. Variabilité thermique annuelle et interannuelle de l'Ocean Atlantique équatorial Est. L'hypothèse dun "El Niño" Atlantique. Ocean Acta, *3*, 209–220.

Merle, J. and T. Delcroix. 1983. Double seasonal tilt of the thermocline in the tropical Atlantic Ocean. Tropical Ocean—Atmos. Newsletter, *18*, 15–16.

Merle, J., M. Fieux and P. Hisard. 1980. Annual signals and interannual anomalies of sea surface temperature in the eastern equatorial Atlantic Ocean. Deep-Sea Res., GATE (Suppl. II), *26*, 77–102.

Michelchen N. 1985. The Southern Oscillation and interannual upwelling variations off northwest Africa and in the Gulf of Guinea. Tropical Ocean—Atmos. Newsletter, *30*, 17–18.

Miller, F. R. 1985. Weakening of El Niño at the beginning of 1984. Boletin ERFEN No. *12*, 5–7.

Moore, D. W., P. Hisard, J. McCreary, J. Merle, J. J. O'Brien, J. Picaut, J. M. Verstraete and C. Wunsch. 1978. Equatorial adjustment in the eastern Atlantic. Geophys. Res. Lett., *5*, 637–640.

O'Toole, M. J. 1980. Seasonal distribution of temperature and salinity in the surface water off South West Africa, 1972–1974. Investl Rep. Sea Fish. Inst. S. Afr., *121*, 25 pp.

Philander, S. G. H. 1983. El Nino Southern Oscillation phenomena. Nature, *302*, 295–301.

Philander, S. G. H. and R. C. Pacanowski. 1981. The oceanic response to cross-equatorial wings (with application to coastal upwelling in low latitudes). Tellus, *33*, 201–210.

Picaut, J. 1981. Propagation of the seasonal upwelling in the eastern equatorial Atlantic, *in* Recent Progress in Equatorial Oceanography: A Report of the Final Meeting of SCOR Working Group 47, Venice, April 1981. J. P. McCreary, D. W. Moore and J. M. White, eds., Fort Lauderdale, FL, Nova University NYIT Press, 271–281.

Picaut, J., J. Servain, P. Lecomte, M. Seva, S. Lukas and G. Rougier. 1985. FOCAL Climatic atlas of the tropical Atlantic wind stress and sea surface temperature 1964–1979. Universite de Bretagne Occidentale (Laboratoire d'Oceanographie Physique)/University of Hawaii (Joint Institute for Marine and Atmospheric Research). 467 pp.

Piton, B. and S. Wacongne. 1985. Unusual amounts of very saline subsurface water in the eastern Gulf of Guinea in May 1984. Tropical Ocean—Atmos. Newsletter, *32*, 5–8.

Rasmusson, E. M. and T. H. Carpenter. 1982. Variations in tropical sea surface temperature and surface wind fields associated with the Southern Oscillation/El Niño. Mon. Weath. Rev., *110*, 354–384.

Rasmusson, E. M., V. E. Kousky and K. M. Weickmann. 1985. Interannual and intraseasonal fluctuations in the equatorial Pacific and major swings in the Southern Oscillation. IAMAP/IAPSO Joint Assembly, 5–16 August 1985, Honolulu, HI. Paper JS1-02.

Reid, J. L. 1964a. A transequatorial Atlantic oceanographic section in July 1963 compared with other Atlantic and Pacific sections. J. Geophys. Res., *69*, 5205–5215.

—— 1964b. Evidence of a South Equatorial Countercurrent in the Atlantic Ocean in July 1963. Nature, *203*, 182.

Reverdin, G. 1985. Heat budget of the tropical Atlantic Ocean. Deep-Sea Res., *32*, 363–368.

Reverdin G. and M. J. McPhaden (1986). Near surface current and temperature variability observed in the equatorial Atlantic from drifting buoys. J. Geophys. Res., *91*, 6569–6581.

Schott, G. 1931. The Peru (Humboldt) Current and its northern vicinity in normal and abnormal conditions. Annalen der Hydrographie und Maritimen Meterologie, *59*, 161–169; 200–213; 240–253. (Translated from German by U. Radok, 1980).

Servain, J. 1985. Relation entre la position latitudinale de la zone de Convergence Intertropicale et la temperature de surface de la mer dans l'Atlantique tropical. Veille Climatique Satellitaire. Bull. No. *9*, 34–36.

Servain, J., D. Legler, J. Picaut, V. Verbeque and M. Seva. 1985. Oceanic variability and wind stress forcing in the tropical Atlantic Ocean. IAMAP/IAPSO Joint Assembly, 5–16 August 1985, Honolulu, HI, Paper 06-16.

Servain J., J. Picaut and J. Merle 1982. Evidence of remote forcing in the equatorial Atlantic Ocean. J. Phys. Oceanogr., *12*, 457–463.

Shannon, L. V. 1985. The Benguela ecosystem Part I. Evolution of the Benguela, physical features and processes. Oceanogr. Mar. Biol. Ann. Rev., *23*, 105–182.

Shannon, L. V., R. J. M. Crawford and D. C. Duffy. 1984. Pelagic fisheries and warm events: a comparative study. S. Afr. J. Sci., *80*, 51–60.

Shelton, P. A., A. J. Boyd and M. J. Armstrong. 1985. The influence of large-scale environmental processes on neritic fish populations in the Benguela Current system. CalCOFI Rep., *26*, 72–92.

Stander, G. H. 1962. The pilchard of South West Africa (*Sardinops ocellata*). General hydrology of the waters off Walvis Bay, South West Africa, 1957–1958. Investl Rep. Mar. Res. Lab. S.W. Afr., *5*, 63 pp.

—— 1963. The pilchard of South West Africe (*Sardinops ocellata*). Temperature: its annual cycles and relation to wind and spawning. Investl Rep. Mar. Res. Lab. S.W. Afr., *9*, 57 pp.

Stander, G. H. and A. H. B. De Decker. 1969. Some physical and biological aspects of an oceanographic anomaly off South West Africa in 1963. Investl Rep. Div. Sea Fish. S. Afr., *81*, 46 pp.

Strong, A. E. and E. P. McClain. 1984. Improved ocean surface temperatures from space—Comparisons with drifting buoys. Bull. Amer. Met. Soc., *65*, 138–142.

Walker, N. D. 1986. Satellite observations of the Agulhas Current and episodic upwelling south of Africa. Deep-Sea Res. (in press).

Walker, N., J. Tauton-Clark and J. Pugh. 1984. Sea temperatures off the South African west coast as indicators of Benguela warm events. S. Afr. J. Sci., *80*, 72–77.

Walsh, J. J. 1978. The biological consequences of interaction of the climatic, El Nino, and event scales of variability in the eastern tropical Pacific. Rapp. P.-v. Réun. Cons. int. Explor. Mer, *173*, 182–192.

Walter, H. 1937. Die ökologischen verhältnisse in der Namib-nebelwüste (Südwestafrika) unter auswertung de aufzeichnungen des Dr G. Boss (Swakopmund), *in* Jahrbücher für Wissenschaftliche Botanik, N. Pringsheim, ed., Verlag von Gebrüder Borntraeger, Leipzig, 58–222.

Ward, J. D., M. K. Seely and N. Lancaster. 1983. On the antiquity of the Namib. S. Afr. J. Sci., *79*, 175–183.

Verstraete, J. M. 1985a. Further evidence of poleward propagation of the mean seasonal coastal upwelling in the Gulf of Guinea. Tropical Ocean–Atmos. Newsletter, *29*, 8–10.

—— 1985b. Seasonal variations of heat content and mean sea level in the eastern tropical Atlantic. Influence of the equatorial counter currents. IAMAP/IAPSO Joint Assembly, 5–16 August 1985, Honolulu, HI, Paper JS5-10.

Voituriez, B. 1983. Les variations saisonnieres des courants équatoriax à 40W et l'upwelling équatorial du Golfe de Guinée II–Le courant equatorial sud. Oceanogr. Trop., *18*, 185–199.

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