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THE BENGUELA NIÑO 1995 OBSERVED IN ANGOLAN WATERS

by

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ABSTRACT

During the cruise by R/V "Dr. Fridtjof Nansen" in February-March 1995, we observed that the upper ocean layers were very warm and brackish. Comparing with a similar cruise performed in 1994, the water temperature was up to 8°C warmer, and the salinity some 5 psu lower. The maximum salinity differences was found at the surface, but the temperature deviations were maximum at typically 30 to 50m depth. The thermocline was found at 20 to 30m greater depths than usual. The horizontal and vertical distribution of the phenomenon is discussed, as well as the time-evolution.

We believe this is an Benguela "Niño", a phenomenon similar to the well known "El Niño" in the Southern Pacific. While the Pacific "El Niño" occurs up to several times per decade, the South Atlantic counterpart has been observed about once per decade. The former "Niños" were also characterized by warm surface water, but in contrast to Niño-95 the surface salinity have usually been observed to be higher than normal. The Benguela Niños are believed to be caused by warm, saline water advected from north or north-west. The low salinity of the Niño-95 corresponds to an excess off-shore precipitation of the order of 3000mm above normal.

The significance of Benguela Niño-95 as a global climate perturbation is discussed. During the Niño-95 the abundance estimates of three important pelagic species were very low.

1. INTRODUCTION

Angola, which is situated in central south-west Africa, has a coastline of more than 1600km (Fig.1). The region is dominated by wind from a southerly direction. Local upwelling is therefore taking place along the coast, making these waters relatively productive. The northern part of the extremely rich Benguela upwelling system penetrates northwards into Angolan waters from the South. The front between the Benguela and Angola waters is usually found at about 15°S. For an excellent, resent review of the Benguela system and adjacent waters, sea Shannon & Nelson (1995).

A survey performed by R/V "Dr. Fridtjof Nansen" in March 1995 revealed anomalous oceanographic conditions; The upper layer was dominated by warm, brackish water. Warm events have been observed in these waters before (Shannon et. al 1986), and there are three possible sources for anomalous warm conditions:

Firstly, a relaxation of the equator-ward wind-stress will lead to a reduced upwelling, and therefore a warming of the near shore surface waters.

Secondly, as the Benguela boundary current is bounded both equator-ward and poleward by warmer waters, the advection from south or north may cause anomalous warm conditions. It is documented that in 1986, which was an anomalous warm year, intrusions of warm Aghulas water from the south took place. However, usually warm events are associated with water penetrating south along the Angolan coast into Namibian waters.

Finally, a third possibility is that an "El Niño" type phenomenon has occurredd. Shannon *et al* (1986) discussed various warm events, and found that what they called "Benguela Niños" probably had occurredd at a rate of about one per decade during the 20th century , i.e. much less frequent than the Pacific counterpart. However, the Benguela Niños may have a large impact on the productivity in the Benguela system. Boyd *et al* (1987) showed that the last recorded Benguela Niño in 1984 was associated with low concentrations of nutrients on the Namibian shelf.

There has been some discussion if the Benguela Niños are related to a reduced local equatorward upwelling favourable wind, or is remotely triggered by the slackening of the zonal windstress in the equatorial west Atlantic, and thus of the same nature as the Pacific counterpart. The latter seems to be the present understanding of the phenomenon as described by three well documented Benguela Niños in 1934, 1963 and 1984, Shannon *et al* (1986). The historical point of view has also been that the Benguela Niños were caused by southward intrusion of the warm, saline Angolan current to the Namibian coast, while the most recent understanding is that they are rather caused by the advection of warm, saline tropical and equatorial water from west and north west, again the same nature as its Pacific counterpart, (Shannon and Nelson, 1995).

The abnormal warm conditions found in March 1995 are discussed in the light of the above theories, and it is concluded that an El Niño type phenomenon probably has occurred. However, there is one major difference between the 1995 event and the previous Benguela Niños; the anomalous low salinities in the upper layers. The origin of the fresh water perturbation is discussed. We also demonstrate that the Benguela Niño 95 was associated with low estimates of three important pelagic species, and that it represents a major climatic signal.

2. DATA AND METHODS.

The surveys.

This paper is mainly based on two surveys carried out in March 1994 and March 1995 by R/V "Dr. Fridtjof Nansen". The surveys covered the Angolan Coast from Cabinda at about 5°S to Benguela at about 12°30'S, see the 1995 station map in Figure 1. Thus the southernmost part of the coast was not surveyed. Fortunately the Namibian R/V Welwitchia, was operating in Namibian waters at the same time, and mapped the southern limit of the 1995 anomaly (O'Toole, personal communication).

The 1995 survey started outside Cabinda in the north and went south to Benguela, and then the region up to Luanda was covered a second time. This gave a possibility to study the time evolution of the anomalous conditions on the time scale of up to a few weeks.

The region was also surveyed in August 1995 when the anomaly had disappeared. Thus an estimate of the decay time of the event was possible.

Instruments.

The hydrographic parameters (temperature and salinity) was obtained by a Seabird 911 CTD plus system, equipped with a carousel sampler with Niskin bottles. The CTD salinities were checked against water samples analysed on a Guildline Portasal salinometer on board. For the 1995 cruise 179 calibration points gave a standard error of about 0.03 which is accurate enough for the for the present investigation.

The temperature and pressure sensors were calibrated in the laboratory prior to the cruises, and are believed to keep the factory standards, ±0.01°C and ±0.25% in pressure.

Current measurements were obtained with Aanderaa RCM-7 current meters. The accuracy of the measurements are believed to be as indicated by the producer; about ±1cm/s for current speed and ±5° for current direction.

Methods.

Vertical profiles and results from the current measurements were drawn with the Grapher from Golden Software.

Vertical sections were produced by the SECTION program package developed at Geophysical Institute, University of Bergen (Røyset & Bjerke, 1982) rewritten for PC by P. Andersen (personal communication). A cubic spline method is applied.

Horizontal distribution maps were constructed by subjective analysis. The various fields are drawn by hand, while the changes of the fields from one year to another were obtained by overlaying the two individual fields, and drawing isolines for constant differences.

3. RESULTS

Vertical profiles.

It will be demonstrated that the conditions in March 1995 were rather anomalous by comparison with a similar survey made by R/V "Dr. Fridtjof Nansen" in March 1994. The results obtained during the 1994 survey were quite typical for the season, thus 1994 may be considered as a "normal" year.

Comparisons between typical vertical temperature and salinity profiles for the two years are given in Fig.2 (CTD station 93, 1995, for position see Fig.1). The 1994 profiles are quite common for the peak warm season, with surface temperature above 28°C and a thermocline depth of about 20m. Also note the rather weak stratification in the 1994 salinity profile, with surface values just below 35 psu, despite that the profiles were obtained during the wet season.

The 1995 profiles demonstrate the rather substantial heating compared to 1994, especially between 20m and 50m depth, and the dominance of brackish water in the upper 40m. The maximum heating was found to be more than 8°C at about 30m depth. The thermocline depth had increased to about the double for this position, from 20 to 40m depth. The surface signal was rather small, though (about 1°C), which makes it difficult to reveal this phenomenon by remote sensing.

The salinity stratification in 1995 was substantial. The maximum salinity difference was found at the surface, with a salinity deficit of more than 3 psu.

Vertical sections.

The CTD station 93 shown in Fig.2, is one of the stations defining a section outside Pta das Palmeirinhas at about 9°

10'S (see station map in Fig.1), which is centrally placed at the Angolan Coast, and representative for the water masses found in the Angolan economical zone. This section was also taken in 1994, and the changes in T and S in the upper 200m for the two years are shown in Fig.3.

We note the substantial warming in the upper ~100m, with a maximum amplitude of more than 8°C at about 30m depth off the continental slope, see Fig. 3a. Even at 100m depth the warming was almost 2°C.

The salinity changes was limited to the upper 40m or so, with a maximum salinity deficit at the surface of more than 4 psu in the near shore zone.

Horizontal distribution.

a. *Temperature change* (30m depth).

As the anomalous signal in temperature was rather small at the surface, we have chosen to show the changes in the horizontal temperature distribution at 30m depth (Fig. 4a). We note the rather substantial warming ranging from about 1°C near the coast, to more than 6°C beyond the continental slope, the maximum was found in the northern and central part. The fact that there was a trend towards smaller differences in the south may be a temporal rather than a spatial phenomenon, see discussion below.

b. *Salinity change* (5m depth)

The surface (i.e. 5m depth) salinity difference between the two years is shown in Fig. 4b, and indicate an increased influence of fresh water in 1995, resulting in a decrease in surface salinities from 3 to 5 psu. Outside the Congo River, the surface salinities are usually dominated by river run-off, and the isolines for the change between the two years shown in Fig. 4b is a rather oversimplified view of a patchy field.

4. DISCUSSION

The Benguela "Niños"

The "El Niño" phenomenon known from the south-east Pacific, as an anomalously warm surface water layer occasionally hitting the coast having a detrimental effect on the fishery, and giving heavy rain in the otherwise arid land areas, has its counterpart in the SE Atlantic (Shannon *et al* 1986, Shannon & Nelson (in Press), and are called Benguela Niños. While the Pacific El Niño occurs up to several times per decade, and often in two consecutive years, the Benguela Niños are much less frequent (about 1 per decade). This year (1995) the Pacific El Niño for the first time occurred for the fourth consecutive year, and has triggered the discussion if this may be related to the anthropogenic emission of greenhouse gases (Wuetrich,1995).

The average heating of the upper 200m (Fig.2) was substantial; the mean increase in temperature being 2.3°C. Taking into consideration that the heat capacity of the atmosphere is equivalent to about 2-3m of the heat capacity of the ocean per unit area, indicates how important it is to take the ocean into consideration when climatic trends are discussed.

There is one big difference between the "Benguela Niño 1995" and those reported earlier (Shannon *et al* 1986), namely the very low salinities found in the upper layers (Figs 2,3 and 4). The amplitude of this salinity deficit does not seem to be related to the distance from the coast (see Fig.5), so heavy flooding from the rivers (including the Congo River) does not seem to be the source of this fresh water anomaly. A possible source is therefore an increased off-shore precipitation. Heavy rain has been reported both in Angola and Namibia during the last austral summer (1994-95). The amount of precipitation needed to explain the reduced salinity may be calculated as follows:

Assuming that an amount of fresh water (Δh) is distributed over a water column H, the salinity balance equation reads:

$$\int_{-H}^{0} \rho_{94} S_{94}(z)dz = \int_{-H}^{\Delta h} \rho_{95} S_{95}(z)dz$$

where ρ is the density and S salinity, indexes indicate years. Neglecting the variation in the density and splitting up the integral on the right hand side and re-arranging gives the following expression for the increase in fresh water content (precipitation) in the water column:

$$\Delta h = \frac{1}{S_{95}(0)} \int_{-H}^{0} S_{94}(z) - S_{95}(z)dz$$

where $S_{95}(0)$ is the surface salinity. A numerical integration of this equation down to depths where the salinity perturbation is smaller (at least 40m) gives an increase in fresh water content corresponding to about 3000mm precipitation. Thus a possible explanation of the salt deficit is that the precipitation over the sea during the Benguela Niño 1995 was 3000mm above normal.

Locally or remotely forced?

To try to map the westward extension of the Benguela Niño 95, we repeated the Pta de Palmeirnhas section and prolonged it to more than 200km from the coast (Fig.5). However, within these limits the surface layer continued to be dominated by the deep, warm, brackish surface layer, without any clear trends in the amplitudes, except maybe for a small reduction in the depth of the brackish layer with distance from the coast.

If the Benguela Niño was forced by the relaxation of the local upwelling favourable winds, one would expect that the phenomenon had a horizontal scale comparable to the Rossby's internal radius of deformation, which is the theoretical horizontal scale of an upwelling phenomenon Gill (1982).

The internal radius of deformation (R) given by

$$R^2 = g'D/f^2$$

where D is the depth of the surface layer and f is the Coriolis parameter. The reduced g' is given by

$$g' = g \Delta\rho/\rho$$

were g is the constant of gravity, $\Delta\rho$ the density difference between the upper and lower layer and ρ is the density of the lower layer. R was found to be around 60km in 1994 increasing to ~100km in 1995, thus it seems clear that the Benguela Niño not is related to the relaxation of the local upwelling.

Time has not allowed us to obtain information of the wind distribution in the south Atlantic for the actual period, so for now it remains open if the phenomenon was triggered by a reduced westward windstress in the equatorial west Atlantic (Carton & Huang, 1994).

North - south extension.

The northern limit of the Niño-95 could not be determined, because it was beyond the area surveyed. The southernmost extension was observed by the Namibian R/V "Welwitchia" to reach the latitude of at least 24°S with about the same water characteristics as found in Angolan waters, but higher temperatures than normal have been reported even as far south as Lüderitz at ~27°S (M. O'Toole, private communication).

Temporal variation

As the innermost stations at Pta das Palmeirinhas was repeated after about 3 weeks, it is possible to study the time development of the Benguela Niño 95. In Fig. 6 we have shown how the profiles in position CTD st 93 changed between March 11 and March 31. Note that the temperature shows a decreasing trend, while the salinity is increasing. Thus it seems that the Benguela Niño had passed its peak while the second profile was taken. Therefore, caution should be taken in interpreting the tendency of a decreasing temperature difference at 30m depth towards the south (Fig. 4a), as it may be due to this temporal variation rather than a true spatial change. The amplitude of the Benguela Niño observed in Namibian waters at 16°S in the middle of March seems to be of the same amplitude as in central Angola (M. O'Toole, private communication), also indicating that it is the time variation which dominates the trend in Fig.4a.

The individual temperature profiles (Fig. 6) show that a substantial cooling had occurred even down to more than 200m depth in the 3 week period. This is probably a dynamic effect, related to variations in the currents. The idea that the Benguela Niños are driven by advection of water masses from west and north west, a southward current is expected along the coast while the Niño is developing, and a return flow should be the case when the phenomenon is diminishing. A such reversal of the currents in the surface layers, will provoke changes in the distribution of the pressure forces with depth, and may therefore even result in a reversal of the currents in the deeper layers, thereby creating changes in the tilt of the density surfaces. As the density here is dominated by the temperature at this depth a southward subsurface flow will tilt the isothermes up towards the coast, thereby creating an apparent deep cooling as indicated in Fig.6.

A current meter rig was anchored for about 18 hours during the last part of the cruise (March 18th) at position 11° 44'S, 13° 26'E (see map Fig.1), while the amplitude of the temperature and salinity disturbance obviously was decreasing (see Fig.6). The results of the current measurements confirmed a northward flow in the surface layer. The current component at 2m depth towards north is shown in Fig.7. The current was unidirectional during this period, despite a substantial tidal signal, the average current being rather strong, about 30 cm/s. Thus the Benguela Niño was obviously retreating during the last couple of weeks in March.

A CTD survey performed by R/V "Dr. Fridtjof Nansen" in August 1995 was extended to more than 500km from the coast, but no sign of the warm, brackish "Niño" water was found, indicating that the decay time of an Benguela Niño is less than 4 months.

Impact on pelagic fish abundance

The biomass abundance of 3 important pelagic species are shown in Fig. 8, (Luyeye 1995). All abundance estimates for the last 10 years are included. A dramatic decline of the abundance of all the three species in the first quarter of 1995 is obvious, and it is tempting to relate this decline to the Benguela "Niño" hitting the Angolan coast during this period. However, caution should be taken in interpreting the results, as the climatic conditions may have influenced the migration patterns and the schooling behaviour. For the Sardinella, for instance, the concentrations seemed to have been very loose throughout the March 1995 survey, making it difficult by the acoustic methods applied to distinguish it from other pelagic fish and plankton. An underestimate of the biomass may therefore have occured.

5. CONCLUDING REMARKS

It is appropriate to define the oceanographic conditions in the Angolan waters in March 1995 as a Benguela Niño. The fact that a maximum southward extension to about 24 °S rules out the Aghulas water as a possible source of perturbation. The horizontal scale of the event is much larger (>200km) than the local internal Rossby radius (~100km), therefor the relaxation of the local upwelling does not provide a satisfactorily explanation of the abnormal conditions. Thus we conclude that this is a Benguela Niño related to the relaxation of the trade winds. Although we at the present stage do not have information on the wind conditions in the South Atlantic, it is well documented that the three of the previous Benguela Niños (1934, 1963 and 1984) are related to reduced westward zonal windstress in the equatorial western Atlantic off Brazil (Shannon *et al* 1986). It is also believed that a sudden relaxation in the wind stress is more important than the absolute value. This is also confirmed by model simulations (Carton and Huang 1994), and it is going to be very instructive to see simulation of the 1995 event.

Although previous Benguela Niños are associated with higher than normal water salinities, it is well known that heavy rain have occurred on land during the former events, leading for instance to flooding of rivers in the Namib Desert (Shannon *et al* 1986). Heavy rain have also been reported during the Niño-95 event, and a possible source of the brackish water is an off-shore precipitation of about 3000mm above normal. The rivers do not seem to be the source of the low salinity anomaly, as the amplitude does not decrease with distance from the coast, see Fig. 5b.

It has previously been documented (Boyd *et al* 1987) that Benguela Niños have resulted in nutrient depleted water in the otherwise very productive Benguela waters. This is because the influx of nutrient poor water from west and north west impacted the whole water column on the shelf. Thus even if the local wind remains favourable for upwelling, the source of nutrient rich water subsurface water is limited, thus restricting the productivity in the region.

The biomass estimates of the 3 important pelagic species (Fig.8) may be biased due to the extreme climatic conditions met in February-March 1995. Future surveys will indicate if the warm, brackish surface waters had any long term influence on the abundance of these species.

There are vast heat perturbations related to an event as the Benguela Niño-95, and the change in heat content from 1994 to 1995 (Fig.2) is equivalent to a surface heat flux of the order of $50W/m^2$. In comparison the man-made emission of greenhouse gases have resulted in a radiative forcing of about $1W/m^2$. This illustrates how difficult it is to estimate an eventual man-made climatic warming in the atmosphere, when vast quantities of heat is bouncing around in the ocean.

Acknowledgements

We are very grateful to the Captains and the crew on "R/V Dr. Fridtjof Nansen" for a professional and pleasent cooperation. O. Alvheim is acknowledged for his enthusiastic and clever performance of the broad spectrum of tasks during the field work. We should also mention that the reference list is not complete.

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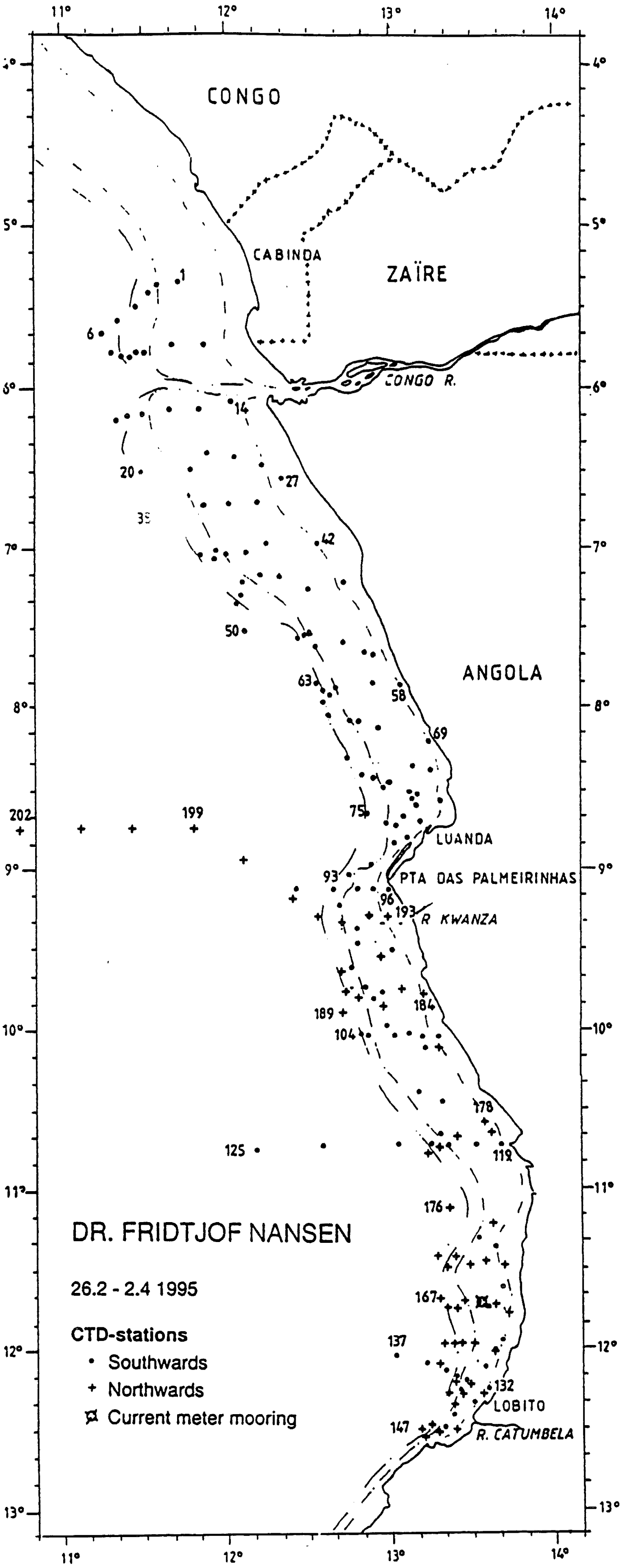

Figure 1. Station map for the survey performed in March 1995. Dots represent CTD stations when the coast was covered from north to south, and crosses the second survey of the southern part in the end of the month. The station net occupied in March 1994 is comparable with the stations represented by the dots. CTD stations taken in August 1995 also covered the same area, and in addition stations were obtained as far west as 8°E.

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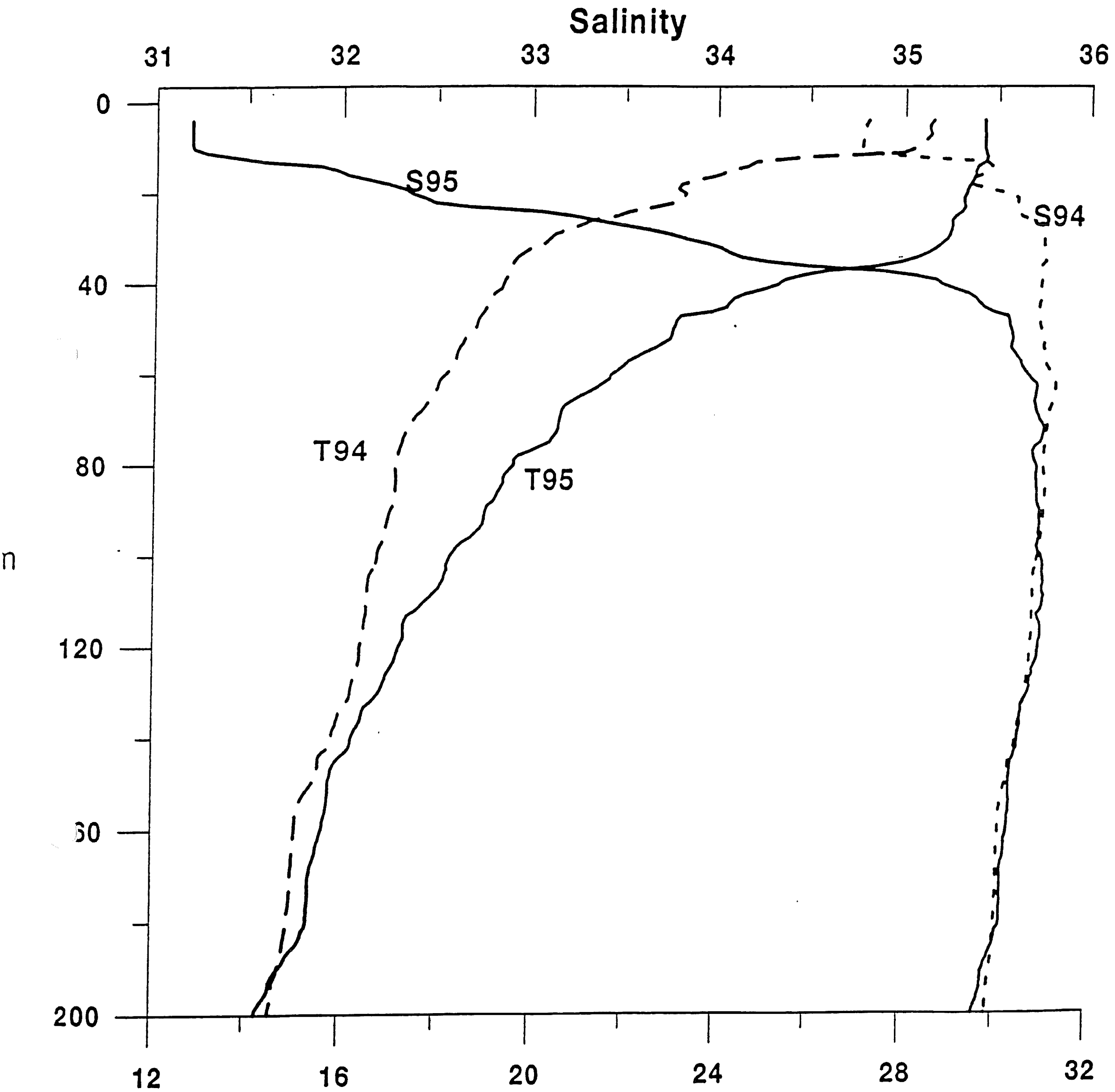

Figure 2. Profiles of temperature and salinity obtained in position CTD 93 (See Fig.1) in March 1994 and March 1995.

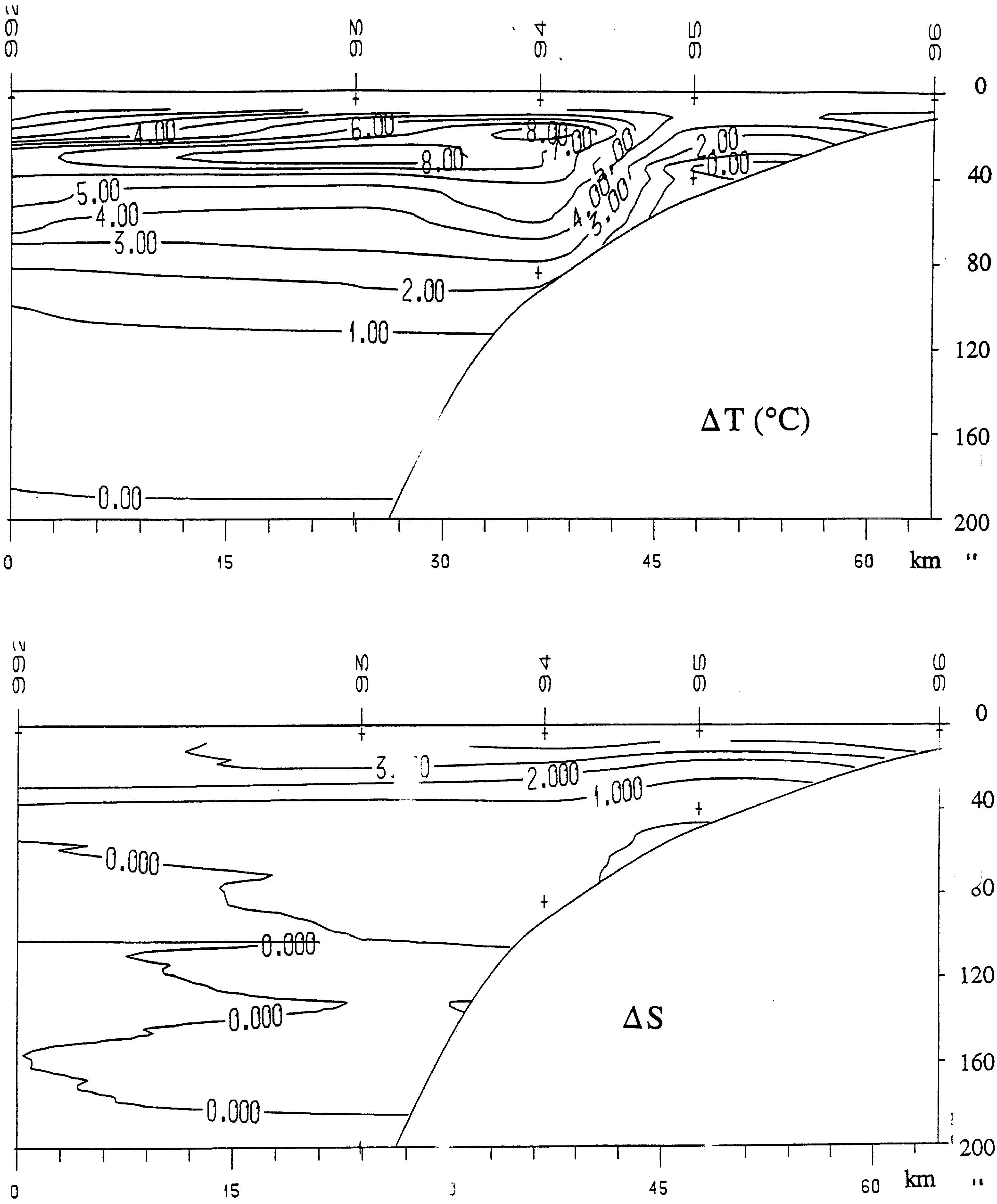

Figure 3. Changes of properties for the Pta Das Palmeirinhas section 1994-1995 (March).
a)Temperature increase (ΔT) b) Salinity decrease (ΔS)

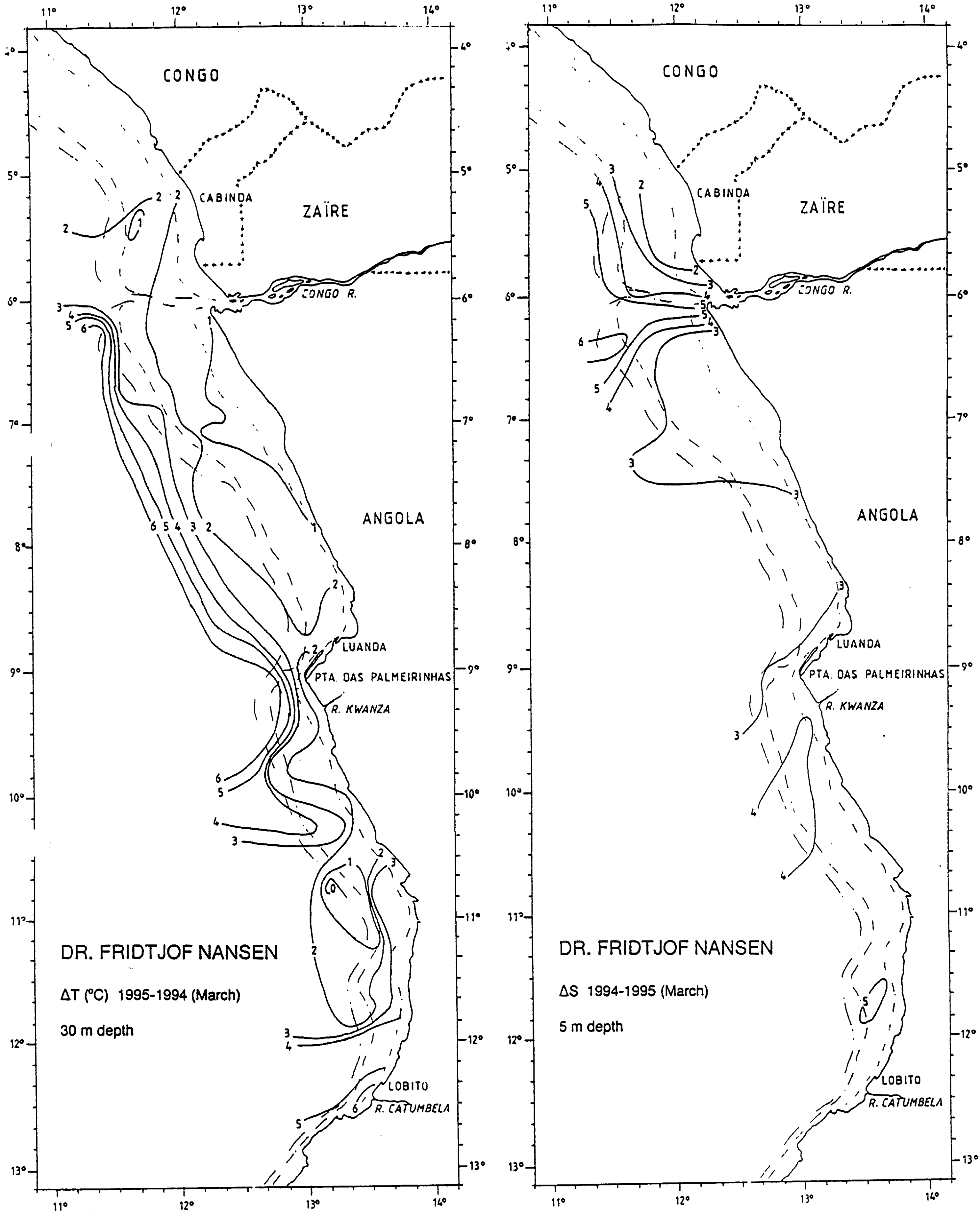

Figure 4. Changes of properties along the Angolan coast 1994-1995 (March). a)Temperature increase (ΔT) in 30m depth b) Salinity decrease (Δ S) at surface (5m depth).

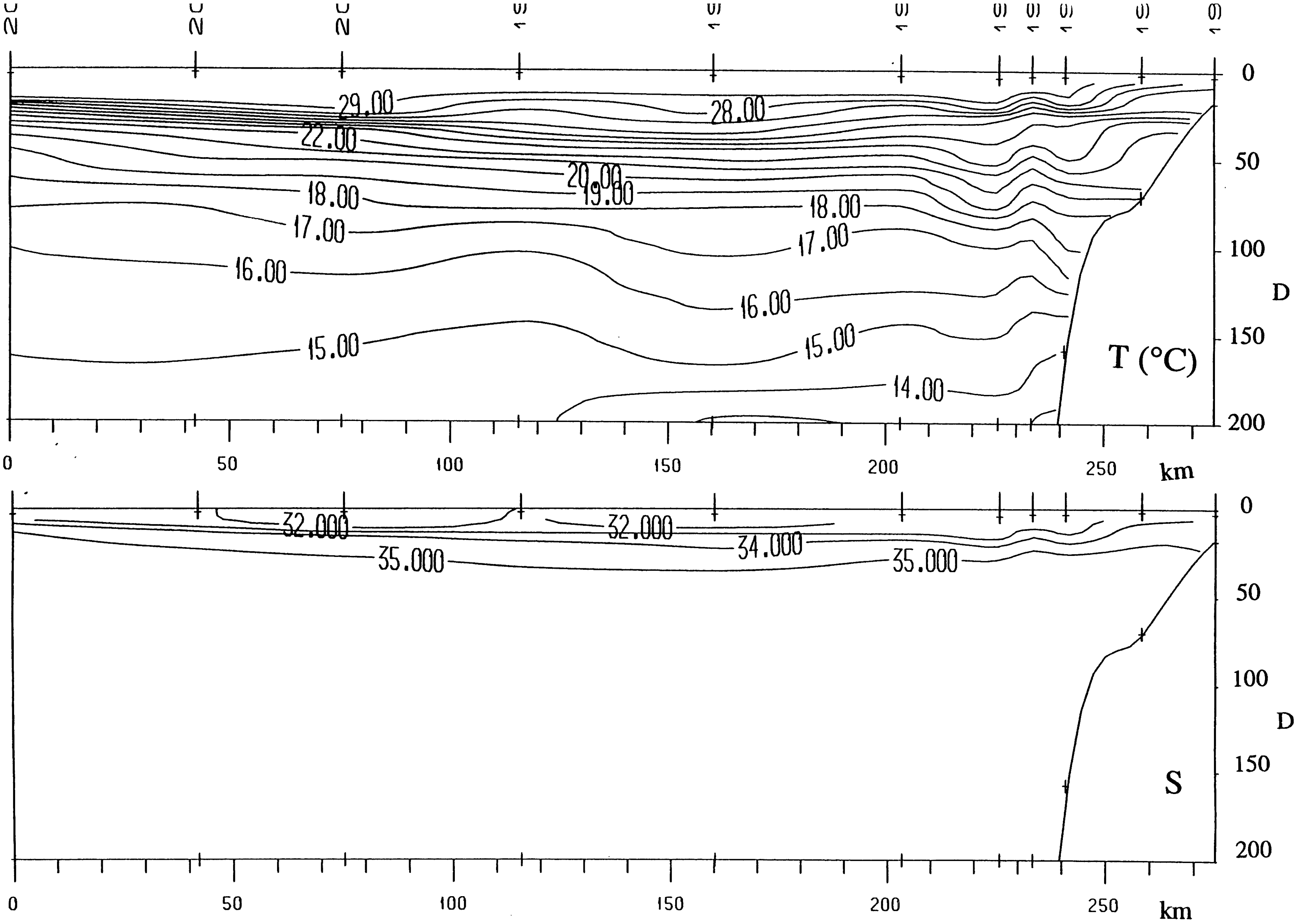

Figure 5. CTD section showing vertical distribution of a) Temperature and b) Salinity extended to more than 200km from the coast in March 1995. Note that the horizontal scale is different compared with Fig.3

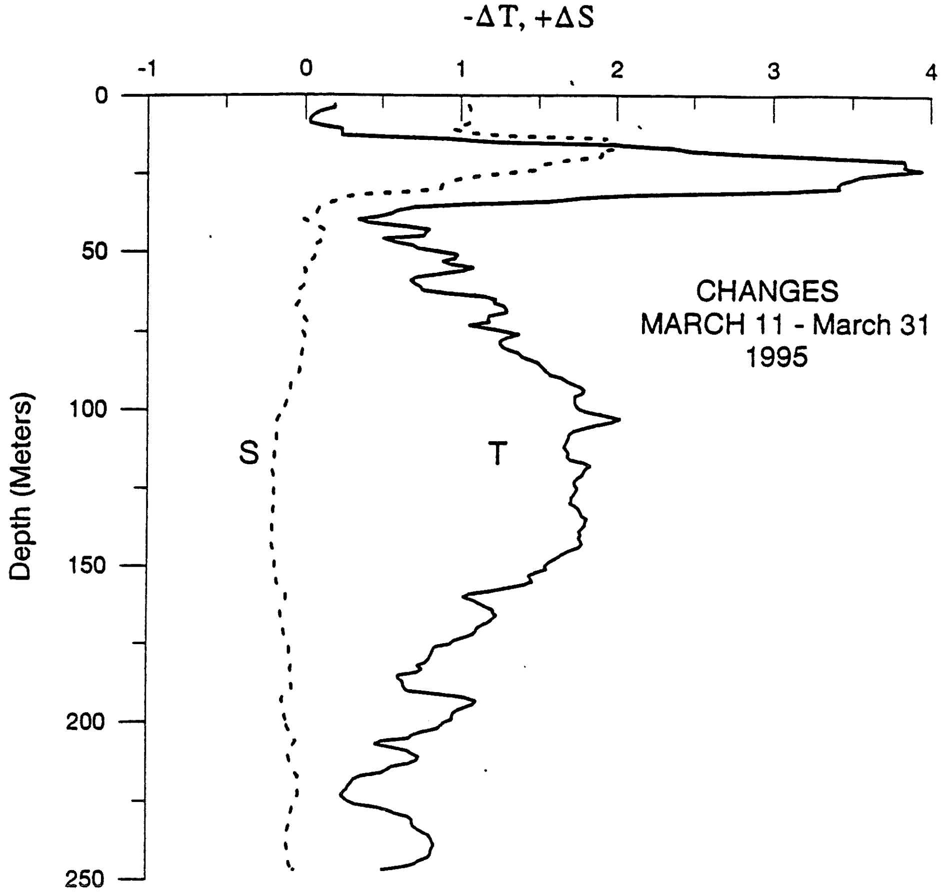

Figure 6. Changes in vertical profiles of temperature and salinity from March 11 to March 31, 1995, showing that the "Niño" was retreating in this period.

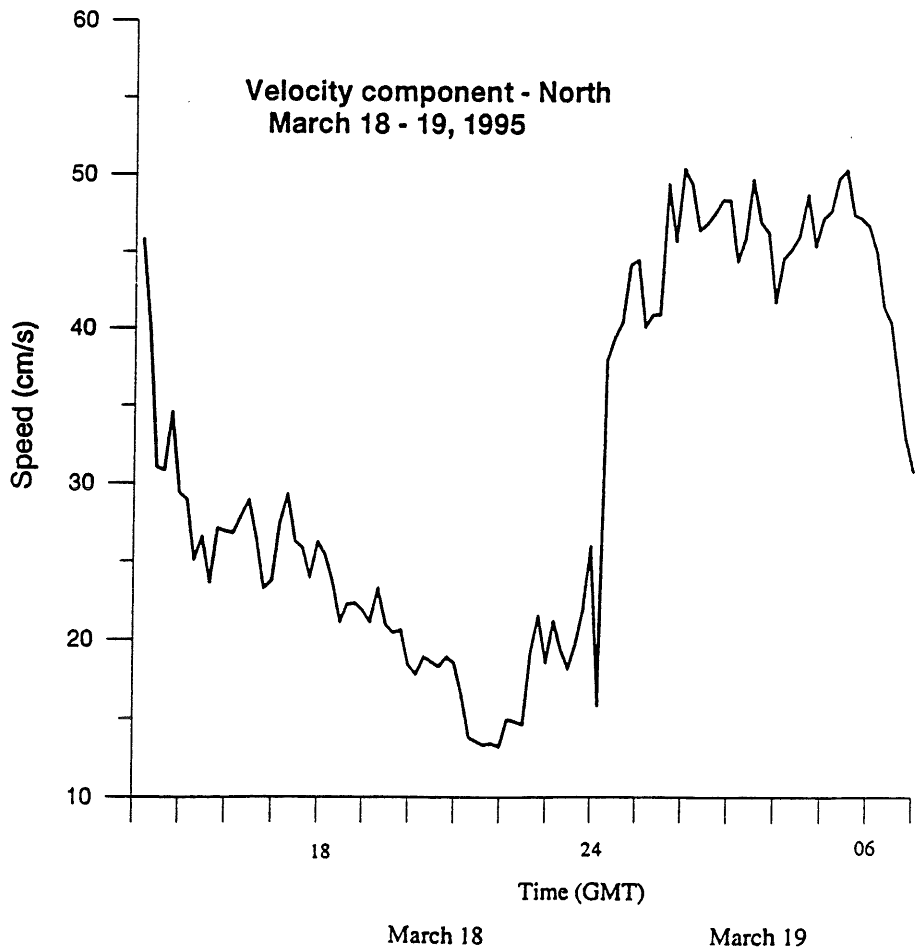

Figure 7. Northward component of current in 2m depth in position 11° 44'S, 13° 26'E.

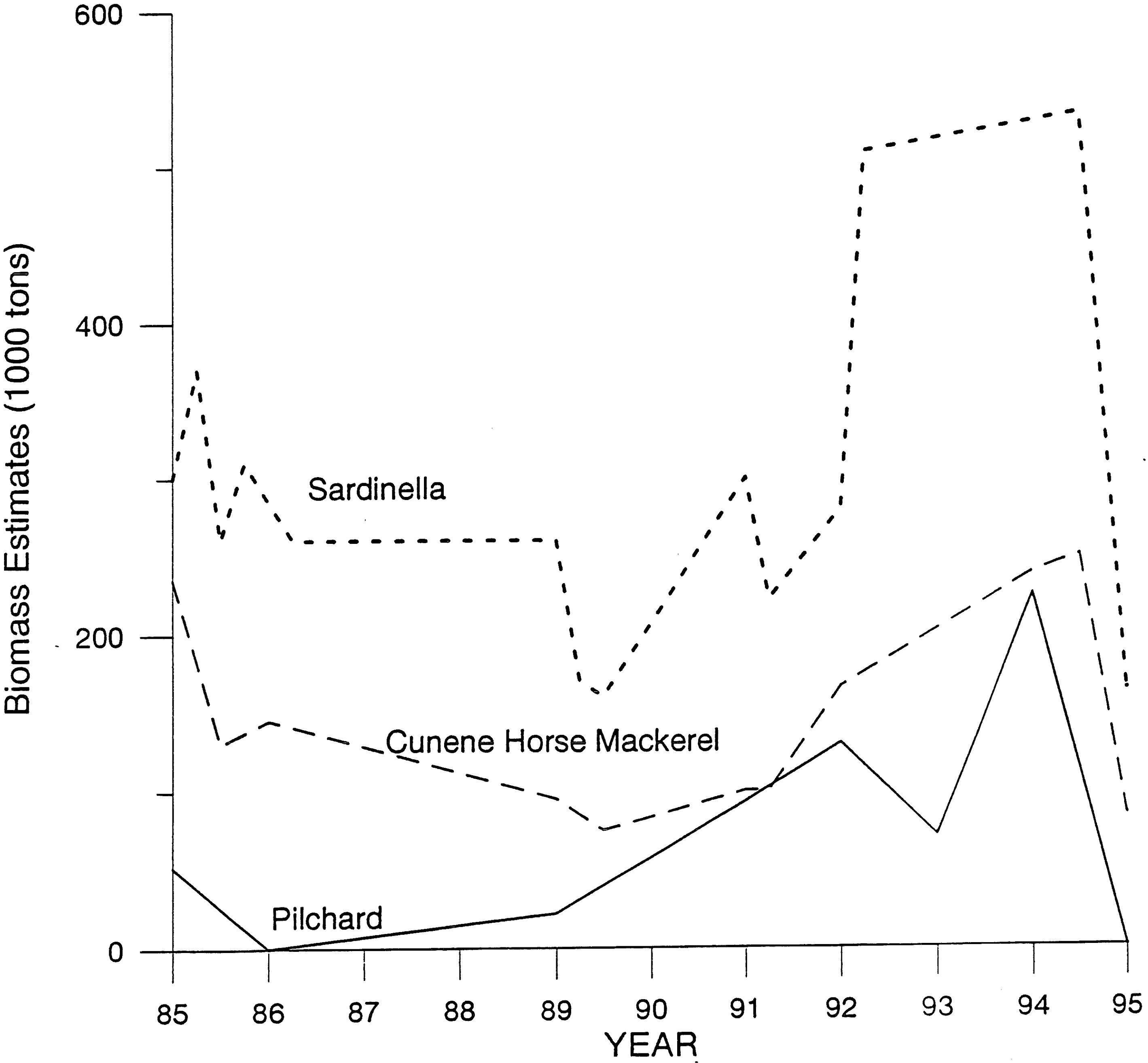

Figure 8. Biomass estimates of three important pelagic species 1985-1995 (After Lueye, 1995).