SPATIAL AND TEMPORAL VARIABILITY OF COASTAL TEMPERATURE AND SALINITY IN ANGOLAN WATERS

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ABSTRACT

To study the coastal hydro-climate in the central Angolan region, *in situ* temperature and satellite derived SST and *in situ* salinity were used to describe both the SST and SSS fields off Angola during the period 1969-1999 with some gaps. Emphasis was placed upon the Lobito coastal oceanographic station (12° 19S 13° 34E) mean temperature and salinity distributions and the seasonal and interannual temperature and salinity variability.

The main aims of this study were thus to identify, quantify and analyze the above parameters and so to establish their effects on the appropriate time scales of variability.

All *in situ* temperature measurements were obtained at oceanographic stations by lowering four Nansen bottles equipped with two reversing thermometers fixed to a marked position on the hydrographic wire to the standard levels i.e. 35, 20, 10 and 0 m respectively. The water samples were kept in small onboard bottles and salinity concentrations were analyzed by using Knudsen's method in the laboratory after every hydrographic station. The mean temperature pattern was characterized by a long warm season, centered in March, a long cold season, centered in August, a short warm season and a short cold season, established from November to January. It is suggested that the salinity minimum was associated with maximum precipitation. Furthermore, temperature and salinity analysis was related to three more variables: surface wind, Southern Oscillation Index (SOI) and precipitation. Lobito SST was compared with *in situ* SST at Pointe-Noire oceanographic station (04° 48S; 11° 51S), near the equator. It was observed that in recent years off Lobito there was an upsurge of warm events, this pattern repeated in 1995, 1996, 1997, 1998 and 1999. Interannual SSS variability off Angola was strongly related to the so-called Benguela Niño-related precipitation changes. During warm (cool) events, the SSS field was characterized by fresher-than-average SSS (saltier-than-average SSS) mainly in central and northern Angolan coastal region. The central Angolan system (Lobito) presented different patterns [extremely warm (cool), warmer (cooler)], from the northern Benguela.

An other important finding of the present work was that the mean trade winds off Lobito were mostly south and southwesterly. The extent to which the south and northward flows could generate warm and cold phases is discussed, and some associations with temperature and salinity patterns are noted.

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CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

A detailed and thorough knowledge of the coastal and larger scale marine environment off Angola is likely to benefit for a number of different agencies e.g. agriculture, fisheries and offshore mineral exploration.

Angola is the northernmost country of the Benguela system. The coastline extends along 1650 km, from the temperate waters of the southernmost region, which are influenced by the northern branch of the Benguela current to the Angola current, which flows in a southward direction. The convergence of these two currents forms the Benguela-Angola front. Its median position is at 15°S, but it moves further south when the warm flux of the Angola current intensifies, as it tends to do during the first quarter (Shannon *et al.*, 1987). The continental shelf distance out to a depth of 200 meters is relatively narrow and the shelf covers an area of about 21 000 km^2. Bordering the south Atlantic Ocean and situated between Namibia in the south and the Democratic Republic of the Congo in the north Figure 1-1 Angola has an exclusive fishing zone of 200 n.m. and a territorial sea out to a distance of 20 n.m. from the coast.

Angola is located in the equatorial tropical region, its climate being tempered by both sea and altitude. In the northern half of the central plateau the climate is mainly humid and tropical, whereas a dry tropical climate prevails in the regions of the south. The northern part of the coastal plain is humid and temperate, while the central and southern parts are affected by the relatively cool Benguela current.
In the interior highlands, the rainy season (http://www.bbc.co.uk/weather/) lasts from November to April followed by a cool dry season from May to October. Rainfall is high in the north and in the central highlands (the annual average is 1,250-1,750 mm) and decreases rapidly along the coastal plan (with an annual average of 250-1,000 mm). South of Benguela the average is less than 100 mm a year.

It is convenient to divide the Angolan littoral areas into three main climatic regions: the northern (5-9°S), the central (9-13°S) and the southern (13-17°S). Offshore one finds a highly variable ecosystem, with major environmental perturbations historically having occurred at about ten-year intervals. For instance warm events occurred in 1934, 1949, 1963, 1984 and 1995 and probably also in 1910, in the mid 1920s and during the period 1972-74.(Taunton-Clark, 1990; BENEFIT Science Plan, 1997).

A better understanding the of Angolan offshore Sea Surface Temperature (SST) and its scales and ranges of variability will make it possible to prepare in advance specific mitigation procedures for abnormal events (e.g. warmer or cooler episodes). The central aim of this thesis, then, is to contribute to a better understanding of the variability and predictability of SST off Angola.

Interannual variability in the tropical Atlantic Ocean is often regarded as being dwarfed by the powerful influence of the annual cycle (Merle *et al.*, 1980). However, it has been established that anomalous deviations from the annual cycle appear in the ocean-atmosphere system at various time-scales (from a few months to many years). This is particularly true for the SST, even if the range of the SST anomalies remains smaller with respect to the range of the seasonal variability (Servain *et al.*, 1985). Previous studies have shown that the ocean-atmosphere inter-annual variability in the tropical Atlantic can be represented by two main modes: a shorter time-scale mode (comprising a few months), which is similar to the El Niño in the Pacific Ocean (e.g. Zebiak, 1993), which manifests itself primarily near the equator and in shallow waters; and a longer time-scale mode (spanning many years), which has no counterpart in the Pacific.
The latter mode is also known as the "Atlantic dipole" mode (e.g. Hastenrath, 1978; Servain, 1991; Servain *et al.*, 1998a). It is characterized by a north-south inter-hemispheric gradient in SST. Very recently, Servain *et al.*, (1999b, 1999) have shown using observations that these two main modes appear to be linked statistically in the inter-annual frequency band.
The highly variable south-east Atlantic marine environment has been shown to experience specific phenomena such as the Benguela Niños, in addition to long-term trends in global and hemispheric SST and marine air temperature (Taunton-Clark, 1990 *op cit*).

Global records have indicated an overall increase of 0.57°C in surface temperature from 1961 to 1997 with a slightly greater increase in the southern than in the northern hemisphere (Jones *et al.*, 1999). The record shows that the warmest year recorded in the 20th century occurred in 1998, the warmest 10 years in succession occurred in 1989-98, and the warmest decade of the 20 th century is expected to be the 1990s.

1.1.1 Motivation

The southeast Atlantic especially the equatorial Atlantic and ocean adjacent to Angola – is a little researched area. Few studies have thus far been done in the area, primarily due to a lack of well-equipped research vessels in the region, as well as shortage of expert scientists in marine science from colonial times to the 1990s, when the situation began to improve.

In order to study the coastal hydro-climate in the central Angolan region, daily temperature and salinity data has been collected by ex-MEBPA (Missão de Estudos Bioceanológicos e de Pescas de Angola) from Lobito fixed coastal station since 1968, i.e. before the independence of the Republic of Angola. Unfortunately, after Angola became independent in 1975, most of the MBEPA team left the country and many projects initiated by them, including that of the Lobito fixed station, did not fully achieve their goals.

The main reason why a detailed, thorough study of the southeast Atlantic is so vitally important for the region is because in Angola, fish is the main source of protein for people living in the coastal region. Both fishermen and managers of fishing resources would thus benefit from a improved knowledge of the coastal ocean. As a result of the civil war which has ravaged Angola since its independence from Portugal on 11 November 1975, about 60% of the total population of 10. 864, 512 (July 1988 estimate) has moved to the coastal zone or its surrounding areas.

The main aims of this study are thus identify and quantify the key marine environmental features and to describe and analyse the relevant spatial and temporal oceanic parameters such as sea surface temperature and salinity and so to establish their effects on the appropriate time and space scales of variability. Knowledge of the surface wind time scales of variability is also relevant for the study area.

In order to understand the effects of environmental variables on fish resources, it is necessary to know the magnitudes of temporal changes in the oceans, including the period of such changes and their spatial scales. Quantitative knowledge of the short and long-term changes in the ocean is needed to draw conclusions on anomalies from mean or long-term changes in the ocean. An improved understanding of the impact of environmental factors on recruitment and distribution of the most important commercial pelagic fish species in Angola, i.e. sardinellas and horse mackerels will greatly contribute to the management of pelagic fish resources (Luyeye, 2001; Duarte, 2001).

The daily time series at the Lobito station during the years 1969-1974and 1978-1988 are particularly valuable for the study of marine climate variations on seasonal and inter-annual time scales in the area. They constitute a valuable source of background data for scientists interested in examining climatic variability in the area. It is also hoped that this present study of environmental variables will contribute to an improved understanding of the impact of the environment – and most importantly of changes in the environment – on pelagic fish resources. The position of Lobito station in the area may be of strategic significance monitoring fluctuations of the Angola Benguela Front (ABF).

Combining data from both Lobito and additional processed satellite derived SST imagery from the regional project known as "Environmental Conditions and Fluctuations in Recruitment and Distribution of Small Pelagic Fish Stocks" (ENVIFISH), which has been funded by the European Union, will provide a good basis for improving our understanding of local oceanographic processes. Sensors on satellites provide a large amount of high quality data that can offer an invaluable source of information on large spatial and temporal scales and give a holistic view of the highly dynamic marine environment. Lutjeharms and Meeuwis (1987) have noted that in the past, and specifically in respect of the oceans surrounding the African continent, there has been a systematic bias of research cruises towards the southern part of Africa, virtually to the exclusion of the southeast Atlantic. Nowadays, however, satellite derived data provides us with a more holistic and systematic research initiative.

In order to address typical questions such as the following, a suitable data set has to be found.

- What constitutes a useful index of movement of the Angola-Benguela front?
- What is the relationship between SST and its vertical variation in the coastal zone?
- What is the nature and extent of seasonal and inter-annual SST variability?
- What is the influence of the Congo River on the salinity of the Angolan coast?

Fortunately, such a data set does exist: It consists of daily measurements of temperature and salinity up to 40m deep off Lobito during 1969-74 and 1978-1988. This data set, referred to hereunder as the Lobito fixed station, in conjunction with satellite derived and NCEP reanalysis wind data, will form the basis of this investigation.

1.1.2 Hypotheses

Using the daily temperature and salinity data obtained at the Lobito fixed station, the following hypotheses will be explored:

a) *In situ* temperature measurements at Lobito, Angola are dominated by a seasonal signal?.
b) There is a SST relationship between the interannual temperature anomalies at Lobito and temperatures in the equatorial Atlantic.
c) There is a relation between the inter-annual temperature anomalies at Lobito and the Pacific El Niño or La Niña.
d) Equatorially driven warm events have mostly been experienced during March and April. *In situ* temperature data from Lobito are available for both periods (1969-74 and 1978-88). That the following hypothesis can thus be considered on the basis of two six – year periods in each data set, namely: to determine whether the mean March temperatures for the period 1969 to 1974 was either the same or different to that for the period 1978 to 1983.
e) The most pronounced salinity minimum found off Lobito and its surroundings during the warm season is related to the outflows of the Congo River, which increase at that time of year.

It is anticipated that this present study may update previous related reports or works, because the emphasis will be on both vertical station data (i.e. from the Lobito station) and satellite - derived SST data with combined record lengths of about 30 years.

1.2 Literature Review

1.2.1 Atmospheric forcing over Angola

The atmosphere and the ocean are coupled energy systems, with each providing some of the driving force to the other. Their respective properties and the state of the interface between them (viz. the sea surface) determine to a large extent the exchange of mass and energy between the two media (Levaestu and Hayes, 1981). The climate in and around the Atlantic Ocean has been observed to vary in broad spatial patterns and on a variety of timescales during the twentieth century (Richard *et al.*, 2000).

The South Atlantic Anticyclone (SAA) is maintained throughout the year, with seasonal differences in pressure being on the order of 3-4 mb. It shifts seasonally over 6° of latitude, reaching its northern and southern extremities in May and February respectively, and over 13° of longitude, reaching an extreme westward position in August (Tyson, 1986).

The coastal ocean off Angola experiences atmospheric forcing from both the equatorial and the higher latitude regions, depending on the geographical position, under consideration. The boundary separating the north and south trades is variously called the Inter-Tropical Front (ITF) over land, or more generally the Inter-Tropical Convergence Zone (ITCZ). The ITCZ represents the band of wind convergence separating the northern and southern Hadley cells. Here the wind is weak and variable. The strengthening of the Hadley cells, due to an intensification of the Azore and St. Helena Highs during their respective winters, results in a meridional displacement of the ITCZ (see Figure 1-2). Low pressure produced by summertime heat loading in the Sahara results in a increased meridional pressure gradient and an additional northward displacement of the ITCZ over West Africa during this season. In the boreal winter the ITCZ remains north of the Gulf of Guinea coast (Ajao and Houghton, 1998).

When the ITCZ is displaced southward, the surface waters south of the equatorial Atlantic are anomalously warm, while waters in much of the tropical north Atlantic are anomalously cold. Positive/negative sea level pressure departures in the north/south tropical Atlantic drive a counterclockwise anomalous surface circulation, weakening southeasterly trades south of the equator and strengthening northeasterly trades north of the equator (Hastenrath and Heller, 1977; Markham and McLain, 1977; Moura and Shukla, 1981; Hastenrath, 1984a; Lough, 1986).

Wind conditions

South and southerly winds are dominant off Lobito. Patterns or wind conditions were observed during the R/V *Fridtjof Nansen* survey along the whole Angolan coast for the period between 06.08 and 24.08.1999 (see Figure 1-3).

The dominant wind system over the South Atlantic Ocean is the South Atlantic Anticyclone (SAA). The southeast trades and equatorial easterly winds are weakest during January-March and strongest in June-September. Mean winds near the Angolan coast are approximately southwesterly throughout the year, and thus parallel to the southern Angolan coast and slightly onshore further north. Wind speed varies comparatively little in the course of the year, except for a brief period from July-September – where winds are particularly strong (Hirst and Hastenrath, 1983).

Figure 1-4 summarizes the distribution of annual mean relative wind stress or, more correctly, wind speed squared, in the tropical Atlantic. It can be seen from the Figure 1-4 that the nearshore wind stress north of 15°S latitude is substantially lower than in the areas south of the same latitude and farther offshore, and also that there is a progressive clockwise rotation of the wind vectors within 400 km of the coast between 10 and 20°S.

Hellerman and Rosenstein (1983) recalculated monthly normals and standard errors of the eastward and northward components of the wind stress in the lower 10 m of the atmosphere using over 35 million surface observations, covering the world's oceans from 1870-1976. Figure 1-5 displays the January and July wind stress normals from the above-mentioned data of observations. It can be seen from the same that the mean wind field is quite stable, depicting typical features of the atmospheric circulation over the ocean in subtropical and tropical latitudes. As the number of observations is sufficiently large over most of the world's oceans, the standard error of the mean of easterly wind-stress component to be less than 0.1 dyn cm^{-2} meanwhile at the high latitudes of the southern hemisphere, easterly wind-stress is about 0.5 dyn cm^{-2}.

The surface wind patterns during January and July over the south Atlantic are shown in Figure 1-6 with wind roses in 10° squares. A relative steadiness is clearly visible in each season, in both direction and speed, of the trade winds near Africa. By far the most observations are of winds weaker than Beaufort force 5 (less than 11 m s^{-1}) (Höflich, 1984).

A study undertaken by Hardman-Mountford (*pers. comm.* 2001) gave some idea of the annual European Center for Medium range Weather Forecasting (ECMWF) wind cycle off the Angolan coast. The mean ECMWF wind field showed the main area of atmospheric circulation to be the south-easterly trade winds. The zonal winds also clearly show the midlatitude westerlies to the south, the south-westerly monsoon winds towards the coast in the north and some onshore winds in the west coast upwelling area. The meridional winds also show a northerly component to the midlatitude winds, in the southeast and southwest corners of the scene, and a northerly component to winds on the southern Angolan coast, between Lobito and Namibe. Standard deviation of the zonal winds illustrates that the least variability to occur in the trade and monsoon wind areas, and the highest variability (~4 m s^{-1}) to occur in the circumpolar winds, especially south of the African continent. The standard deviation of the meridional winds indicates that the greatest variability occurs around the Cape (>3 m s^{-1}) and that the lowest variability occurs in the Angolan offshore area. Northerly winds are also seen along the Angolan coast between Lobito and Namibe in all months except December.

1.2.2 The main marine environmental features off Angola

The Angolan coastal ocean is sandwiched between the south Equatorial current system in the north and the Benguela current system in the south.

Equatorial System

Figure 1-7 is a schematic summary of the elements of the southeast Atlantic Ocean current system.

1 The Equatorial Undercurrent (EUC) is the strongest, with maximum speeds exceeding 1.2 m s^{-1} in its core at a depth of about 100 m and transports up to 15 Sv. It is strongest in the west and weakens along its path as a result of frictional losses to the surrounding waters (Figure 1-8). Observations show (Düing *et al.*, 1975) that it swings back and forth between two extreme positions 90 km either side of the

Equator, at a rate of once every 2-3 weeks, speed and transport oscillate between the maximum given above and their respective minimum of 0.6 m s^{-1} and 4 Sv.

2 The South Equatorial Current (SEC), is a region of broad and uniform westward flow with speeds of 0.1-0.3 m s^{-1}, and extends from about 3°N to at least 15°S. It is interspersed with an eastward flow both at the surface and below the thermocline.

3 The South Equatorial Countercurrent (SECC) is weak, narrow and variable, based on 2° averages in latitude. It often shows a maximum speed (around 0.1 m s^{-1}) below 100 m depth and is characterized by a weak westward flow at the surface.

4 The South Equatorial Undercurrent (SEUC) is narrow and swift, with maximum speeds of 0.4 m s^{-1} near 200 m depth.

No much exchange occurs between the hemispheres in the eastern part of the equatorial Atlantic (Moralinari, 1982), the termination region of all eastward flow (Figure 1-9). The South Equatorial Countercurrent turns south, driving a cyclonic gyre with its centre at 13°S, 4°E which extends from just below the surface to at least 300 m depth with velocities approaching 0.5 m s^{-1} near the African coast. This relatively strong subsurface flow is known as the Angola Current. By opposing the northward movement of the Benguela Current, it creates the Angola-Benguela Front (ABF).

Angola Dome

The presence of the cyclonic feature known as the Angola Dome, its center near 13°S, 5°E, had originally been detected by Moroshkin *et al.*, (1970) during a survey in 1968. Its existence and location has been confirmed in the historical hydrographic data set (Gordon and Bosley, 1991). This feature is situated in a region of anticiclonic wind stress curl and also appears in the Levitus gridden data set. Questions about the seasonal or interannual variation of the large-scale cyclonic circulation in the Angola Dome are yet to be answered. A similar gyre, centered near 10°N, 22°W is driven by the North Equatorial Countercurrent (Mazeika, 1967) which is prevented from flowing north by the east-west orientation of the coastline. Its velocity intensifies to an average 0.4 m s^{-1} along the Ivory Coast before its energy is dissipated in the Gulf of Guinea. Because of the observed doming of the thermocline in the austral and boreal summers, the two gyres are respectively known as the Angola and Guinea Domes (Figure 1-10). The associated circulation exists throughout the year, although it weakens in winter, only reaching a depth of 150 m.

Angola Current

Wacongne and Piton (1990) considered the southward turn of the SEUC to be a source of water for a highly variable poleward undercurrent which they observed in current meter measurements taken at the continental shelf break at 1°-6°S. This undercurrent, which Wacongne and Piton *op cit.* referred to as the Gabon-Congo Undercurrent, was observed to have an average speed of 8 cm s^{-1} toward the south, and they conjectured that it feeds into the Angola Current farther south.

The first quasi-synoptic hydrographic survey of the Angola Basin was made by the R/V *Kurchatov* from 5 April to 9 June 1968, during the southern autumn. Measurements from that cruise were used by Moroshkin, Bubnov and Bulatov (1970) to observe a cyclonic geostrophic gyre less than 1000 km across and centered near 13°S 4°E, more than 600 km southwest of the thermal dome. The gyre descends from just beneath a very thin (10-20 m) wind driven surface layer to a depth of about 300 m, and produced subsurface southward velocities of up to 50 cm s^{-1} in a narrow coastal current which they referred to as the Angola Current. This Angola Current influences the coast of Angola carrying warm equatorial waters southward. It moves over the shelf, reaching its maximum velocity in March between 9° and 12°S latitude and measures 0.7 m s^{-1} at the surface and 0.88 m s^{-1} at a depth of 100 m (Dias, 1972). The range of its activity usually does not extend further south than the mouth of the Cunene River at the border with Namibia.

Northern Benguela System

The Benguela region is part of the south-east Atlantic lying between 14°S and 37°S, with a western boundary near the 0° meridian. The Benguela Current is regarded as the eastern boundary current of the South Atlantic gyre, in keeping with the generally accepted international terminology of Stramma and Peterson (1989), rather than the more limited definition adopted by Hart and Currie (1960), Stander (1964), Shannon (1966), Bang (1971) and Nelson and Hutchings (1983). The northern boundary of the Benguela ecosystem is the Angola-Benguela frontal zone.

Angola-Benguela Front (ABF)

The Benguela Upwelling system is bounded on the equatorward side in the north by the warm Angolan Current, which flows poleward. The front that separates the Angola and Benguela systems occurs at about 16°S (Hart and Currie *op cit*). Shannon *et al.* (1987) used a variety of historical data to characterize the horizontal and vertical nature as well as the seasonal variation of the front. The front is a persistent feature in the upper 50 m and occurs between 15 and 17°S, although the variability at a short time scale (e.g.of days) is in the same order as its seasonal variability. A typical surface temperature gradient near the coast is 4°C per 111 km (temperatures ranging from 17 to 21°C).

Seasonal averaged sea surface temperatures and satellite derived frontal positions (in Shannon *et al.*, 1987) illustrate the general extent of the Angola-Benguela Front's variability. On shorter time-scales of days to weeks, significant frontal movement and variability is evident. On occasions there are multiple fronts, most commonly during summer when the poleward flow in the Angola Current is strongest (Shannon *et al.*, *op cit*). A study by Kostianoy (1994) suggests that two or three fronts are the norm, rather than the exception and that it would be more appropriate to consider the region as a frontal zone rather than a single front, one being associated with the Angola Current and another with a tongue from the northern Namibian upwelling cell. The Angola - Benguela Front may be maintained by a combination of factors. These include coastal orientation, bathymetry and dynamical considerations of the current systems to the north and south of the front.

Recently, Kostianoy and Lutjeharms (1999) found that the short-term as well as long-term hydrographic characteristics of the Angola Benguela Frontal Zone (ABFZ) are largely controlled by the behavior of the southern border (18.5°S), where the width of the ABFZ is greatest (2.5° latitude) and where the temperature difference across the frontal zone is also greatest (7° C). By contrast, when the southern front is farthest north (16°S), the frontal zone is narrower (1.5° latitude) and the temperature difference is smaller (4° C).

Upwelling

The basic mechanism of wind-driven coastal upwelling is well understood. Equatorward winds induce net offshore surface Ekman transport, which brings about transport divergence near the coast. The Ekman transport can be quantified in terms of an upwelling index, which is the monthly mean Ekman transport derived from observed winds and expressed in units of m^3 s^{-1} per 100 m of coastline (Bakun, 1996).

The upwelling ecosystem off the Angolan coast is subject to considerable variability, with prominent time scales ranging from days to months. The greatest intensity of upwelling is located at 16°S, i.e. Southern Lobito town. Further, it is most pronounced from October to March (Andrews and Huchings, 1980). According to Walker (1989) this can be ascribed to the domination of a South Atlantic high pressure cell at this time of year which creates suitable conditions for the development of strong south-easterly gale-force and upwelling favorable winds along the west coast of Africa. The locations and characteristics of the main upwelling cells in the Benguela Upwelling System have been documented and described by authors such as Nelson and Hutchings (1983), Shannon (1985), Shannon and Nelson (1996) and Lutjeharms and Meeuwis (1987). Shillington (1998) reviewed the Benguela Current System.

1.2.3 Sea Surface Temperature (SST) and Sea Surface Salinity (SSS) variability off Angola

SST is an important oceanic variable that assists describing the feedback of the ocean to the atmosphere. The amplitudes of SST changes depend on the existing horizontal (and vertical) gradients of the properties in the surface layers of the oceans as well as on the driving forces in the atmosphere (Laevastu and Hayes, 1981). The SST seasonal variations have their largest amplitude in the Angolan and equatorial upwelling areas. In these areas the increase in amplitude is obviously due to the intense surface cooling which occurs during from July to September (Merle, Fieux and Hisard, 1980).

In a study on the characteristics of temperature and salinity in the intertropical Eastern Atlantic, Berrit (1958, 1961) noted that the year is divided into two periods, viz. cold (T<24°C) and warm (T>27°C).

Berrit and Dias (1977) examined the marine climate at two stations of the Angola coastal ocean, basing their conclusions on 5 years of daily measurements of temperature and salinity. At Lobito measurements were taken at 4 levels above a depth of 40 m. At Lucira (13° 51S; 12° 31S), south of Lobito, only surface conditions were observed the mean annual temperature cycles were similar at every level, with two observed maxima and minima. These maxima and minima varied by two months from one year to another. The amplitude of the annual tend decreased with depth, from a range of 10°C at the surface to 7°C at the 35 m depth. The main maximum fluctuated, from one year to another, by about 4°C. Similarly, the main minimum was observed to vary by about 1.5°C. The warm and cold seasons were described with the same criteria as those at Pointe-Noire (5°S), north of Cabinda (5° 50S):

there was no little warm season, either in Lobito or in Lucira, but only an increase of temperature, which divided the cold season into a great and a little cold season. The daily variability was in the order of 1°C and did not decrease with depth, perhaps as an effect of internal waves (Berrit and Dias, 1977).

Berrit and Dias *op cit* also found that the mean salinity was lower at Lobito than at Lucira. Furthermore, it increased sharply with the depth. The variations of salinity were, on the average, a surface phenomenon occurring within the first 10 m layer. Two periods of low salinity levels in the water were observed. They also found that the mean annual cycle of salinity was variable and that the main salinity minima at Lobito, varied from 35.34 psu to 33.19 psu.

A warm saline tongue of tropical Atlantic thermocline water, which Gordon and Bosley (1991) also denoted as South Atlantic Central Water (SACW), e.g. Hagen (1981) sometimes extends along the shelf edge as far as 27°S. Lass *et al.* (2000) found that the pattern of the horizontal distribution of temperature and salinity below the mixed layer consisted of a broad plateau of warm and saline water north of about 14°S. This water was separated from cooler and less saline water between 15°S and 17°S with a centre located al least 150 km offshore.

Using SST and SSS data from surveys conducted from 1984-1989 by the Angolan R/V *Goa*, Fidel and Filipe (1995) observed SST and SSS seasonal patterns. During the warm season, SST decreased poleward while during the cold season SSS decreased equatorward (see Table 1-1).

1.2.3.1 Inter-annual events

Much of the interannual variability in the Atlantic sector is independent of the Southern Oscillation (Philander, 1990). Notwithstanding this, there are occasions during which El Niño-like phenomena do occur in the Atlantic.

El Niño Southern Oscillation (ENSO)

The term El Niño originally referred to 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 in the eastern Pacific so that local Peruvian equatorward winds do not bring cool nutrient rich water to the surface. During this time, a southward flow of water occurs along the coasts of Ecuador and Peru. In some years anomalously warm water covers much of the equatorial 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. Philander *op cit*; Walsh *et al*., 1980; Arntz and Tarazona, 1990; Luyeye, 1995).

North Atlantic Oscillation (NAO)

The variability of the NAO and the Tropical Atlantic dominate the climate of the Atlantic sector and the surrounding continents on inter-annual to decadal timescales (Marshall *et al*., 2001).

There is a recurring, low-frequency climate phenomena in the tropical Atlantic, which exhibits spatially coherent patterns of SST in the subtropics of either hemisphere. This climate phenomenon, which involves a low-frequency oscillation of the SST gradient across the equator, is often referred to as the tropical "dipole mode" because of the structure of the the SST anomaly. Although the dipole in the SST usually occurs with the opposite sign in each hemisphere, the development does not always show a perfect out-of-phase relationship between the northern and southern components. The actual correlation between northern and southern hemisphere subtropical SST has been a subject of considerable debate in recent years (Servain, 1991; Houghton and Tourre, 1992; Enfield and Mayer, 1997).

Various processes and feedback mechanisms have been postulated in an attempt to explain the variability in the tropical and subtropical Atlantic climate on decadal time scales. These include soil moisture, albedo and surface roughness feedbacks over land (see Nicholson, 1989). A certain portion of low-frequency SST fluctuations in the tropical Atlantic may be influenced by the Pacific, particularly the ENSO related anomalies. However, it has not been determined quantitatively how much tropical Atlantic SST variability is attributed to "remote" influences and how much is due to "local" air-sea interactions. The extra-tropical influences, such as the influence of the North Atlantic Oscillation on the tropical Atlantic dipole, or vice versa, are also as yet unclear (Marshall *et al.*, 2001.).

Warm events

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 an El Niño-type situation have occurred, viz. in 1963 and in 1984 (Shannon *et al.,* 1986).

Hirst and Hastenrath (1983) regarded the Angolan littoral as the obvious corollary to the Niño region of the south American coast and have shown 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%. Hirst and Hastenrath' s 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 15°S (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 15°S for evidence of the Atlantic equivalent of the Peruvian Niño.

Because of their similarity to classical El Niño events in the Pacific Ocean, Shannon *et al.* (1986) termed these events the Benguela Niños. The Benguela Niños differ from the Pacific El Niño in that they are less intense and less frequent, reflecting rather the spatial scales of the Atlantic Ocean so-called Benguela Niños are the main inter-annual warm events in the northern Benguela region, being superimposed on the normal intrannual changes in the structure and location of the Angola-Benguela Front. They are generally observed as intrusions of warm, saline surface waters on the Namibian shelf (Boyd *et al.*, 1987). Shannon *et al.* (1986) discussed the Benguela Niño in detail, and concluded that it occurs about once every 10 years. Much of the interannual variability in the Atlantic sector is independent of the Southern Oscillation (Philander, 1990). Historical records have already identified the Benguela Niños, and have shown that they cover a wide range of conditions, it is further evident that the amplitudes of different El Niños episodes vary enormously. This prompted Quinn *et al.* (1978) to introduce four El Niño categories-strong, moderate, weak, and very weak, nevertheless, there are still considerable differences within each category.

The last Benguela El Niño event took place during March 1995, when the upper ocean temperatures in the Angolan-Namibian coastal waters were anomalously high, with positive temperature anomalies of up to 8°C. Maximum temperature differences were recorded at depths of 30-50 m deep, reflecting a deepening of the thermocline its from normal depths of 10-30 m. The unusually warm water mass covered the Angolan coast from Cabinda (5°S), the northern limit of the survey area, to at least 24°S, off central Namibia (Gammelsrod *et al.*, 1995; 1998).

Recently, Interannual variability of the tropical Atlantic and its association with El Niño Southern Osciliation (ENSO) have been studied, and thus the connection of the tropical Atlantic to other basins.

Xie and Tanimoto (1998) and Tanimoto and Xie (1999) propose through modeling and empirical studies that decadal extratropical forcing of the Tropics, excited by the North Atlantic oscillation (NAO), can force a dipole pattern linking the two hemispheres. In addition to the tropical-midlatitude link, there is also evidence of a tropical connection between El Niño event in the Pacific and anomalously warm in the northern tropical Atlantic. Lanzante (1996) and Enfield and Mayer (1997) state that 25% of the variance of the interhemispheric mode is forced by El Niño-Southern Oscillation (ENSO) events. A relationship between the Atlantic mode and Pacific variability has also been suggested by previous studies (Servain 1991; Carton and Huang 1994). They suggest a relaxation of the trade winds in the western Atlantic leads to an accumulation of warm water. Servain (1991) shows a mean correlation of –0.28 when the southern Atlantic (south of 5°N) leads ENSO events (cool events) by 6-11 months; Enfield and Mayer (1997) show a correlation of –0.3 with the principal component time series of their southern Atlantic index (3°S-3°N) found a –0.07 correlation.

In recent years the tropical eastern Atlantic has experienced an upsurge of warm events with SST increases of 2 to 3°C above the normal. These may be linked to general climate variability over the entire African continent. Although warm events in the Atlantic tend to exhibit a decadal character (Jury, 1996), this pattern was in fact repeated in 1995, 1996 and 1998.

1.2.4 The influence of Angolan Rivers on Salinity

River runoff variations depend directly on climatic fluctuations that regulate inland precipitation.

The major freshwater buoyancy input of the Congo Rivers produces extensive offshore freshwater plumes, reducing the surface salinity in the Gulf of Guinea. Proximity to the equator, however, means that the influence of the earth's rotation is relatively small (the baroclinic Rossby radius is 80 km), and thus these plumes tend not to form well-organized coastal centers and pronounced zonal fronts. The extensive River systems off Angola are the Congo River (6°S) at the border with Democratic Republic of Congo in the north, the Kwanza River (~9° 30S) in the south of Luanda and the Cunene River (17° 10S) in the south, at the border with Namibia.

Of the above, the Congo River runoffs have the most important offshore influence. Runoff variations, concomitant to precipitation variations, have definite repercussions on their level salinity (Binet 1983a *et al.*, 1983b).

Because of the extremely arid nature of the climate of southern Angola, freshwater input to the coastal ocean is generally not significant except occasionally in summer when flooding occurs in the interior of country.

With regards to the Congo River, there are steep gradients of temperatures (increasing) and salinity (decreasing) towards the mouth of the river. In the central region of Angola both parameters (temperature and salinity) have gradients running to the coastline, which is in fact characteristic of the southward flow of the Angolan current. South of Tombwa, however, the salinity is low, suggesting extensive inflow of fresh water from the Cunene River.

Finally, poleward advections of low salinity water caused by the heavy rains in northern and central Angola respectively, form tongues that have been observed mainly in the warm (or rainy) season in the last two decades during the cruises performed with R/V *Fridtjof Nansen*.

CHAPTER 2: DATA AND METHODS

2.1 Data

2.1.1 Introduction

Two different data sets are used as input in this study. Firstly, historical, daily *in situ* measurements of temperature and salinity were made at four depths (0, 10, 20 and 35 m) at the Lobito fixed station [(1969-1974; 1978-1988) (12° 19S; 13° 34E).] Although the measurements were taken on a daily basis, there was no data collection over weekends. Nevertheless, an impressively large data set is available. Secondly, the Cloud and Ocean Remote Sensing around Africa (CORSA) Satellite derived Sea Surface Temperature for the Environmental Conditions and Fluctuations in Recruitment and Distribution of Small Pelagic Fish Stocks (ENVIFISH) project was available, for the period January 1982 - December 1999. The CORSA is a project of the Marine Environment Unit of the Space Applications Institute of the Joint Research Centre of the European Commission (JRC/SAI/ME).

In addition to the historical *in situ* and the satellite derived data, an attempt was made to obtain wind records from the Lobito coastal meteorological station. As this was unsuccessful, surface wind data from the National Weather Service's National Centers for Environmental Prediction (NCEP). NCEP reanalysis wind data have been extracted at 12° 30S; 12° 30E for a 32-year period from 1967 to 1998. It is thus intended that the NCEP wind data time series will replace the Lobito *in situ* wind measurements.

In the seventies, data sets of both temperature and salinity from ex-Missão de Estudos Biológicos de Pescas de Angola (MEBPA) were used by researchers to study marine the climate in central Angola (e.g. Berrit and Dias, 1977). For the time period available, the data sets did not reveal significant cooling or warming trends. Nevertheless, the presently available data sets should be suitable for a regional climatic variability study. The temperature and salinity measurements were made by the MEBPA as part of the Fishery Oceanography program.

The available data sets are described in more detail below.

2.1.2 Temperature and Salinity data at Lobito station

Since February 1968, routine oceanographic observations of temperature and salinity were made at the Lobito coastal station. Data were collected daily at 08h 30' GMT except on Sundays and public holidays, at depths of 0, 10, 20 and 35 m, at a point where the total water depth was 40 m. The station from which the data were obtained is the oceanography observing station at Lobito identified in Figure 1-1. The observational team reached the station by means of a small wooden motor boat equipped with a winch. The Nansen bottles were equipped with two reversing thermometers which were fixed to the winch's wire. The salt concentration was analyzed by using Knudsen's method (Knudsen, 1901).

The salinity of seawater is essentially a measure of the mass of dissolved salts in one kilogram of seawater. An average value for the oceans is about 35 grams per kilogram. It is not practical to measure this quantity directly, and thus for a long time it was determined indirectly by measuring the halide content (*Cl*, mostly chloride) by means of silver nitrate titration and using, on the basis of previous careful analyses, a linear relation ($S=1.806\ 55 \times Cl$) between total dissolved salts and halide (Pond and Pickard, 1995). However, it has been demonstrated that there is a close relationship between the salinity and the electrical conductivity of seawater and, as this latter property can now be measured easily and precisely, it has for some time been used to estimate salinity. Alternatively, conductivity, temperature and pressure sensors may be mounted together in an underwater unit which is lowered through the depth range of interest and the instrument [(a Conductivity Temperature and Density (CTD)], which either records the data internally or transmits them as electrical signals to instruments on deck. In this way, a continuous record of temperature and conductivity (or salinity) against depth can be obtained. The relations between salinity, conductivity, temperature and pressure have been redetermined in recent years [Unesco (1979, 1981) and Lewis (1980)].

A data inventory at the Lobito station has been made (Table 2-1). Unfortunately, there are unavoidable missing data in the records (see Table 2-2). In some cases, the numbers of observations tend to decrease with depth.

The number of measurements or observations shows a tendency to decline from 1978 to 1980 as revealed in Figure 2-1 1981 was a good year with regard to the number of measurements made but from 1982 to 1986 the number of measurements decreases. 1985 was the year with the least measurements of the two periods, whereas 1971 – obviously before Angolan independence – was the year with the highest number of measurements.

From Table 2-2 it can be seen that the monthly amounts of both temperature and salinity data varied from one year to the next. It is evident that these variations occurred for political and financial reasons. For example, in 1976 and 1977 no observations were made for either temperature or salinity. In general, however, observations appear to be sufficiently dense to enable sampling of short-term (days), seasonal and inter-annual temperature and salinity variability.

The data set, called "Ocean Lobito Data on PC", contains files that report daily temperature and salinity at a monthly oceanographic station. The data is presented in the form of a table: Each file begins with a line which reads: "Station #"-"Daily Temperatures and Salinities and Depth" and then "coordinates"; "temperature (°C)"; "salinity (psu)"; "depth" and "day". The actual information is entered into the correct columns and rows underneath; for example, see Table 2-3. These values were entered from the original archives. For each depth the arithmetic mean for the month is also tabulated (Table 2-3). It has been time-consuming and painstaking work to transfer all the data from paper records to a suitable electronic medium.

2.1.3 CORSA Satellite derived Sea Surface Temperatures

One of the most useful oceanographic applications of operational weather satellite data is the mapping of SST from infrared imagery. While it is widely accepted that satellite infrared sensors measure radiation from only the surface skin of the ocean, most oceanographers are interested in SST more representative of the upper meters of the ocean, commonly referred to as the bulk SST. The bulk-skin temperature differences may depend on wind and surface heat flux conditions. The bulk-skin temperature difference can vary between day and night as well as with different cloud conditions, which can mask the horizontal variability of SST in regions of weak horizontal temperature gradients (Schluessel *et al.*, 1990)

Both the thickness and the temperature gradient of the ocean's skin layer are determined by the same heat exchange processes. The skin temperature responds most rapidly to the generally upward directed net longwave radiance. Since water has high emissivity at the infrared (Friedmann, 1969; Downing and Williams, 1975), the longwave radiation is emitted from (or absorbed by) the upper few micrometers of the ocean, thus cooling (or warming) the skin layer.

Weekly, NOAA SST images from January 1982-December 1999 have been processed for the SADC region by JRC, Italy for the Angolan, Namibian and South African partners of the ENVIFISH project, a 3-year project funded by the European Union (1998-2001). The data are stored on two CD volumes and comprises weekly and monthly mean values of CORSA sea surface temperatures calculated from 5-channel Advanced Very High Resolution (AVHRR) at anominal 4 km spatial resolution on board the NOAA -7, -9 and -11 polar orbiting satellites. The area covered by CORSA is the following: 0°-40°S, 2°W-29°E, equiangular projection with 25 pixels per degree in both latitude and longitude.

2.1.3.1 Satellite derived SST data off Lobito

To develop a better understanding of the temporal variability of trends, satellite-derived SST data off Lobito has been extracted for the area 11° 42S-12° 24S; 12° 48E-13° 24E and combined with the fixed station data. The thereby created joint data-sets together provide an integrated data series which will be used to investigate long term trends, from 1969-1998.

2.1.4 NCEP wind reanalysis data

The NCEP/NCAR Reanalysis Project is a joint project of the National Center for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR) (Kalnay *et al.*, 1996). This joint effort has produced new atmospheric analyses using historical data from 1948 onwards. The project involves the recovery of land surface, ship, rawinsonde, aircraft, satellite and other data sources. NCEP/NCAR is responsible for the quality control and assimilation of these data sets, which are gridded with a resolution of 2.5 X 2.5 degrees. The NCEP data which have been used in this particular study are monthly means from a grid cell closest to Lobito.

2.1.5 Additional data

Three other series of data have been used:

(a) *In situ* monthly SST at Pointe-Noire Oceanographic coastal station;

(b) various rainfall records;

(c) Southern Oscillation Index (SOI).

These are described in more detail below.

(a) *In situ* monthly SST at Pointe-Noire: Monthly SST means were available at Pointe-Noire coastal station (04° 48S; 11° 51E) for the period 1964-1998 by the former Office de Recherche Scientifique et Technique d' Outre Mer (ORSTOM) de Pointe-Noire (Figure 1-1). ORSTOM has recently become the Instititut de Recherche pour le Développement (IRD). Observations were made daily, except on weekends and holidays at 09h ±1h (GMT +01:00).

(b) Monthly mean rainfall was available from data recorded at five by the former Serviços Meteorológicos de Angola (SMA) at five meteorological stations, namely Cabinda (5°33S; 12°11E), Soyo (06°07S; 12° 21E), Luanda (8°51S; 13°14E) and Lobito (12°22S; 13°32E) for the period 1953-1972. The stations are presented in Figure 1-1.

(c) The Southern Oscillation Index (SOI) is calculated from the monthly or seasonal fluctuations in the air pressure difference between Tahiti (17° 32S; 149° 34W) and Darwin (17° 23S 130° 44E), both of which are situation in the Pacific Ocean.

Figure 2-2 is a summary of all the forms of data that have been used in the present dissertation.

2.2 Methods

2.2.1 Measurements

2.2.1.2 Temperature and salinity at Lobito

The surface water temperature was determined by means of an ordinary mercury-in-glass thermometer, which is capable of calibration to 1/10°C. The thermometer is of a small thermal capacity in order to attain equilibrium rapidly. When a sample of surface water is taken with a bucket, the temperature has to be determined immediately; otherwise heating or cooling of the water sample by radiation, conduction, and evaporation may have a measurable effect upon the temperature (Sverdrup *et al.*, 1942). Surface temperature obtained in this way, represents the conditions in the upper 1m of water.

The basic instrument for measuring sub-surface temperatures is the protected reversing thermometer developed especially for oceanographic use (Figure 2-3). It is a mercury-in-glass thermometer, which is generally mounted upon water sampling bottles so that both the temperature and the water sample for salinity or other chemical or physical tests are obtained at the same level. The protected reversing thermometer is enclosed in an outer glass case to protect it from the pressure of the water, and thus records temperatures without being influenced by external pressure. The reversing thermometer is sent down in the set position (Figure 2-3) with the reservoir, the capillary, and part of the bulb filled with mercury. When the water-bottle is closed to collect the sample, the thermometer is inverted, and, as a result of its construction, the mercury breaks at a particular point and sets, thereby indicating the in situ temperature at the depth of reversal.

As described above, all temperature measurements were obtained at oceanographic stations by lowering four Nansen bottles equipped with two reversing thermometers fixed to a marked position on the hydrographic wire to the standard levels i.e. 35, 20, 10 and 0 m respectively. After a short period of time, the Nansen bottles were reversed and were then pulled back up to the surface for reading the measurements. A drift angle was used to correct the "real" depth during storms on the sea. The values of measurements were written down on paper. The final values at measurements of the standard level were obtained by computing the mean of both thermometers' values.

The readings obtained from the reversing thermometers do however have to be corrected according to the changes that occur due to the differences between the *in situ* temperature at reversal and the temperature at which the thermometer is read.

Thus the following equation is commonly used to correct of the *in situ* water temperature, T_w, (Siedler, 1968).

$$T_w = T_g + \frac{(T_w + V_0)\ (T_g + t)}{K - 100} \qquad (2\text{-}1)$$

where

T_g = scale corrected temperature of the reversing thermometer,

t = scale corrected temperature of the auxiliary thermometer,

K = thermal expansion of the thermometer system,

V_0 = volume of mercury in the small bulb and in the capillary up to the 0°C graduation expressed in terms of degree units of the capillary.

After corrections, the reversing thermometer yields a temperature reading to an accuracy of about ± 0.002°C in routine use.

When large numbers of observations have to be corrected, it may be convenient to prepare graphs or tables for each thermometer from which T_w can be obtained for any value of T_g and t (Figure 2-4)

Clearly, diurnal or daily variability cannot be sampled by having only one observation per day at a fixed time, e.g. 08h 30' local time (GMT +01:00) (Kuhlbrodt and Reger, 1938).

Water samples were kept in small onboard bottles and salinity concentrations were analyzed by using Knudsen's method in the laboratory after every hydrographic station.

In the determination of chlorinity, speed as well as accuracy, is desirable so that large numbers of samples can be analysed within a short period of time. The basic procedure for the routine determination of chlorinity was developed by Knudsen, who modified Mohr's method. The halogen ions in seawater are titrated with silver nitrate using potassium chromate as an indicator. The chemical reactions involved are as follows:

$$Cl^- + Ag^+ \rightarrow AgCl \text{ and } Br^- + Ag^+ \rightarrow AgBr \qquad (2\text{-}2)$$

$$CrO_4^{2-} + 2Ag^+ \Leftrightarrow Ag_2CrO_4 \qquad (2\text{-}3)$$

As soon as all the halide ions (except fluoride) have been precipitated and a slight excess of silver ions is present, red silver chromate is formed. A faint red colour in the solution indicates the end-point of titration.

The results are commonly calculated using the Tables of Knudsen (Knudsen, 1901) (Table 2-4).

The Knudsen pipette (Figure 2-5) allows the delivery of a constant volume, about 15 ml of a sample, with precision. It consists of an ordinary bulb pipette fitted with a two-way tap, and a double entry.

To ensure that results from all oceanographic laboratories are consistent, the silver nitrate solution is standardized against the international Standard Seawater. This is natural seawater, diluted with a little distilled water to give a chlorinity of ca. 19.38. The chlorinity of this standard is determined with an accuracy of 0.001 psu at the "Depot d' Eau Normale", Charlottenlund Slot, Charlottenlund, Denmark, from which sealed hard glass ampoules of Standard Seawater can be purchased.

As it is inconvenient continuously to prepare a silver nitrate solution of the correct concentration, and as the silver nitrate solution moreover tends to vary over time, it has been found practical to introduce a factor (f), which is obtained as follows:

$$f = \frac{chlorinity\ of\ Standard\ Seawater}{\frac{1}{2} direct\ titration\ of\ Standard\ Seawater,\ read\ from\ burette} \qquad (2\text{-}4)$$

direct titration of sample, read from burette

The correct titre of a sample is

$$T_c = f * \frac{direct\ titration\ of\ sample,\ read\ from\ burette}{2} \qquad (2\text{-}5)$$

Table 2-4, calculated by E. Föyn on the basis of Knudsen's Hydrographical Tables, sets out the correlation between the correct titre and the salinity.

The accuracy of the basic temperature data is subject to a degree of uncertainty, not only as a result of instrumental limitations but also due to the difficulty of accurately reading the thermometer, and possible errors in reading.

Original archives of raw data record contain all the information originally collected and are available at IIM-Lobito.

The data from Lobito has been collected and tabulated by hand and thereafter transferred to a computer file with the aim of using a computer for analysis. Standard time series analysis and MS Excel graphs were used to analyse the data.

2.2.1.3 Satellite derived SST data

Weekly maps of satellite derived multichannel sea surface temperatures are available at the Marine Environment Unit of the Space Application Institute (ME-SAI) at the Joint Research Centre (JRC) of the European Commission (EC). These maps form of part the Clouds and Ocean Remote Sensing Archive (CORSA) products. The SST data were processed from level 1b to the weekly composites used in the study.

There are three major problems that limit the accuracy of the comparisons between SST derived values and *in situ* measurements. The first two in fact can be attributed to the nature of the *in situ* data. *In situ* SST data collection methods have varied over time and with technological improvements. It is therefore very difficult to establish the intrinsic variability and uncertainty of *in situ* SST measurements (Folland *et al.*, 1984 Jones *et al.*,1986).. The CORSA data were nominally to have an accuracy of 0.1° Kelvin.

2.2.1.4 NCEP wind reanalysis data

The wind fields are derived by Goddard Code 916 from the NCEP CPC geopotential heights using a balanced wind approximation (Randel, 1987; Newman *et al.*, 1988).

NCEP datasets contain basic fields such as the u- and v-wind components, temperature, and humidity. However, the archives differ from each other because of their horizontal and vertical resolution, as well as in the specific fields provided by the NCEP.

The NCEP typically saves their model output in GRIB format. However, at ARL the data are reprocessed and stored in a 1-byte packing algorithm. This 1-byte packing is slightly more compact than GRIB and can be directly used on a variety of computing platforms with direct access I/O.

The data array is packed and stored as one-byte characters. To preserve as much data precision as possible the difference between the values at grid points is saved and packed rather than the actual values. The grid is then reconstructed by adding the differences between the grid values starting with the first value, which is stored in unpacked ASCII form in the header record.

The u and v wind components are combined to give a wind vector, **V**, which has both magnitude, W, and direction, θ. The magnitude is represented by:

$$W = \sqrt{(u)^2 + (v)^2}$$

and the direction by:

$$\theta = \arctan(u/v)$$

2.2.2 Time series statistical analysis techniques

Similar methods have been applied for the analyses of temperature, salinity and wind.

A time series is a collection of observations made sequentially and may reveal certain characteristic variations, some, or all of which, are present to varying degrees in different measurements. Analysis of such variability is of great value in many areas of research. Moreover, when studying time series, not only the recorded values should be considered but also other relevant information, about the process in question. In other words, it is necessary to understand the actual process of measuring and obtaining temperature, salinity, surface wind and other additional data.

The time series used for analysis of temperature and salinity can be considered as the discrete one because the two variables (i.e. temperature and salinity) are analyzed in a univariate series, as they were taken and observed at the same instant. The time that elapsed between the start and the finish of the recordings is given in point 2.1.2.

Traditional methods of time-series analysis are mainly concerned with decomposing the variation in a series into trend, seasonal variation, other cyclic changes, and remaining "irregular" fluctuation. Both temperature and salinity data presented in this thesis, are known to contain a strong seasonal cycle which may be modified by local effects of runoff, tidal stirring and wind mixing.

A time series is often adequately described as a function of four components. These are: the trend, cyclic, periodic and stochastic components. A trend describes any gradual increase or decrease in the variate values with time. If the increase or decrease happens abruptly the change is referred to as a jump. A cycle in the series causes an alternating rise and fall in the variate values in question with respect to the trend line (even if trend line does not exist). The daily or seasonal change in the variate values as a result of lunar or solar activities illustrates the periodic component in the series (Shan *et al.*, 1993).

In our presentation however we shall not include the cyclic component in the expression for the time series and restrict it to

$$x_t = \alpha + \beta t + \gamma \cos(\delta t) + \varepsilon_t \tag{2-6}$$

where α, β, λ and δ are parameters. In this expression (the model that describes the time series at hand) the (linear) trend component is represented by the terms $\alpha + \beta t$, the periodic component by $\lambda \cos(\delta t)$ and the stochastic component by ε_t.

The first two components in expression (2-6) are deterministic in nature. The presence of such deterministic components in the structure of the time series renders the series to be non-stationary, that is to say time dependent or time-variant. (Shan *et al.*, 1993).

Smoothing always involves some form of local averaging of data in such a way that the nonsystematic components of individual observations cancel each other out. The most common technique is moving average smoothing which replaces each element of the series by either a simple or a weighted average of *n* surrounding elements, where *n* is the width of the smoothing "window" (see Box and Jenkis, 1976; Velleman and Hoaglin, 1981).

A procedure for dealing with a trend, is to use a linear filter which converts one time series, x_t, into another, y_t, by means of the following linear operation (Chatfield, 1989).

$$y_t = \sum_{r=-q}^{+s} a_r x_{t+r} \tag{2-7}$$

where a_r is a set of weights. In order to smooth out local fluctuations and to estimate the local mean, we should clearly choose the weights so that $\sum a_r = 1$, and in that case the operation is often referred to as a moving average.

Moving averages are often symmetric with $s = q$ and $a_j = a_{-j}$. The simplest example of a symmetric smoothing filter is the simple moving average, for which $a_r = 1/(2q+1)$ for $r = -q,....,+q$, and the smoothed value of x_t is given by

$$Sm(x_t) = \frac{1}{2q+1} \sum_{r=-q}^{+q} x_{t+r} \tag{2-8}$$

Having estimated the trend, we can look at the local fluctuations by examining the following

$$\begin{aligned} \mathrm{Re}\, s(x_t) &= \text{Residual from smoothed value} \\ &= x_t - Sm(x_t) \\ &= \sum_{r=-q}^{+s} b_r x_{t-r} \end{aligned} \tag{2-9}$$

This is also a linear filter, and if $\sum a_r = 1$, then $\sum b_r = 0$, $b_0 = 1 - a_0$ and $b_r = -a_r$ for $r \neq 0$.

The analysis of time series that exhibit seasonal variation depends on whether one wants to (a) measure the seasonal effect and/or (b) eliminate seasonality. For series showing little trend, it is usually adequate to estimate the seasonal effect for a particular period (e.g. January) by finding the average of each January observation minus the corresponding yearly average in the additive case. If a trend is present in the data, however, the multiplicative model should be used instead.

For a series that does contain a substantial trend, a more sophisticated approach may be required. With monthly data, for instance, the most commonly method of eliminating the seasonal effect is to calculate (Chatfield, 1989) the following:

$$S_m(x_t) = \frac{\frac{1}{2}x_{t-6} + x_{t-5} + x_{t-4} + \ldots x_t \ldots + x_{t+5} + \frac{1}{2}x_{t+6}}{12} \qquad (2\text{-}10)$$

For complete data collection (i.e. where there are no missing values) the monthly average would be computed as:

$$\overline{X} = \frac{\sum_{j=1}^{N} x_j}{N} \qquad (2\text{-}11)$$

where N is the total number of observations in the month

With regard to the present dissertation, however, the data sets were not complete. Thus, by means of simplifying the formulas above, the results were obtained as follows:

Temperature and salinity weekly average values

In order to obtain the weekly average values, the daily data of a working week day i.e. from Monday to Friday was divided by the number of observations made in that particular week, (N = is usually 6, but in exceptional cases of missing data, may be as small as 2).

$$\overline{X}_{weekly} = \frac{\sum_j X_j}{N} \qquad (2\text{-}12)$$

where

$\overline{X}_{weekly}$ = weekly average of the daily values

N = the total number of observations made on week $_i$

Temperature and salinity average monthly values

The average monthly values were obtained by taking the mean weekly data and averaging over the month. (The month was considered to have four weeks, as the last remaining days of the same month are averaged with the fourth week of the month)
No averaging was applied to the NCEP wind data, as the original data was in monthly average format.

Seasonal climatology of temperature and salinity

By using, the monthly means for both periods (69-74; 78-88) a climatology was formed by averaging the January-December monthly values, over the period concerned. This was done at the standard depths of observations were calculated to study seasonal variations. They were computed at the standard depths based on all observations within each month (from January to December) for all the years i.e. six years for the first period and eleven for the second one.

Temperature and salinity weekly anomalies

In order to obtain anomalies, one can deseasonalize the data to eliminate seasonality. If the seasonal variability is removed from seasonal data, then the residuals may provide useful information. The seasonal variation was removed from the temperature/salinity by the simple procedure of calculating the 48 weekly averages and subtracting the appropriate one from each individual observation.

$$An_j = X_j - \overline{X}_j \qquad (2\text{-}13)$$

where

An_j - anomaly data value of week j, (for the six and eleven year period)

$\overline{X}_j$ - average data values of weeks j, (for the six and eleven year period)

X_j - data values on week j

ex: $\sum_{69}^{74}$ (all week$_i$) of period 1969-74

Temperature, salinity and wind running means

By using moving averages of appropriate orders, cyclical, seasonal and irregular patterns may be eliminated, thus leaving only the trend movement.
In order to remove high frequencies the SST/SSS weekly data was filtered, thus smoothing the series by introducing the three week moving average using Hanning's procedure.

$$M.A. = \frac{X_j}{4} + \frac{X_{j+1}}{2} + \frac{X_{j+2}}{4} \qquad (2\text{-}14)$$

where

$M.A.$ = moving average

x_j = the value at time j

x_{j+1} = the value at time $j+1$

x_{j+2} = the value at time $j+2$

Wind monthly anomalies

Almost the same procedure that was used in (2-13) was used to determine monthly wind anomalies. The difference is that the seasonal variation was removed from the wind by calculating twelve monthly averages and subtracting the appropriate one from each individual observation

Wind running means

The seasonal variability of the wind could be removed by calculating the one-year (or twelve-month) moving average. This was found by averaging the values over twelve and similarly for subsequent values

2.2.3 Correlation between in situ measurements and satellite data

The relevant correlation coefficient is given by

$$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\left[\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2\right]}} \qquad (2\text{-}15)$$

where given N pairs of observations on two variables x and y.

Using weekly data for SST – *in situ* and satellite derived – between 1982 and 1999, the resulting weekly surface temperatures from CORSA are shown to be consistent with the corresponding weekly sea surface temperature at Lobito station (Figure 2-6). Is interesting to note that satellite SST in almost always warmer than *in situ* SST in the interval 16° - 24°C, but for SST > 24°C there are equal number of values above and below. The differences between data sets may be due to factors such measurement made by satellite infrared sensors during the day and nighttime, solar heating, and vertical mixing.

The analysis (Figure 2-6) showed the linear correlation coefficient (R) had a high value 0.91, whereas the standard deviation was 2.86°C. Note that a similar procedure has been used by Comiso (1999) in a study on temperature variability and trends over the Antarctic. Thus a comparison has been made in order to observe the extent of the difference between satellite and *in situ* SST by using their anomalies (see Figure 2-7)

Analyses were performed by first entering all the relevant data and creating files on Laptech-PC 160.0 MB RAM and thereafter processing the same by using appropriate statistical functions based on the Microsoft ® Excel 97 software package.
Statistical worksheet functions were used to perform statistical analyses on ranges of data. With regard to missing data, the following must be noted: in Excel 97, if an array or reference argument contains text, logical values, or empty cells, those values are ignored; however, cells with the value zero are included.

In order to compute seasonal wind speed for the record 32-year length and to draw feather plot MATLAB software version 5.1.0.421 was used. In this regard feather (x, y) is equivalent to feather $(x + i * y)$. MATLAB displays the feather plot for the angles and magnitudes of the elements of matrices x and y . x while y represent u and v zonal and meridional winds components respectively.

2.2.4 Satellite extended SST

As reported in 2.1.3.1 satellite derived SST data from the area has been extended to 11° 42'S 12°24'S; 13° 48'E 13° 24'E, close to Lobito, has been extracted for the 18-year period of 1982-1999.

2.2.5 Index of stratification

In order to explore daily and climatology stratification, the periods of January-December 1970 and the period of 1969-74 were respectively used as examples.

Daily index

One of the aims of the current research project is to investigate both intra-seasonal and seasonal temperature and salinity variability off Lobito. To observe the thermal stratification throughout the year, an index and a mean index of stratification were computed.

To obtain a daily index the daily temperature difference between the surface and bottom temperature of the same day was computed and thereafter data have been condensed.

$$\Delta t_j = t_{0,j} - t_{35,j} \qquad (2\text{-}16)$$

where

$t_{o,j}$ = temperature at surface of day $_j$

$t_{35,j}$ - temperature at 35m depth of day $_j$

Climatology index

The previous method used for temperature and salinity have been applied to determine the climatology index ,as well in computing the average weekly value, the average monthly value (4 weeks) and the climatology.

The mean index of stratification was produced for the period 1969-74 and is defined by subtracting the mean monthly averages for the period at surface and bottom.

$$\overline{\Delta t_i} = \sum_{j=1}^{30/31} \frac{\Delta t_j}{30/31} \qquad (2\text{-}17)$$

where i refers to i^{th} month

CHAPTER 3: RESULTS

In this chapter, the vertical measurements of temperature and salinity at Lobito are examined at a variety of time scales.

3.1 Description of the results

3.1.1 Event scales

To investigate the short within month time scale variability at the Lobito station, temperature difference data were examined for the entire year of 1970, from January-December (Figures 3-1). Note that interpolation has been made to fill the gaps because there no data was collected over weekends or public holidays. An approximate time scale of the variability for 1970 was obtained by dividing the days of a given month by the numbers of peaks within that month. Figure 3-2 indicates the variation of the approximate number of events per month for 1970. It can be seen that the range in length of an event is 4-8 during 1970.

3.1.2 Seasonal variations

3.1.2.1 Temperature

Weekly means

To get an indicator of the seasonal fluctuations in temperature at surface, 10 m, 20 m and 35 m, the daily data were composited into weekly mean values for the period 1969-74 (Figure 3-3) and for the period 1978-88 (Figure 3-4). The range in SST for both periods was 9.8°C (18-27.8°C) although the seasonal curve for 1978-1988 is smoother than that for period 1969-1974. This primary reason for this is that the former period spans eleven years whereas the latter spans only five years. In July (weeks 2, 3 and 4) of the period 1969-74, there was an unusual increase of surface temperature, reaching about 22°C. The weekly mean SST at this time of year should have ranged from 18 to 20°C. There is an another unusual increase in the weekly mean SST in the first week of September of the period 1978-88 i.e. it can be seen that the temperature (19.04°C) at 20m is slightly higher (18.09°C) than at 10m (difference of 0.95°C).

The temperature curves' structures in respect of periods 1969-74 and 1978-88 (Figures 3-3 and 3-4) respectively display an assymetrical shape which can be divided into two parts of unequal shapes and sizes. The highest points of both parts refer to two warm periods, one warmer (February-March) than the other (November). The mean temperature differences between two warm periods for the periods 1969-74 and 1978-88 were found to be 3.73°C at surface and 2.52°C at 35 m depth respectively.

The amplitude of the mean weekly SST variation for both periods 1969-74 and 1978-88 is shown in Figures 3-3 and 3-4 (8.39°C and 8.83°C respectively) and the weekly mean SST values are presented in Table 3-1.

Monthly means

The monthly mean SST at Lobito in central Angola (Figure 3-5), is highest in March (26.99°C) and lowest in August (18.08°C). A second lower SST maximum is observed in November (23.25 °C) and a second SST minimum appears in December (22.60°C). Temperature maxima and minima (Figure 3-6) were observed in the same months for 1978-1988 as for 1969-1974 (Figure 3-5) namely, a maximum in March (26.48°C), another, less marked, in November (23.28°C), a minimum appeared in August (18.44°C) and a second minimum was observed in December (23.04°C). In the cold periods the water is well mixed whereas in the first warm period the water is strongly stratified so that here is a substantial temperature difference the between surface and the bottom.

The monthly mean temperature difference for the period 1969-74 (Figure 3-5) between 0m and 35m in the warm period (4.97°C) is higher than in the cold period (1.98°C) similarly for the period 1978-88 (Figure 3-6) the maximum monthly mean SST difference is more noticeable in the warm season (4.82°C) whereas the minimum difference in the cold season is 2.25°C.

The climatological temperature value of the main and secondary warm and cold seasons as well as the temperature differences between surface and bottom are presented in Table 3-2.

At each of the four depth levels (0, 10, 20 and 35m) the pattern remains fairly similar, although the amplitude of the variation is largest at the surface during the period 1969-74 (8.91°C) in comparison with 8.04°C for the period 1978-88. Similarly, the amplitude of the variation is largest at the bottom during the period 1969-74 (5.92°C), in comparison with 5.55°C during 1978-88.

Monthly mean SST values for the periods 1969-74 and 1978-88 are presented in Table 3-3. As can be seen from the said Table 3-3 the monthly mean temperature differences between surface and bottom are larger in the warm season than in cold season, so these differences are likely to be due to the sun's position (Stern, 1999). The result of this is that the temperature variations are not simply sinusoidal. At all levels, there is a secondary minimum in December-January (Figure 3-5 and 3-6).

Weekly SST anomaly maxima and minima

The anomaly maxima and minima appear as the upper and lower boundaries of the temperature and salinity data of a given period time, thus allowing us to compare the extent of the variability among different the period time sets which will be done hereunder.

The weekly data for the three time periods 1969-74, 1978-88, 1982-99, were averaged to obtain a seasonal time series. Weekly anomalies were obtained by subtracting the seasonal mean of each period from the original data. The weekly anomaly maxima for each time period are plotted in Figures 3-7, 3-8, 3-9 and 3-10. Note that the *in situ* SST and SSS at Lobito station refer to the periods 1969-74 and 1978-88 whereas the satellite derived SST off Lobito belong to the period 1982-99. Note too, that period 1982-99 in fact contains part of period 1978-88; however there is no actual duplication of data, as the measurements for the *in situ* and the satellite derived SST have been made in different locations.

Weekly anomaly maxima and minima are compared hereunder for the periods 1969-74, 1978-88 and 1982-99.

Weekly SST anomaly maxima

The SST anomaly maxima curves of the three periods referred above, appear to vary in nearly the same manner, albeit with different magnitudes. From April to December (Figure 3-7) the changes in the SST anomaly maxima vary coherently for the periods 1969-74 and 1982-99. For 1978-88, on the other hand, the SST anomaly maxima show little variability from June to December.

The highest maxima appears to be more pronounced in March for the period 1982-99 (5.85°C) than in February for the period 1969-74 (4.94°C). The lowest change in SST anomaly maxima occurs in March during the period 1978-88 (1.02°C) in March.

The SST anomaly maxima curve for the period 1969-74 tends to follow the SST anomaly maxima curve of the period 1982-99, in February, the SST anomaly maxima of the period 1969-74 is larger by 1.22°C than that of the rest of the period 1982-99.

Weekly SST anomaly minima

It can been observed (Figure 3-8) that both SST anomaly minima for the periods 1969-74 and 1978-88 vary in almost the same manner except in December. From February to April the SST anomaly minima curve of the period 1982-99 tends to follow the SST anomaly minima curves of both periods 1969-74 and 1978-88. The more pronounced SST anomaly minima (-8.91°C) occurred in January in the period 1982-99.

The period 1982-99 had the highest maxima (largest variability) whereas the period 1978-88 exhibited the lowest maxima (smallest variability).

3.1.2.2 Salinity

Weekly means

The weekly mean salinity for the two periods 1969-74 and 1978-88 are shown in Figures 3-11 and 3-12. Large changes in surface salinity are observed at the surface only in March, April and May for both periods. A very unusual low salinity value (34.628 psu) was observed in the fourth week of May in the period 1978-88 (Figure 3-12). This salinity minimum is probably due to river flows and rainfall, which were particularly high during that period.

The amplitude of the mean weekly surface variations in salinity for both periods 1969-74 and 1978-88 is shown in Figures 3-11 and 3-12 (1.263 psu and 1.246 psu respectively) and the weekly mean SSS values are presented in Table 3-4a-b.

Monthly means

The most pronounced monthly mean salinity minimum at Lobito (Figure 3-13) for the period 1969-74 occurs in March (34.701 psu). A smaller secondary minimum appears in November (35.287 psu). From June (35.601 psu) to October (35.528 psu) there is little change except for a slight increase of SSS in September. Between July and September salinity at 10 m is higher than that at 35 m. In August, salinity (35.599 psu) at 10 m depth is higher than that at 35 m

(35.582 psu) depth and in October salinity (35.620 psu) at 20 m is slightly higher than at 10 m depth (35.600 psu). For the period 1978-88 (Figure 3-14) is observed that the monthly mean salinity between July and September at the surface, and at depths of 10 m and 20m is predominantly higher than that at 35 m.

It can be seen that the first and second maximum climatological salinity value are found at 35 m depth whereas the first and second minimum values are found at the surface. However, the overall salinity difference ranges between –0.095 and –0.714 psu for the 1969-74 and 1978-88 periods respectively. The first and second maximum and minimum climatological salinity value as well as the difference in salinity between surface and bottom are presented in Table 3-2.

The amplitude of the monthly variations in salinity for both periods 1969-74 and 1978-88 is shown in Figures 3-13 and 3-14 (0.902 and 1.076 psu at the surface and 0.283 and 0.196 psu at the bottom respectively).

The monthly mean SSS values for the periods 1969-74 and 1978-88 are presented in Table 3-5.

SSS anomaly maxima

The highest SSS anomaly maxima (1.233 psu) for the period 1969-74 (Figure 3-9) are observed in March, in the period 1978-88, a slightly value is observed in February (smaller by 0.212 psu). From September to October and in late December the period 1978-88 had the highest maxima by approximately 0.200 psu.

SSS anomaly minima

The SSS anomaly minima curves (Figure 3-10) for both periods do not vary in the same manner, the SSS anomaly minima curve for the period 1969-74 has it anomaly minima (-2.036 psu) in March, whereas the lowest anomaly minima (-4.453 psu) appears in April for the period 1978-88. The lowest SSS anomaly minima (-3.095 psu) for the two periods are observed in March (1978-88), which is smaller by –1.059 psu. The lowest SSS anomaly (-2.036 psu) for the period 1969-74 occurred in February. The period 1978-88 was the one with the lowest SSA anomaly minima (smallest variability) whereas the period 1969-74 had the highest maxima (largest variability).

3.1.2.3 Wind

The seasonal monthly average wind variation patterns at 12. 30S; 12. 30E off Lobito for the period 1967-98 are shown in Figure 3-15. Mean wind velocities are best analysed by resolving them into zonal and meridional components. From March to August the average zonal wind component (u) is less than the meridional component (v). The average meridional wind (v) reaches its maximum in May (3.50 m s^{-1}), after which it gradually weakens to September. Thereafter it strengthens once more reaching a second lower peak in November (3.25 m s^{-1}). After a minor minimum in January, it again strengthens to its maximum in March.

There is an inverse relation between the components u, and v. In the warm season, the zonal wind component weakens whereas the meridional wind component tends to strengthen and vice versa in cold season. It must be emphasised that the average wind components are always positive. This indicates that there is an equatorward (northerly) onshore wind at all times.

Figure 3-16 displays the average seasonal wind speed pattern over 32-years. There are two peaks: one in May (4.0 m s^{-1}) and one in November (4.12 m s^{-1}) respectively. High speeds also are also registered in October (4.08 m s^{-1}) while the minimum (4.12 m s^{-1}) occurs in September.

In Figure 3-17, with regard to the seasonal wind directions one can see that southerly winds prevail from April to July, that in August this changes slightly to south-southwesterly winds and from September to February southwesterly winds prevail.

Note that the current convention has been used i.e. winds are named by the direction from which they come not toward which they blow, thus winds blowing towards the north are called southerlies.

3.1.3 Interannual variations

3.1.3.1 Temperature

Weekly SST

1969, 1970, 1971 generally have higher maximum weekly SST than 1972. 1973 is also a warm year but the warming occurs earlier in the year (Figure 3-18). Both 1972 and 1974 are cooler than average years.
There is a slow decrease in the range of the seasonal (annual) cycle between 1969-72, and an increase for 1973.
The range of 1969 weekly SST and SSS amplitudes (Table 3-6) are in the order of 13.04 °C and 3.959 psu respectively. These larger than average ranges, and large amplitude values confirm that an event has occurred. Extreme positive weekly SSTA occurred in 1969 which is not typical for the season. At the bottom i.e. at a depth of35 m for the period 1969-74 (Figure 3-19), the weekly temperature variations are more or less parallel with those which occurred at surface. The minima are similar with about 16°C and the curves have an asymmetrical shape, perhaps as an effect of internal waves.

SST weekly patterns for the period 1978-88 (Figures 3-20 and 3-21) can be divided into two sub-periods: 1978-83 and 1984-88, which have different temperature ranges. The sub-period 1984-1988 is characterized by larger weekly SST maxima. The highest weekly SST maxima occurred in 1984, 1986 and 1988. The weekly SST in 1978 was below normal and then again in 1982, but with a smaller value.

Figure 3-22 shows weekly satellite derived SST variations for the period 1982-99. Together with the weekly mean values.

The lowest weekly satellite derived SST (0.48°C below the normal) was registered in 1983 whereas the highest (about 5.10°C) above the normal was registered in 1995. The highest weekly satellite derived SST was (31.45°C) in the second week of March 1995 with the largest seasonal amplitude (10.65°C) of the period 1982-99.

Generally, higher than average weekly SST were observed between 1990 and 1995.

Both weekly temperature and salinity amplitudes at the surface and the bottom (35m depth) for the periods 1969-74 and 1978-88 and weekly satellite derived SST amplitude for the period 1989-99 are presented in Tables 3-6 and 3-7.

Weekly SST Anomaly

SST anomalies (SSTA) indicate the climatic variability in the surface layers of the sea. SSTA, at a given location can vary considerably from one year to another.

In late 1971 and early 1972, the SST tended to be anomalously cool. At the same time, the SSS increased (Figure 3-23). This episode repeats frequently when a cold phase occurs. Throughout the 1969-74 period (Figure 3-24) the SSTA at 35 m are larger by about 2°C than that at surface.

For the eleven years from 1978-1988 the SST (Figure 3-25) appear to be increasing by about +4°C. The largest SSTA observed within the period occurred in 1984. 1978 and 1988 were also consistently warmer than average.

The satellite derived SSTA for the period 1982-99 is plotted in Figure 3-26. As one can see the one-year moving average satellite derived SSTA exhibits an upward tendency over the period 1982-99.

3.1.3.2 Salinity

Weekly SSS

The weekly salinity maximum occurred each year in the period 1969-71 (Figure 3-27) but appeared earlier in 1973. Comparing both SST and SSS weekly patterns (Figures 3-18 and 3-22), it can be observed that both salinity maxima and minima occurred under cool and warm conditions respectively. The most pronounced SSS weekly minimum (32.237 psu) occurred in the warm season of 1969 and the highest salinity (35.890 psu) was observed in 1974. Other SSS weekly minima recorded in 1973 (33.044 psu) in 1972 (35.710 psu); and earlier in 1974 (35.890 psu) (Figure 3-27).

Salinity minima were weaker at 35 m depth (Figures 3-28 and 3-30) and a notable SSS weekly minimum is observed in late 1969 and in 1988.

The weekly SSS patterns for the period 1978-88 (Figure 3.29) have been divided into two shorter sub-periods: 1978-83 and 1984-88. The former was saltier, whereas the latter was less salty. For the period 1978-88 at 35 m depth, salinity maxima were observed in 1978, 1982 and 1983. Lowest salinity was registered in 1986 and 1988 and the most pronounced salinity minimum (31.303 psu) was that of 1984.

For the period 1978-88, the largest amplitude (4.624 psu) of the weekly SSS is that of 1984 and the lowest one (0.943 psu) is that of 1980. Weekly SSS amplitudes are presented in Table 3-4b.

Weekly SSS anomaly

In the central Angola area (10-12°S) the SSS variability is confined to the upper layers and is dominated by interannual variations. Figures 3-23 and 3-31 show the SSS Anomalies for the periods 1969-74 and 1978-88 respectively. There are positive SSSA in 1970, 1972, 1974, 1978 and 83, whereas strong negative SSSA took place in 1969, 1973, 1984, 1986 and 1988.

3.1.3.3 Wind

Interannual wind component variability patterns are shown in Figures 3-33, 3-34, 3-35, 3-36 and 3-37 for the period 1967-98. The zonal wind component (u) in Figure 3-32 can be broken into 3 sub-periods due to the prevailing wind speed revealed in the respective sub-periods, which are: 1967-1978, 1979-1991 and 1992-98. The zonal wind component (u) in the sub-period 1967-78 ranged between 4 and > 0 m s^{-1}, whilst speed in 1979-1991sub-period oscillated from about 3 to about 0 m s^{-1}. During 1992-1998, the zonal wind component speed fluctuated between 4 and <1 m s^{-1} and tended to decrease slightly from 1997. In the 1992 zonal wind component (u) reached a maximum of 4.50 m s^{-1}, the highest values during 1967-98.

Figure 3-33 shows the meridional wind component (v) the period 1967-1998 into two sub-periods i.e. 1967-1977 and 1978-98 can be divided respectively. In the former the meridional wind component (v) fluctuated between 1 and 5 m s^{-1} and in the latter the meridional wind (v) speed mainly ranged from 1 to 4 m s^{-1}, although in 1994, the minimum speed was 0 m s^{-1}. It is noteworthy, that the high speeds registered in 1967-1977 exceeded 4.50 m $s^{-1}$and remained fairly normal thereafter.

By substracting the 1-year moving average from the data component, it can be seen that u and v display strong seasonal residual (Figures 3-37 and 3-38). The zonal wind (u) component exhibits a seasonal signal of magnitude of about 4 m s^{-1} whilst the seasonal signal of the meridional (v) component fluctuates between 2 and 4 m s^{-1}.

Figures 3-34 and 3-35 describe the monthly anomalies of the zonal wind (u) and meridional wind (v) components that have occurred over the past 32 years (1977-1998). If one consider that +1and -1 (wind component anomalies) may represent "imaginary" vertical bar lines it should be noted that one year moving average anomaly curves for u and v lie within this interval, however from 1977 to 1990 (Figure 3-34) the zonal wind component (u) was characterized by a "negative zonal wind (u) anomaly" with an evident though in 1985 and one can observe the "positive zonal wind (u) anomaly" from 1991 onwards. In comparison to the zonal wind (u), the meridional wind (v) anomalies seemed to be more stable, which can be seen from the fact that the one-year moving average fluctuates around zero, except for 1970-1977 when there is a positive anomaly. At no time were the meridional wind (v) anomalies >1.5 m s^{-1}, but in 1982 and 1993, negative anomalies were in order of −1.48 and −1.5 m s^{-1} respectively.

The one-year moving average anomalies of the monthly zonal wind (u) and meridional wind components are presented in Figure 3-36. It can be seen that both zonal and meridional wind anomalies curves tended to decay simultaneously from 1967 – 1984. Between 1984 and 1990, the zonal wind (u) had both larger negative anomalies with an evident though in 1985. 1970-77 had strong zonal (u) and meridional wind (v) component, whereas 1984-90 was characterized by weak zonal wind (u) component and strong meridional wind (v) component and 1991-98 exhibited strong zonal wind (u) component and weak meridional wind (v) component.

3.1.3.4. Extreme events

The SST and SSS weekly time series were used to identify the extreme events (from the highest to the lowest).
Extreme events have been defined as weekly SST ≥ 28.30° C; weekly SST ≤ 17.00° C; weekly SSS ≥ 35.800 psu; weekly SSS ≤ 34.000 psu. There was a tendency for the highest SST and lowest SSS to occur during warming and vice-versa during cooling phases. The extreme events have been identified and summarized in Figures 3-18, 3-19, 3-20, 3-22 and 3-27 and occurred mainly in March-April in the warm season.

There was an unusual increase of weekly satellite derived SST (29.23°C) in the fourth week of December in 1997. Usually warming of this magnitude occurs either in February or March-April. Other unusual events occurred in 1969 and 1988 where warm (SSS minimum) and cold (SSS maximum) phases took place one after the other so that there were in effect two events within a year.

Extreme SST and SSS records for the three observational periods have been registered as follows: the highest weekly SST (30.97°C) and lowest (16.15°C) in 1995 and 1971 and the highest weekly SSS (35.922 psu) and lowest (31.781 psu) both in 1984 respectively.

Table 3-8 summarizes the extreme events that occurred in the three time periods of 1969-74, 1978-88 and 1982-99 for SST and 1969-74 and 1978-88 for SSS

3.1.3.5 Long term trend

There is an almost complete 31-year (1969-1974, 1978-88 and 1982-99) set of observations for SST and a 17-year set for SSS (1969-74 and 1978-88) respectively.

Between 1969 and 1974 (Figure 3-24) the weekly SSTA one-year moving average curve shows a predominantly negative trend. The weekly SSSA one-year moving average curve (Figure 3-26) shows a positive trend for the same period.

For 1978-88, the weekly SSTA one-year moving average curve (Figure 3-25) shows a linearly increasing trend. The weekly SSSA one-year moving average curve shows a positive trend between 1979 and 1983(Figure 3-26).

For the period 1982-99 (Figure 3-31), the weekly satellite derived SSTA one-year moving average curve lies below the normal from 1982 to 1992 with the exception of 1984 and 1988 which were warmer than normal. From 1992 onward, the only cool year is 1997.

Despite these long term trends, some positive weekly SSTA were observed in predominantly negative SSTA periods and vice-versa. However, there appears to be a warming trend toward higher SST from 1982 onwards.

Figure 3-39 schematically summarizes extreme SST and SSS and their relationship to one another. It appears that higher weekly SST are associated with lower weekly SSS and vice-versa.

A one-year moving average is used to smooth the zonal wind (u) and meridional (v) wind components for the period 1967-1999 (Figure 3-40). The zonal wind (u) component speed was generally weak (well below 2.5 m s^{-1}) except for the years 1991 to 1996 when the speed reached a maximum of 3 m s^{-1}. The meridional wind (v) component was larger than the zonal wind (except from 1990 to 1997) and oscillated between 2.25 and 3 m s^{-1} throughout the 32- year period..

Broadly speaking, it appears that the meridional wind (v) had a degree of "linear" decreasing tendency for the whole period, whereas the zonal wind (u) decreased from 1967-1985, increased from 1985-1991, and oscillated about 2.3m s^{-1} from 1991-1998.

3.2 Results of statistical analysis

The standard deviation of a large number of measurements gives a measure of variability. To investigate and describe the temperature and salinity seasonal variability at four water levels in a water a depth of 40 m (0, 10, 20 and 35 m), the standard deviation (S.D.) was computed and presented in Figures 3-41-3-50.

Large variability for both temperature and salinity occurs in the warm season and a smaller variability occurs in the cold season. The magnitude of variability at any given depth, especially for the temperature may differ from that above or below the level (or vice versa).

The temperature variability patterns are different for the 1969-74 and 1978-88 periods (Figures 3-44 and 3-45). Temperature at 10, 20 and 35 m have a higher variability than do surface temperatures, mainly from January – March, but also in October. The maximum temperature variability in the order of 3.5°C magnitude at 20 m occurred in the 4th week i.e. during January within the 1969-74 period (Figure 3-41).

There is no way of comparing temperature variability at different levels for the period 1982-99 (Figures 3-43 and 3-46) because only SST (satellite derived) was available. The highest weekly variability was observed in 3 rd week of April (1.84°C) and also in 3 rd week but in

June (1.89°C) and the lowest in 4^{th} week of June (Figure 3-43). The curve that describes this variability is smooth with a slight decay in August, but revealing no significant seasonal pattern for the 1982-99 period.

Figures 3-47 and 3-48 show seasonal variability on a weekly basis. The highest variability is observed in the 1^{st} week of April (Figure 3-45) with a magnitude in the order of about 1.190 psu. Comparing both periods (Figures 3-47 and 3-48) it can be seen that the salinity at all levels maintained a high variability (Figure 3-47) and in the cold season too, it is noticed that from June to September the magnitude of variability for all levels is nearly the same (about 0.2) whereas in December salinity at 10 m depth has higher the variability of all.

The weekly and monthly salinity variability at 0, 10, 20 and 35 m depth for the periods 1969-74 and 1978-88 are presented in Figures 3-47, 3-48, 3-49 and 3-50. Each period shows a particular pattern. In Figures 3-49 and 3-50 the warm season there had higher variability than the cold season. In Figure 3-50, it is observed that from June - September, the salinity variability curve at 0 m lies above all for other depths. In Figure 3-49, the surface salinity shows higher variability than other levels, but from August - October at 10, 20 and 35 m all have nearly the same magnitude of variability.

Figures 3-51 and 3-52 show the monthly and interannual u and v (wind) components standard deviations for the period 1967-98. The u component (Figure 3-51) has larger degree of variability than the v component from February to August and also from October - December. The v component generally has lower variability than the u component except during the month of September.

The highest variability for u component occurs in March and the lowest in October, whereas the highest variability for v component occurs in September and the lowest in April. From this it appears that u component is more variable that the v component.

From Figure 3-52, it can be seen that the u component has a high variability from 1971 - 1981 and from 1988 - 1992 respectively. The annual variability of the v component son the other hand decreases steadily from 1967-1998.

The standard deviation values of *in situ* SST, satellite derived SST and the u and v (wind) components are represented in Tables 3-9.

3.3 Index of Stratification

Stratification can be defined as a typical seasonal change of thermal structure below the surface.

The thickness of the mixed layer and its aperiodic and periodic undulations are determined mainly by factors such as mixing by action, convective stirring, upwelling, internal waves and others (Laevastu, 1993);

To ascertain the stratification and salinity indexes at Lobito station, both daily differences temperature and salinity data between 0 and 35 m were examined for the entire year of 1970, from 1st January to 31st December. All the data are shown in a compressed form in Figures 3-53 and 3-54.

March and April difference temperature exhibit higher peaks than other months. This means that the coastal ocean was strongly stratified at these times (i.e. during the warm or rainy season) but well mixed (less stratified) during cold season (Figure 3-53). The stratification index is ranging between 1.80 and 7.80 °C in March then decreases, and from June to November the stratification index becomes even smaller ranging between 1 °C and 3 °C.

The difference in the salinity index is also larger (i.e. fresher at surface than at the bottom) in the rainy season and smaller in the cold season. The result of the small difference in the salinity index is probably due to the stronger winds and upwelling during this time period which cause more mixing (Figure 3-54). The difference in the salinity index ranges between –0.528 psu and –2.467 psu in the warm season, whereas the difference in the salinity index becomes smaller in cold season; it varies between 0 and -0.200 psu.

During the warm season, the high stratification and difference in the salinity lead to a stable water column (i.e. fresh water overlying salty water). During the cold season, however, cold and saltier water is found near the surface, while warmer and fresher water is found at the bottom.

The daily stratification index at Lobito station is highly variable from one season to another (Figure 3-53).

Stratification and salinity indices are presented in Tables 3-10 and 3-11 respectively.

CHPTER 4: DISCUSSION AND CONCLUSIONS

Relationship between wind and SST and SSS

One can consider that the atmosphere and ocean interact through both momentum and heat exchanges at the ocean surface. The heat exchange is influenced by cloudiness via changing incoming short-wave radiational heating and by surface winds via changing turbulent entrainment and surface evaporation.

Figure 4-1 schematically summarises the physics of this coupled model i.e. interaction between atmosphere and ocean. Mixed layer temperature affects atmospheric heating and changes lower tropospheric geopotential and surface winds. Changes in surface winds alter mixed layer temperature through directly changing evaporation rate, entrainment rate, and surface convergence/cloudiness. The surface winds also control thermocline displacement, h, via oceanic waves/currents and turbulent mixing and also influence mixed layer depth h_l via Ekman pumping. Both the variations in h and h_l would further modify mixed layer temperature.

The top few tens of meters of the ocean are usually observed to be fairly well mixed, i.e. the temperature and salinity are fairly uniform. Below this region there is a thermocline (and perhaps a halocline) and hence a pycnocline region. The top layer is the oceanic planetary boundary layer where vertical friction effects are important. It is also called the Ekman layer. The dynamics governing the formation of this layer are of considerable interest. Convergences and divergences in the upper layer will lead to "downwelling" and upwelling in the coastal water near a coastal boundary.

Wind is a major forcing factor of upper ocean motions at all scales: mixed layer turbulence, near-inertial waves, upper ocean transport, and large scale currents ultimately redistributing water masses, are all primarily wind-driven.

Wind is also a governing factor of heat, moisture and gas fluxes between the ocean and the atmosphere, and thus a key parameter in the coupled atmosphere/ocean/biosphere system, and in particular in observations and models of climate variability and changes.

Momentum input and its fluctuations generate velocity shear, surface waves which break and hence turbulent mixing in the upper ocean. Thus the temporal evolution of diurnal and seasonal stratification is affected.

Land-sea differences in surface drag on the wind, near the coast, can cause large variations of wind strength. Shear from such causes contributes to curlτ. Warming of air over land and consequent convection may draw sea-air land-wards, generating a see breeze, another wind structure local to the coast.

Seasonal variation of the wind forcing appears to be important in transferring heat from the summer to the winter hemisphere in the tropics, thus helping to moderate the climate. Heat and convection are the origin of some localized coastal weather systems. Sensible heat and water vapor fluxes are necessary elements in radiation and heat budget considerations.

Heat balance studies appear as one of the most promising ways for looking at the influence of the ocean on climate. Recent investigations have drawn attention to the importance of the meridional oceanic heat transport occurring at low latitudes and its influences on the global heat balance (Oort and Vonder Haar, 1976). These investigators pointed out the large seasonal variations of the rate of heat storage by the oceans in the tropics. Phase differences between different parts of the tropical ocean suggest a redistribution of heat by seasonal changes of the equatorial current system. Large seasonal variations in net heat flux have also been observed in the tropics but an almost permanent area of maximum heat gain is observed in the equatorial strip (Figure 4-2)

Comparison of Lobito with the Gulf of Guinea

The SST and SSS variability in Central and northern Angola, which depart from a strictly solar-forced seasonal (sinusoidal) cycle, shows similar patterns in the Gulf of Guinea. The examination of the SST and SSS reveals both SST and SSS seasonal variation patterns that can be described by means of an annual cycle similar to that seasonal patterns described by Berrit (1958) for Pointe Noire, Donguy and Prive (1964) for Abidjan and Servain and Lukas, (1990) for five sections between 0° to 16°S (Figure 4-3),The central part of Angolan SST may behave like the Tropical equatorial system, and thus Lobito thus presents the same qualitative pattern: a long warm season, centered in March, a long cold season, centered in August, a short warm season and a short cold season, established from November to January.

Congo and Niger Rivers are major localized sources of fresh water buoyancy in peak of warm (or rainy) mainly in March and April (see Figures 4-4a-c) which produces poleward currents flowing against prevailing equatoward winds contributing in lowering the salinity along the Angolan coast.

North of ABF i.e. surrounding Lobito and northward up the Angolan coast, upwelling is a seasonal phenomenon as observed in R/V *F. Nansen* cruise reports (1985 - 2000) in Angolan EEZ. The upwelling mainly occurs during the main cold season between June and September, secondly from December to January during the minor cold season. There have been no observations of coastally trapped waves (Huthnance, 1981; Gill, 1992) off Angola. The intensity of coastal upwelling surrounding Lobito during the main and minor cold seasons (Figure 3-17) leads to the affirmation that the wind is responsible for the coastal upwelling occurrence.

Relationship of Lobito SST anomalies with Pointe-Noire

Recently, a number of studies have appeared examining interannual-to-decadal climate variability in the tropical Atlantic sector and have provided conflicting indications of the existence of coupled ocean atmosphere modes in this region. The existence of possible tele-connections of the tropical Atlantic to other basins, such as the Pacific ENSO (e.g. Ruiz-Barradas *et al.* (2000); Rajagopalan *et al.*, (1998); Xie and Taimoto (1998); Robertson *et al.*, 2000 has not been completely established. The results obtained by correlating *in situ* SST at Lobito to those of Pointe-Noire and to SOI index in Pacific yielded useful insights. The correlations are strongly positive between *in situ* SST at Lobito and Pointe-Noire [both periods 69-74 and 78-88, r= +0.86 (+0.89). This coefficients of determination equal 0.74 (0.79)], respectively, which confirms the strong relationship between Lobito and equatorial Atlantic (as represented by Pointe-Noire) (Figures 4-5a-b).

Relationship of Lobito SST with ENSO

Anomalies of SOI (Figure 4-6) show the buildups and subsequent declines of pressure differences. Major buildups and declines (i.e. ≥ or less 3 of anomaly) occurred in 1954-1956, 1965-1966, 1969-1970, 1972-1974, 1981-1982, 1988-1989, 1991-1994, 1997-1998 and 1998-1999. The most notable decline was that of the 1981 and the more recent one in 1997. The notable buildup was observed in 1972-1973. [Studies have been done on the Pacific equatorial SSTs by relating it to the difference of atmospheric pressure between Tahiti and Darwin SOI index (Quinn, 1974 and Quinn and Neal, 1983)].

Analysis by regressing the Lobito *in situ* SST onto the SOI index (Figures 4-7a-b), yielded weak correlations for both periods 69-74 and 78-88. The correlation coefficient r, was 0, and –2.0 respectively. These poor correlations affirm that there is little or no relationship between interannual SST anomalies in tropical Atlantic and the SOI for the above cited periods. It cannot be ascertained whether these teleconnection patterns have been maintained until the present.

Teleconnections

The geographical position of Lobito (coastal station) can be characterized as a strategic one from the climatological point of view, as it is ituated north of ABF and at the southernmost end of the Angola system. It may be used at times to monitor water mass regimes of two systems. Throughout the year this position is very sensitive to the equatoward and/or poleward shifts of the ABF. When warm water moves southward past Lobito, there is a negative north-south SST gradient. When cool water is present north of Lobito, there is a positive north-south gradient. As an example of positive gradient of SST, in 1994 seals' schools appeared at 11 S and beyond, even off Luanda single seals have appeared and caught by the fishermen, it was a major poleward shift ever registered off Angola (*pers. comm.* N. Luyeye, 2001).

North and southward shifts of ITCZ could influence the temporal and spatial seasonal SST. Sutton *et al.* (2000) found that the ITCZ in tropical Atlantic is generally collocated with the region of highest SST, is farthest south in March-April-May, and farthest north in June-July-August and September-October-November.

Antartic circumpolar wave

Shannon *et al.* (1986) documented a case of a major perturbation in the Subtropical Convergence to the south of Africa during December 1986. This resulted in significant northward movement of Subantarctic Surface Water via cold filaments into the Benguela region and may explain a mechanism for such cool anomalies (i.e. Benguela La Niña). Furthermore the Antartic circumpolar wave (White *et al.* 1998) which is taking approximately 8 years to circle the globe, is characterised by a persistent phase relationship between warm (cool) SST anomalies and poleward (equatoward) meridional surface wind anomalies may occasionally cause an impact in the study area during this passage.

Long term trends

A comparison has been made of daily mean *in situ* SST data for April over two equal five year periods i.e. 1969-1974 and 1978-1983 by applying t-test analysis. The mean April 1969-1974 period (25.17°C) is much warmer by +1.84°C than that of 1978-1983 (23.33°C) one. Angolan system is indeed a dynamic one and a given period of time may present different patterns [extremely warm (cool), warmer (cooler)].

Warm and cool events

Since it has been reported that so-called Benguela Niños occur on a quasi-periodic timescale of ~ 10 years (e.g. Jury, 1996), there is a need to pay a particular attention that in recent years the tropical eastern Atlantic has experienced an upsurge of warm events. This pattern repeated in 1995, 1996 and 1999. Most of SADC countries have experienced in recent years unusual rainfall patterns i.e. extreme climate change which is causing a negative economic impact in the respective countries in region.

A vast number of studies in the Pacific have provided two typical types of interannual oscillations: El Niño and La Niña. There are warm and cool events off Lobito. Warm events have been called Benguela Niño (Shannon *et al.*, 1986) (high SST, low SSS) and cool events (low SST, high SSS). As the task of understanding climate variability in the tropical Atlantic region presents a considerable challenge to climate scientists (Sutton *et al.*, 2000) these unusual events may have originated in regions remote from the tropical Atlantic through the atmosphere-ocean system.

Notable interannual SSS variability off Angola is strongly related to the Benguela El Niño-related precipitation changes. During Benguela Niño, the SSS field is characterized by fresher-than-average SSS in central Angolan coast.

Future work

This work can be extended in order to include more parameters for a better understanding of the main phenomena and processes that regulate the Angolan system in a holistic view. Using state-of-art such as satellite derived parameters (in daily, weekly and monthly basis) will help and encourage local, regional and international scientists to collaborate closely. Taking account of strategic position of Lobito station, it would be better if the station can be well equipped because the SST and SSS as well as other meteo and other oceanographic parameters observations must continue.

Finally, there is a need to find some index in order to characterise magnitude of a Benguela Niño. If the predictability of Benguela Niño has been defined although the timescale is becoming shorter but the timescale of cool events has not been defined yet. It is time to do so, thus one must know that not only Benguela Niño has adverse effects to the marine environment and inland, cool event may have too. Furthermore, models should be investigated to reproduce the general or climatological (long-term average) circulation in the Atlantic southern hemisphere. One motivation for developing such models is that they can be used in joint atmosphere-ocean models to study climate and its possible changes.

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FIGURES

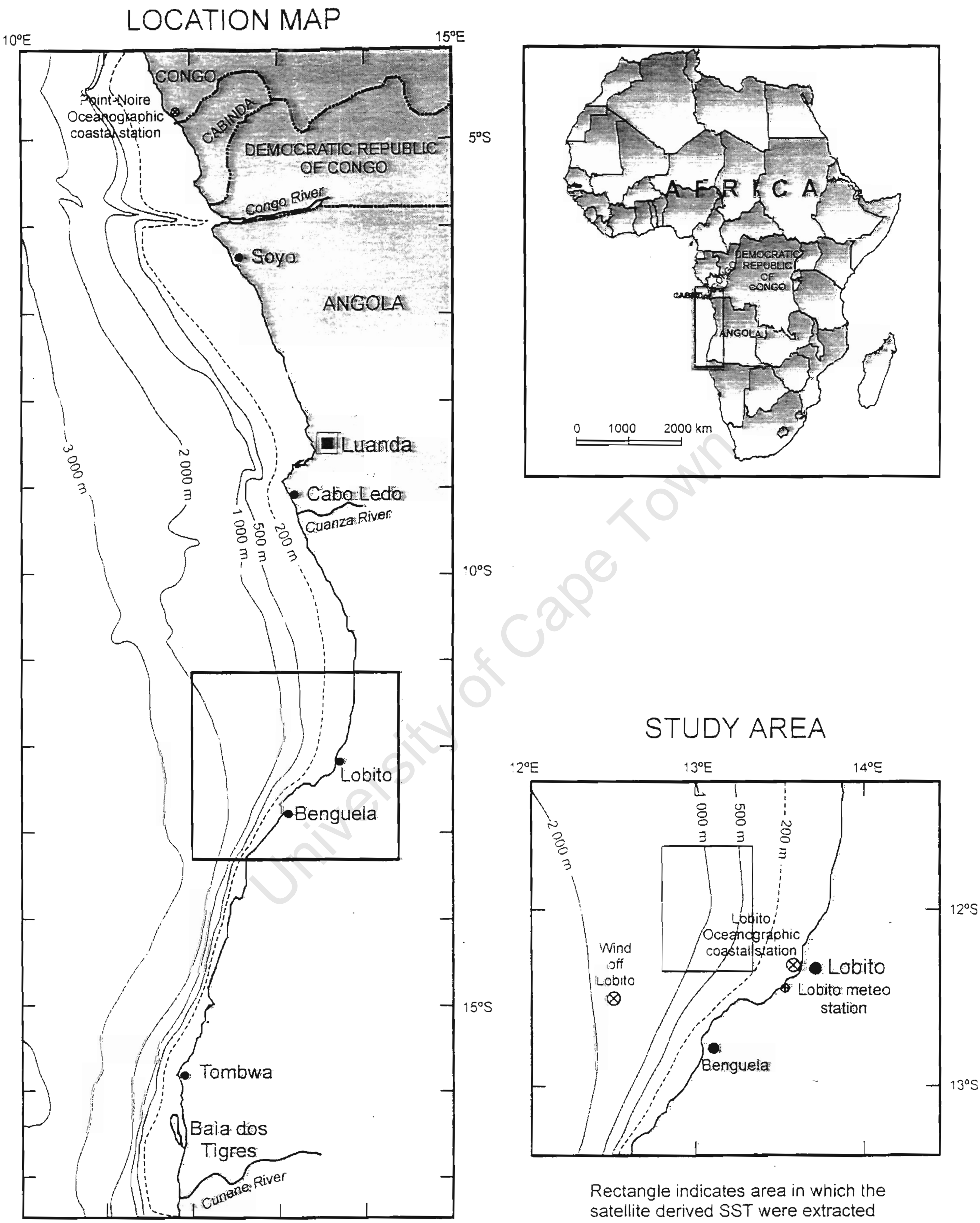


Figure 1-1: Map of coastal ocean off Angola.

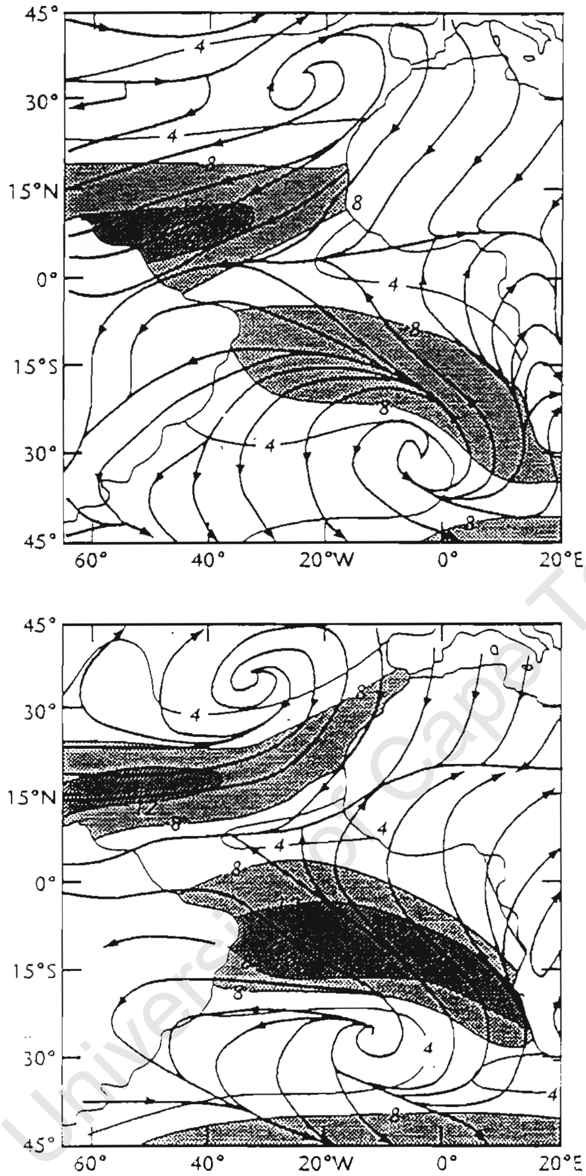


Figure 1-2: Resultant streamlines and isotachs (knots) of surface winds for January (top) and July (bottom). Light shading denotes areas with windspeed greater than 8 knots; heavy shading, greater than 12 knots. Note northward displacemen of the convergence zone in the boreal summer. (Adapted from Riehl, 1979).

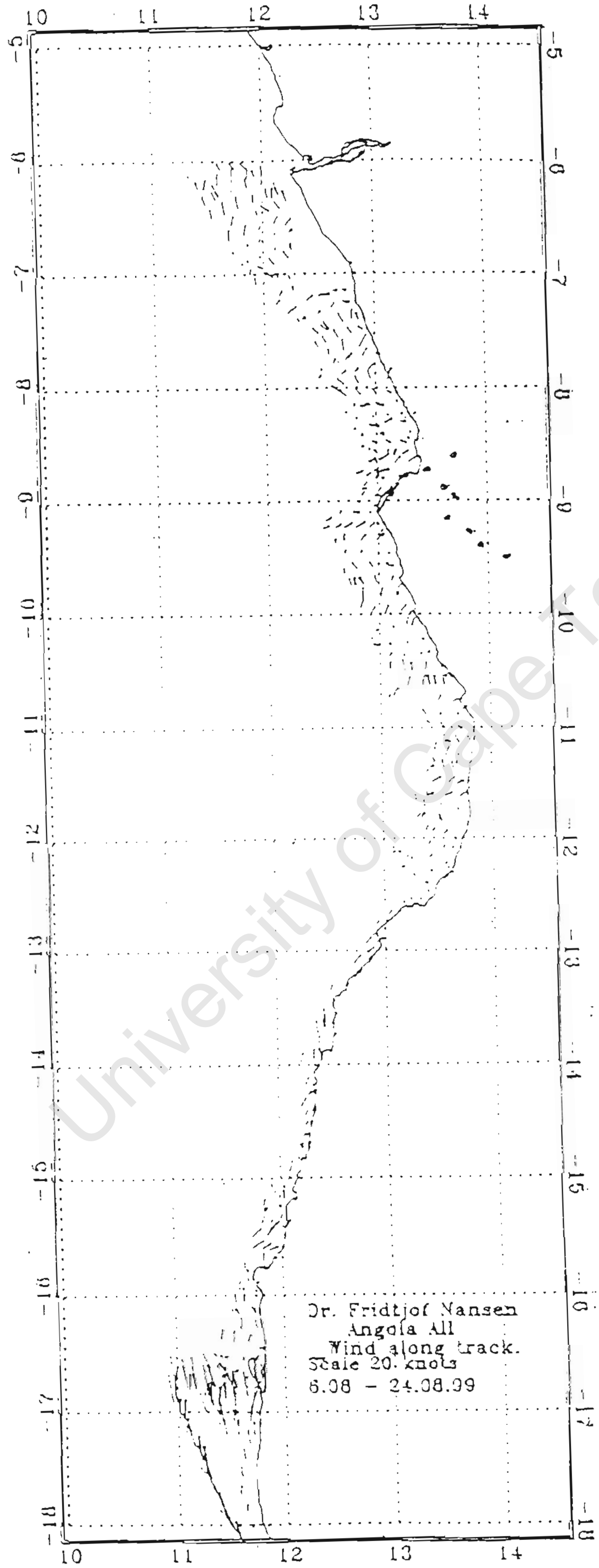


Figure 1-3: The wind conditions from Congo River to Cunene River. Cruise track during 06.08-24.08.1999. Scale 20 Knots. Winds were quite modest throughout, except on the southern shelf, off Baia dos Tigres (16° 40S; 11° 50E), south-south easters prevailed in the area.

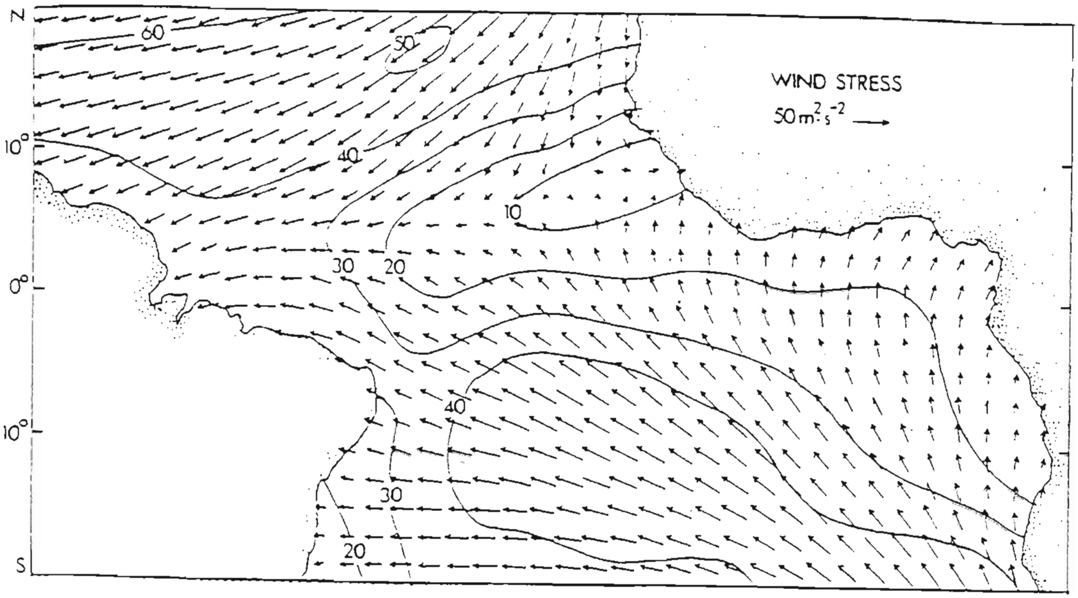


Figure 1-4: Annual mean wind-speed squared (proportional to wind stress) in the equatorial-tropical Atlantic (After Picaut *et al.*, 1985).

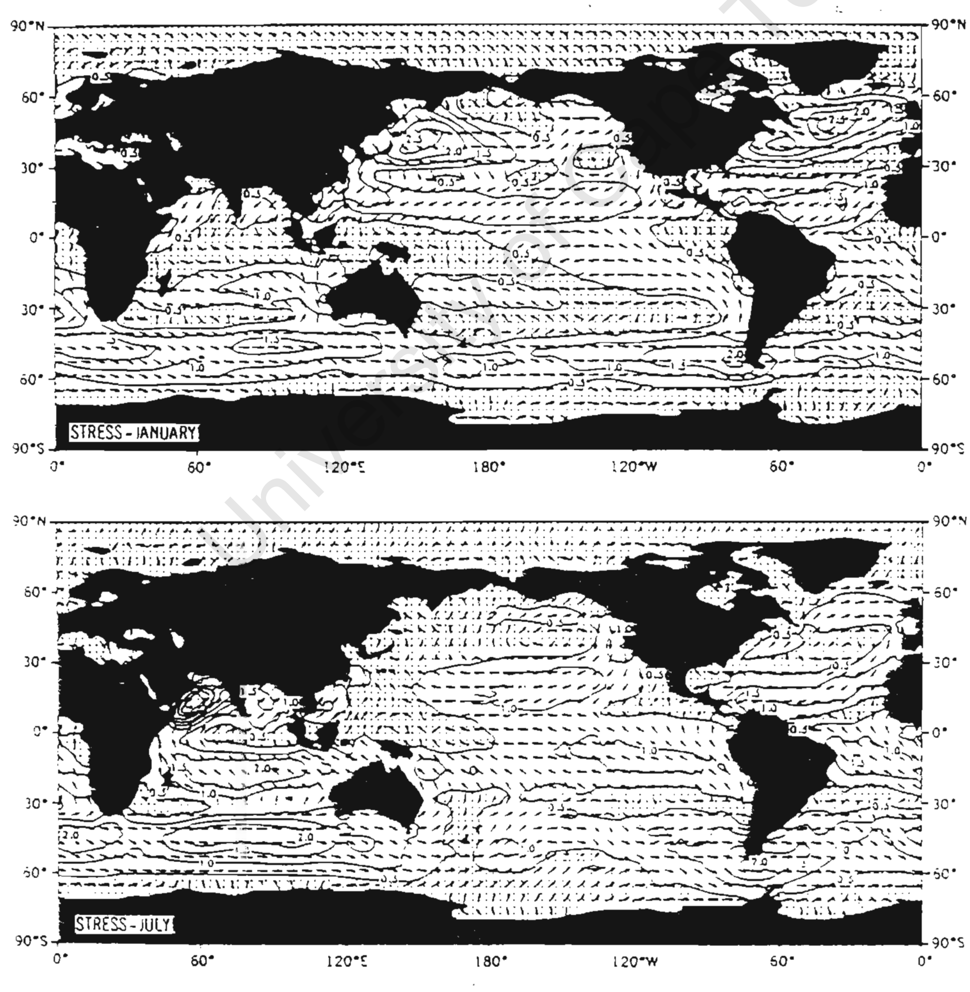


Figure 1-5: Wind stress fields. Arrows indicate direction and contours the magnitude (dyn/cm^2) of the wind stress vectors. Shading marks magnitudes <0.5 dyn/cm^2 (After Hellerman and Rosenstein, 1983).

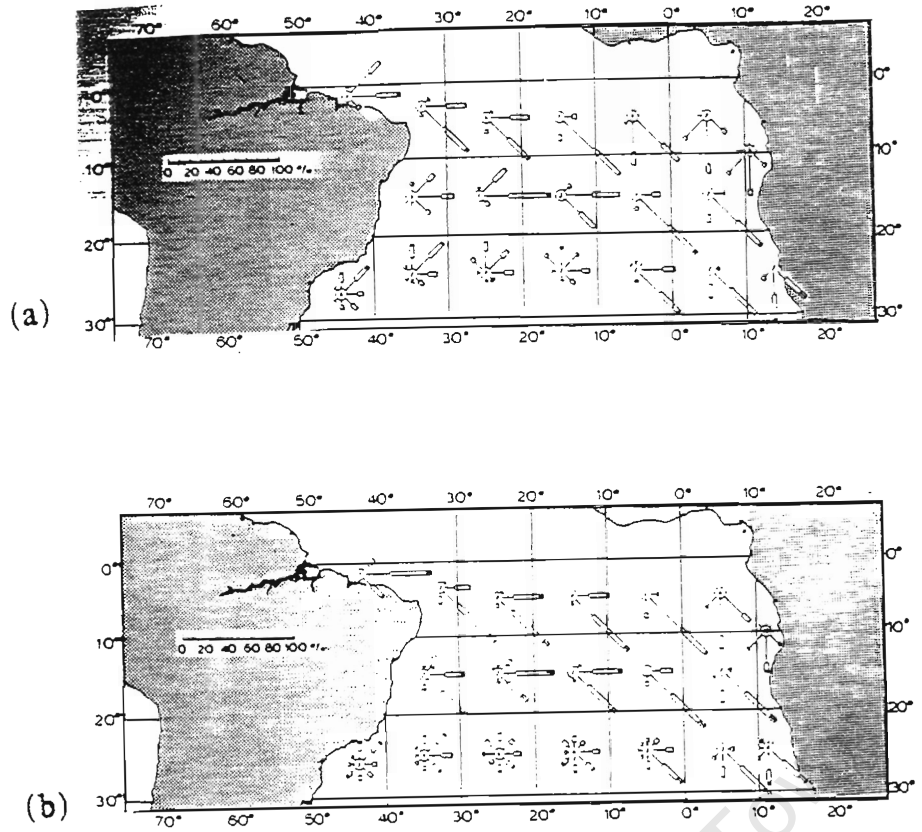


Figure 1-6: Wind roses for 10° squares for (a) January, and (b) July (Hoflich, 1984). Lengths of the arms indicate the mean relative frequencies (according to the scale in upper left) of eight wind directions divided into four groups of wind orce. Form the center outward they are Beaufort 1-3 (0.5-5.5 ms^{-1}), 4-5 (5.5-11 ms^{-1}), 6-7 (11-17 ms^{-1}), and >8 (>17 ms^{-1}). Numbers within the circles are percent occurences of calm or light and variable winds.

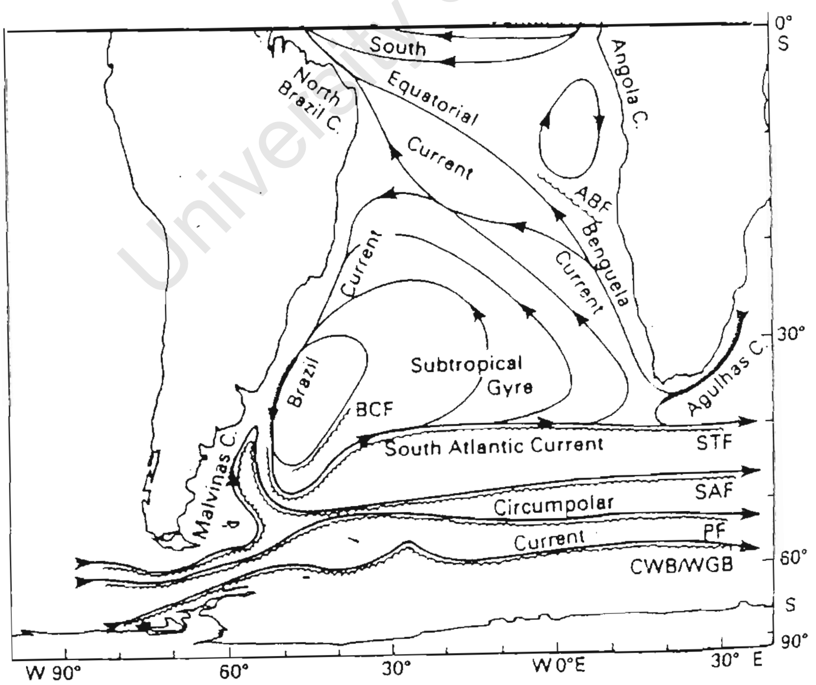


Figure 1-7: Schematic summary of surface currents of the Atlantic Ocean. Abbreviations are used for Angola-Benguela Front (ABF). Adapted from Duncan *et al.* (1982), Krauss (1986) and Peterson and Stramma (1991).

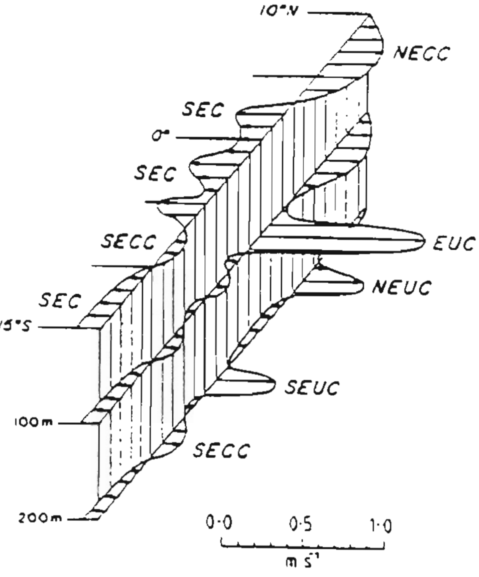


Figure 1-8: A sketch of the structure of the equatorial current system during August. Abbreviations are used for the North Equatorial Countercurrent (NECC),South Equatorial Current (SEC), North Equatorial Undercurrent (NEUC) and the South Equatorial Countercurrent (SEUC). After Peterson and Stramma (1991).

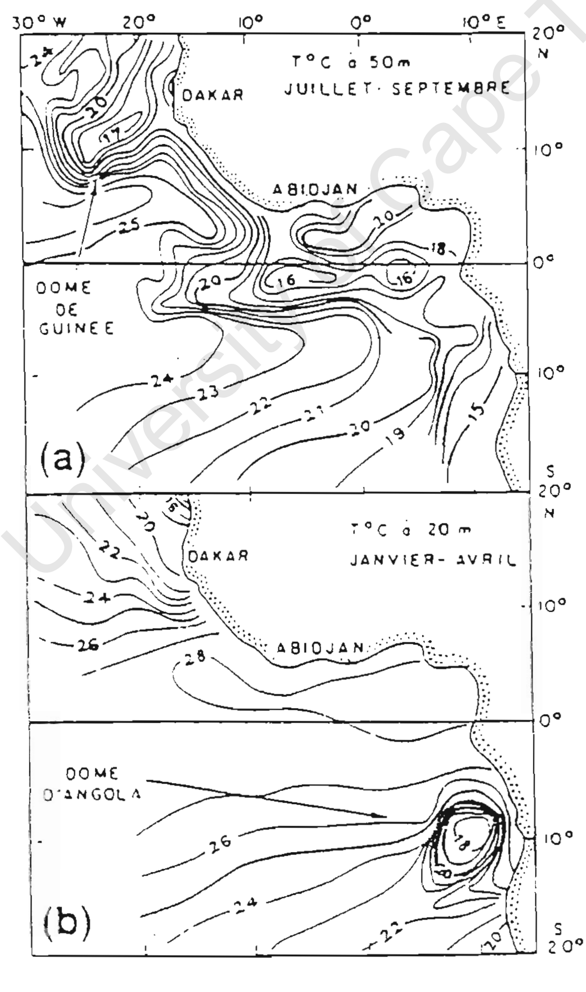


Figure 1-10: The Angola Dome and the Guinea Dome as seen in temperature data from 20 m and 50 m depth. From Peterson and Stramma (1991).

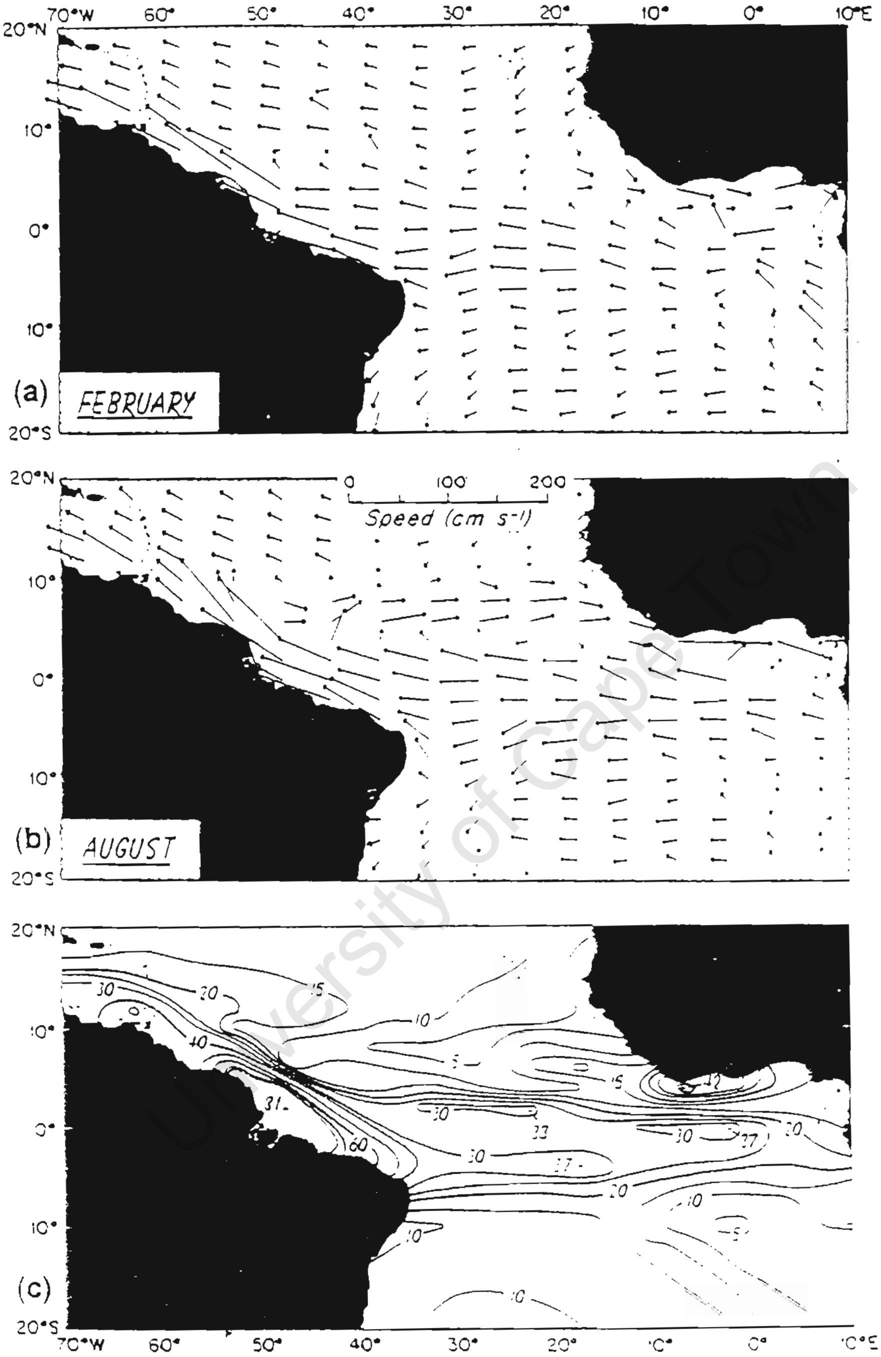


Figure 1-9: Mean surface currents in the equatorial region as derived from ship drift data for a)February, b) August and c) annually-averaged speed in cm s^{-1} (Richardson and Walsh, 1986).

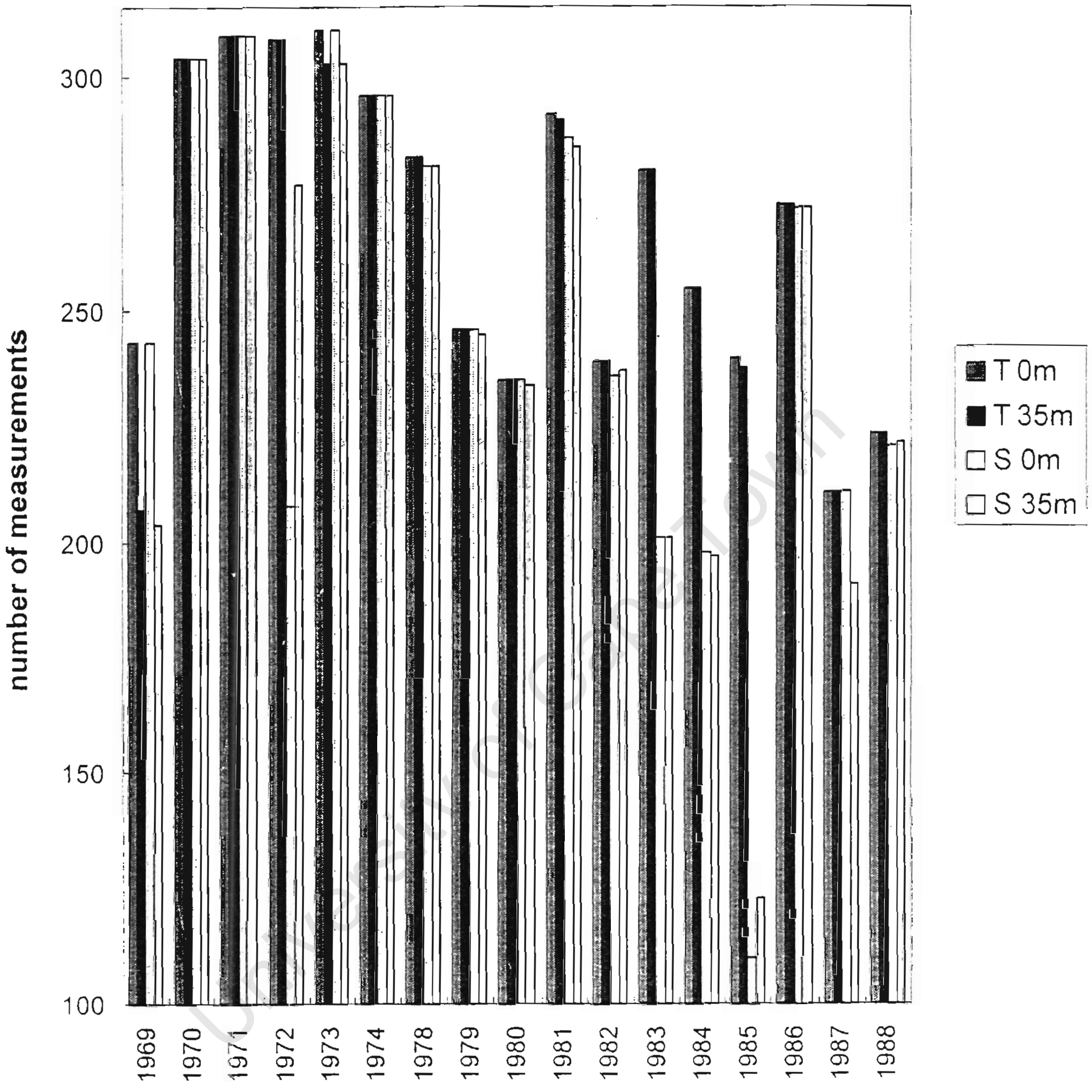


Figure 2-1: Graph in clustered columns comparing SST and SSS measurements made at Lobito oceanographic coastal station during 1969-1988. Note break in data between 1974 and 1978.

1950							
1951	1						
1952	1						
1953	1	2					
1954	1	2					
1955	1	2					
1956	1	2					
1957	1	2					
1958	1	2					
1959	1	2					
1960	1	2					
1961	1	2					
1962	1	2					
1963	1	2					
1964	1	2	3				
1965	1	2	3				
1966	1	2	3				
1967	1	2	3				7
1968	1	2	3				7
1969	1	2	3	4	5		7
1970	1	2	3	4	5		7
1971	1	2	3	4	5		7
1972	1	2	3	4	5		7
1973	1		3	4	5		7
1974	1		3	4	5		7
1975	1		3				7
1976	1		3				7
1977	1		3				7
1978	1		3	4	5		7
1979	1		3	4	5		7
1980	1		3	4	5		7
1981	1		3	4	5		7
1982	1		3	4	5	6	7
1983	1		3	4	5	6	7
1984	1		3	4	5	6	7
1985	1		3	4	5	6	7
1986	1		3	4	5	6	7
1987	1		3	4	5	6	7
1988	1		3	4	5	6	7
1989	1		3			6	7
1990	1		3			6	7
1991	1		3			6	7
1992	1		3			6	7
1993	1		3			6	7
1994	1		3			6	7
1995	1		3			6	7
1996	1		3			6	7
1997	1		3			6	7
1998	1		3			6	7
1999	1					6	
2000	1						

Figure 2-2: Timing of both oceanographic and meteorological data

Legend: 1- SOI Tahiti-Darwin; 2- Precipitation at Cabinda, Soyo and Lobito; 3- SST at Pointe Noire 4- temperature at Lobito; 5- salinity at Lobito; 6- satellite derived SSToff Lobito; 7- Wind off Lobito

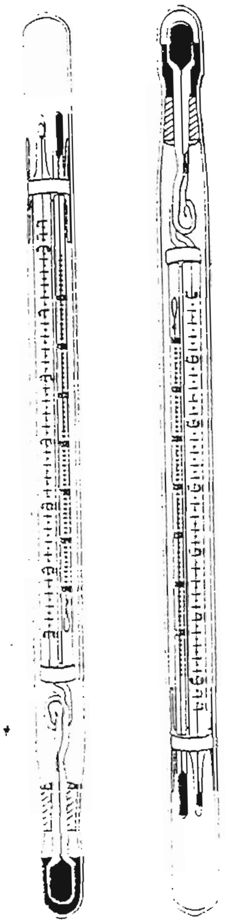


Figure 2-3: The reversing thermometer. To the left: set position. To the right: reversed position (Note, scale division is simplified in the present figure).

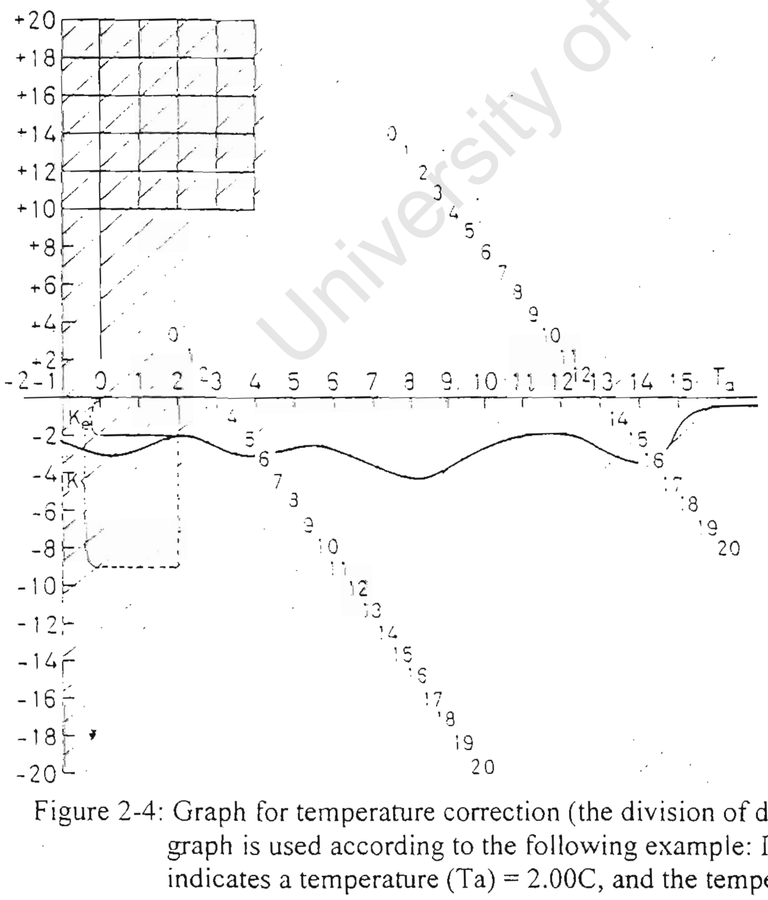


Figure 2-4: Graph for temperature correction (the division of diagram is simplified). The graph is used according to the following example: If the reversing thermometer indicates a temperature (Ta) = 2.00C, and the temperature of the auxiliary thermometer is (t) = 7.0C, the correct *in situ* temperature is given from the equation: $Tw = Ta + K + Ke = 2.00 + (-0.09) + (-0.02) = 1.89C$ Ke: correction specific of the thermometer system, K: Correction caused by thermal expansion, Ke and K are obtained as indicated on the figure.

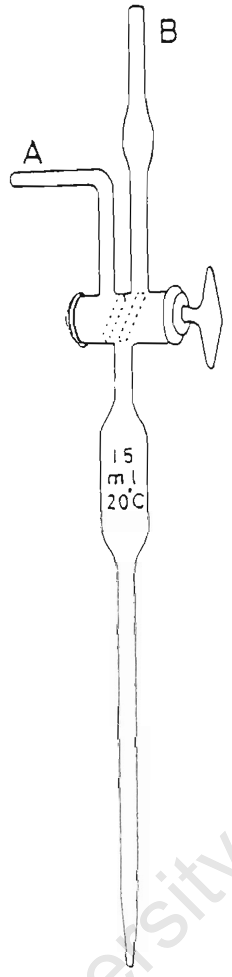


Figure 2-5: The Knudsen pipette.

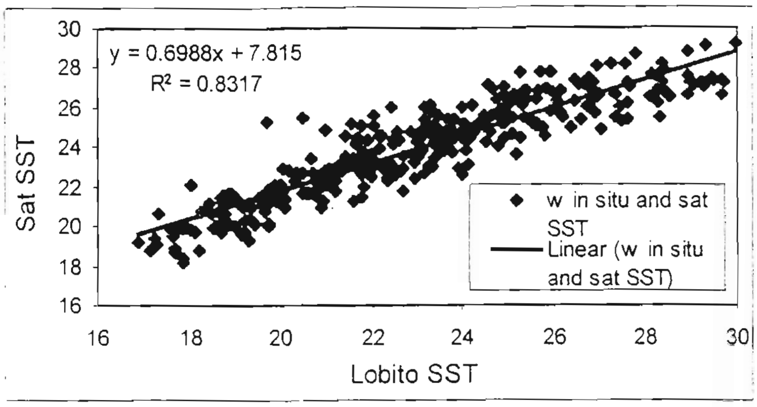


Figure 2-6: Scatterplot for comparison of weekly satellite derived and *in situ* SST anomalies between 1982 and 1988.

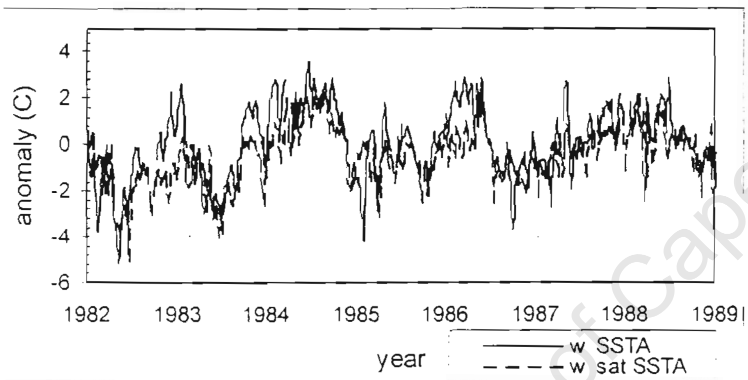


Figure 2-7: Comparison of weekly satellite derived and *in situ* SST anomalies between 1982 and1988.

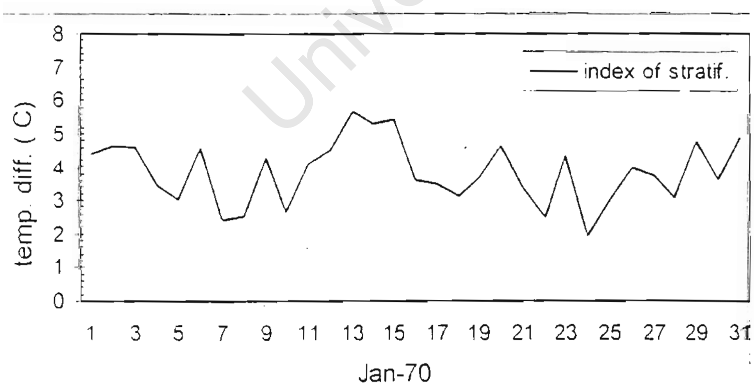


Figure 3-1: Daily temperature difference between surface and 35 m *in situ* Lobito data for January - December 1970.

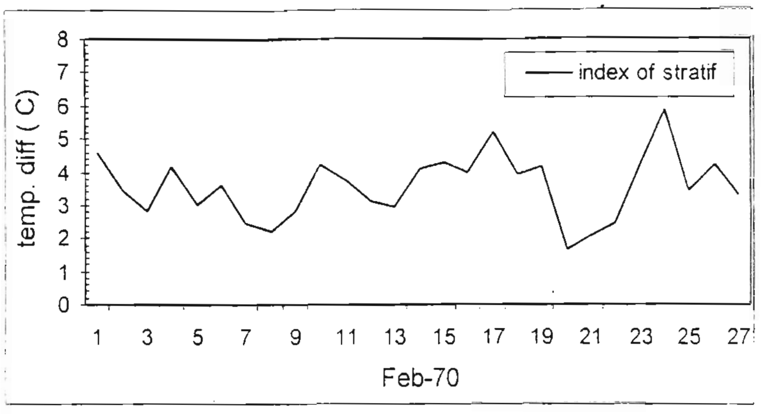
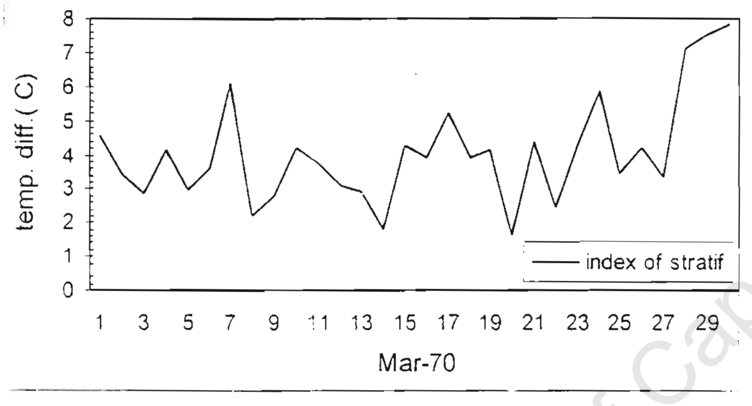
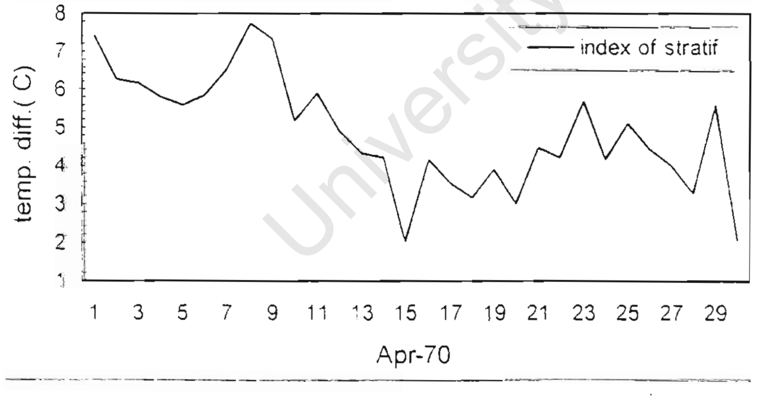


Figure 3-1: continuation





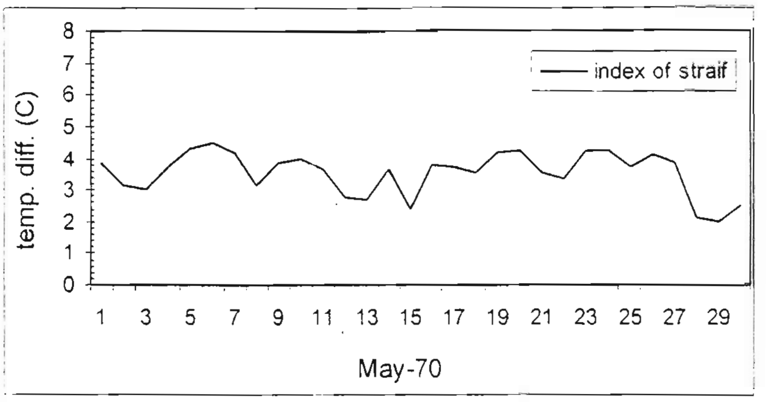
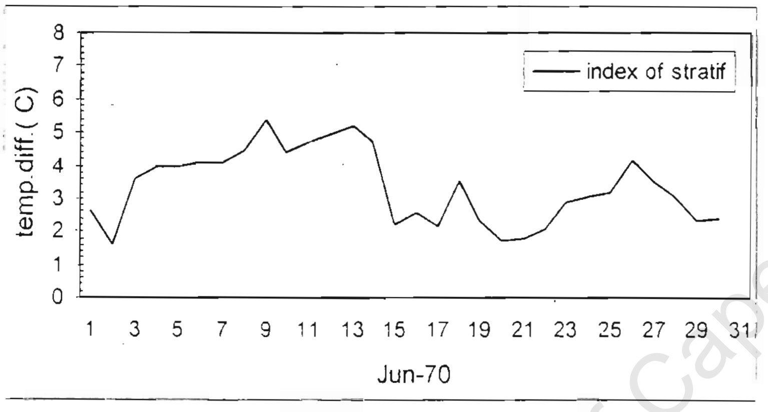
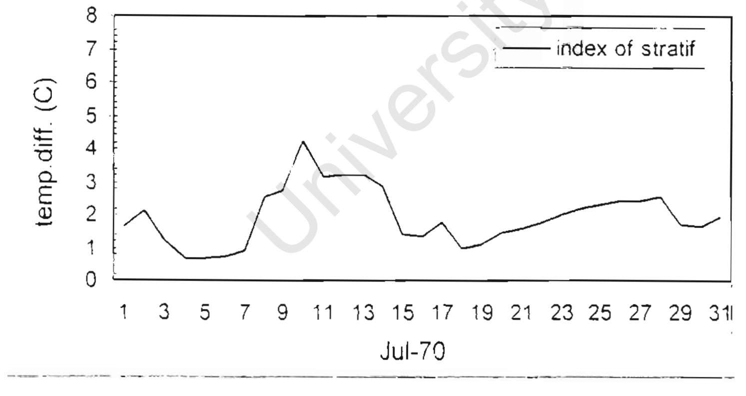


Figure 3-1: continuation





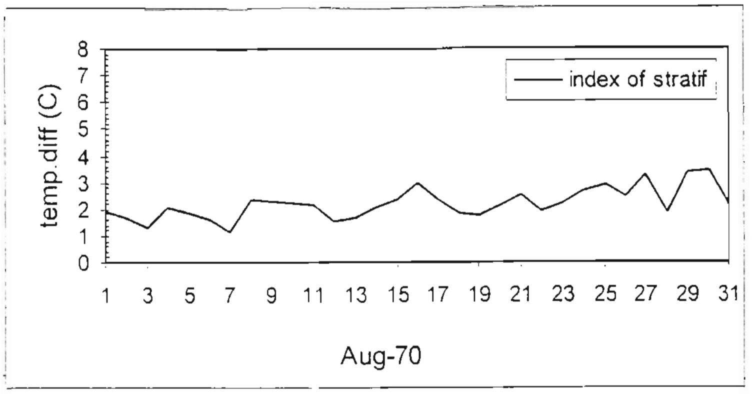
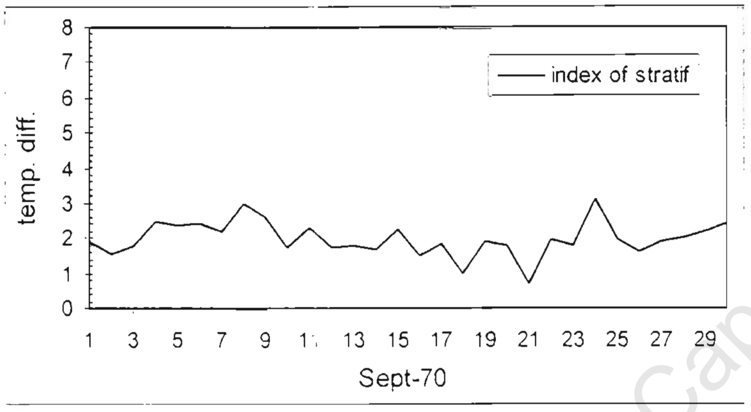
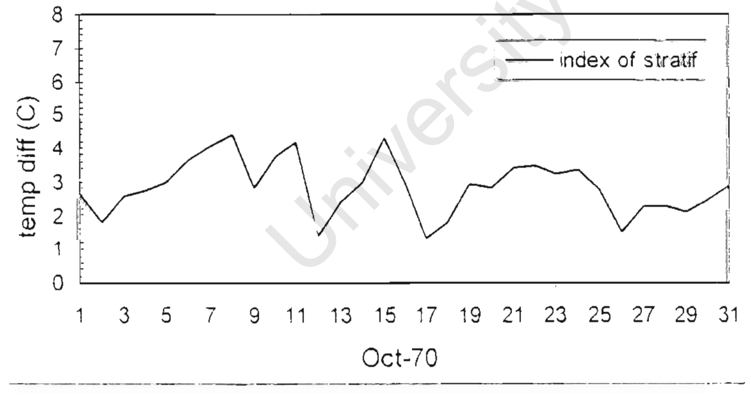


Figure 3-1: continuation





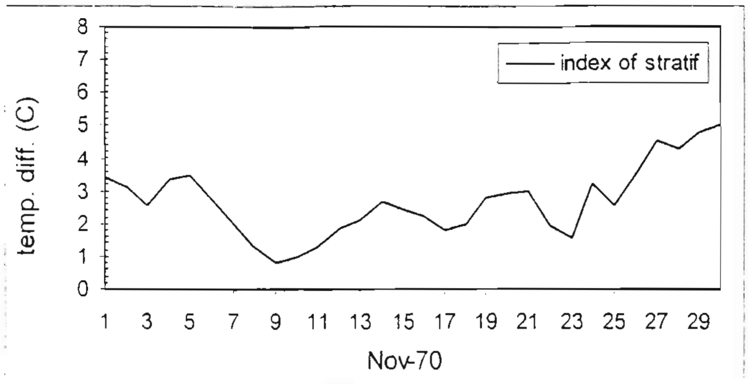
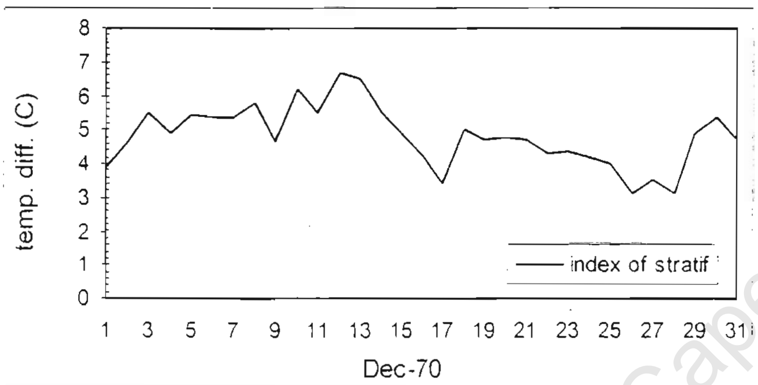


Figure 3-1: continuation



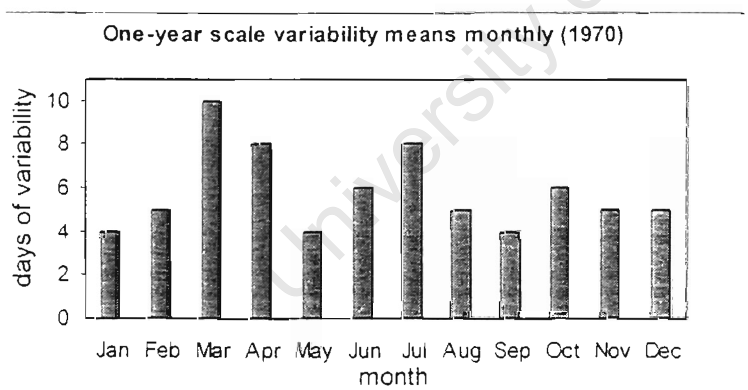


Figure 3-2: Number of events per month (from Figure 3-1) for 1970 off Lobito.

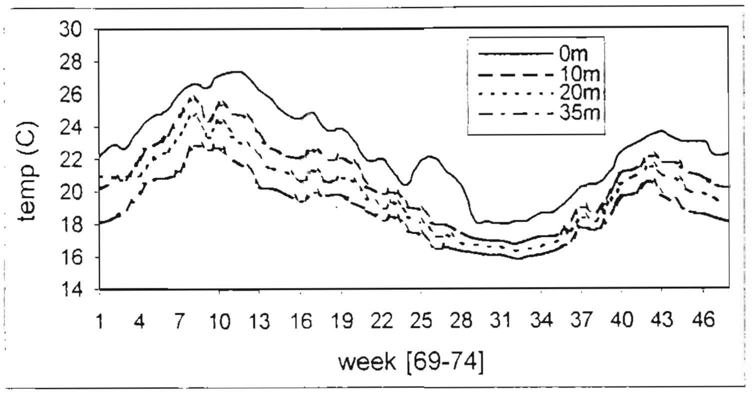


Figure 3-3: Weekly mean temperature for 0, 10, 20, 35 m depths for the period 1969-74.

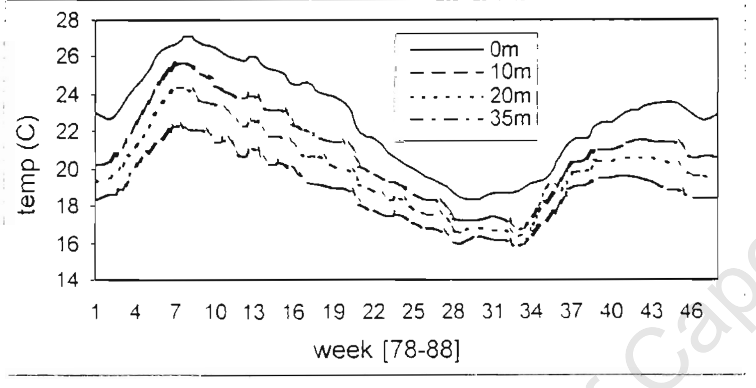


Figure 3-4: Weekly mean temperature for 0, 10, 20, 35 m depths for the period 1978-88.

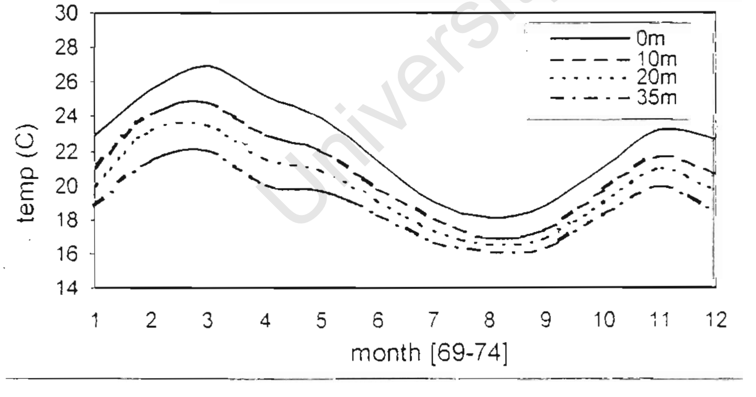


Figure 3-5: Monthly mean temperature for 0, 10, 20, 35 m depths for the period 1969-74.

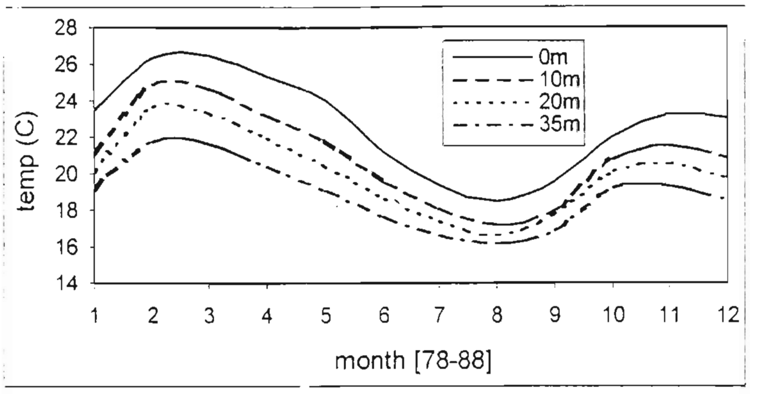


Figure 3-6: Monthly mean temperature for 0, 10, 20, 35 m depths for the period 1978-88.

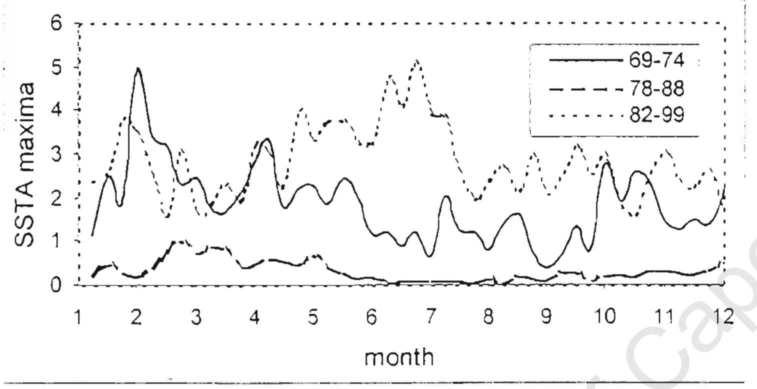


Figure 3-7: Comparison of the weekly SSTA maxima for the periods 1969-74, 1978-88 and 1982-99.

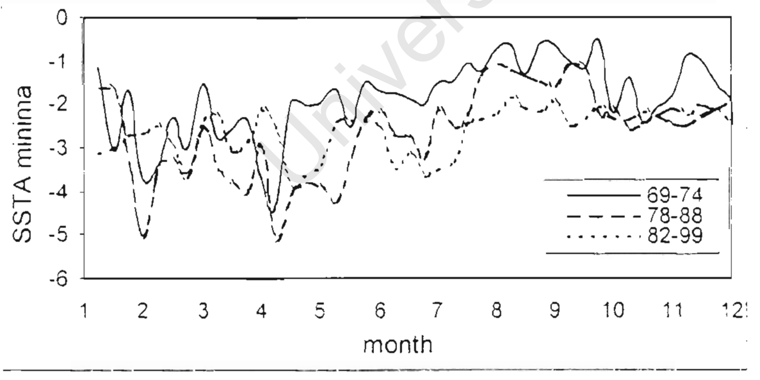


Figure 3-8: Comparison of the weekly SSTA minima for the periods 1969-74, 1978-88 and 1982-99.

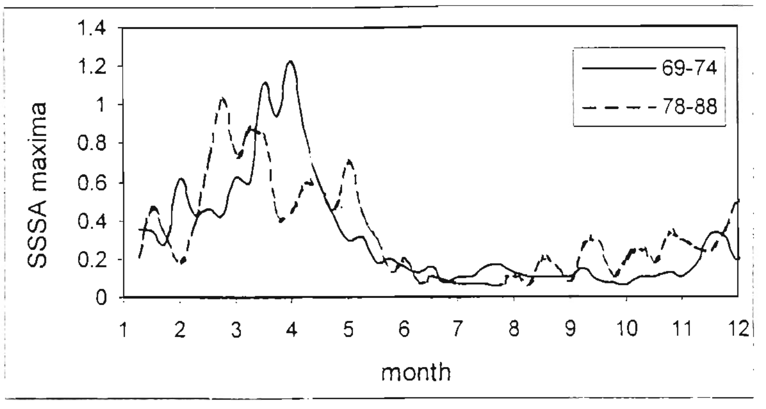


Figure 3-9: Comparison of the weekly SSSA maxima for the periods 1969-74, 1978-88.

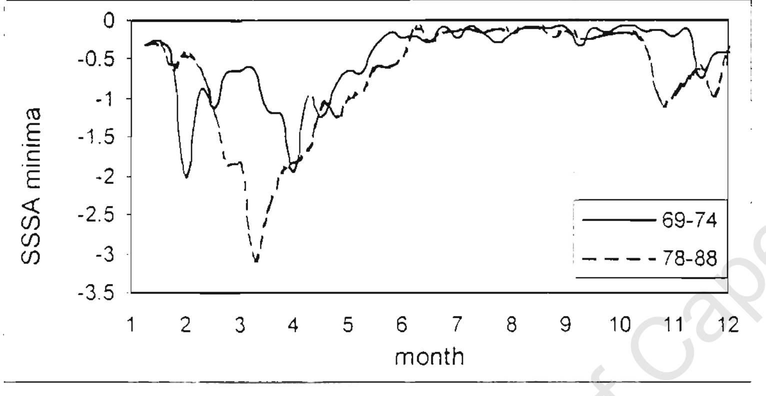


Figure 3-10: Comparison of the weekly SSSA minima for the periods 1969-74, 1978-88.

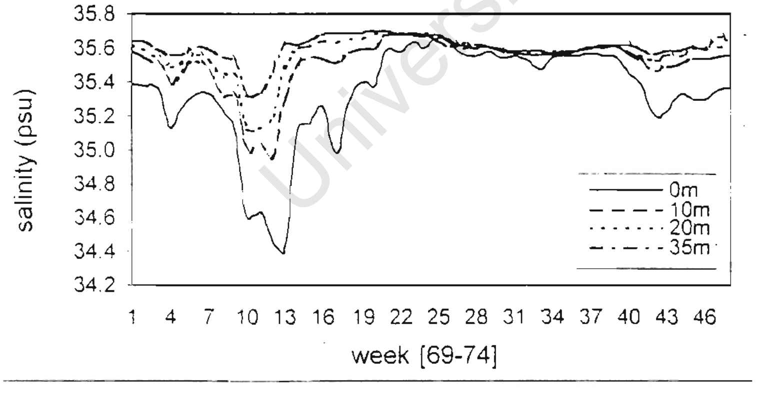


Figure 3-11: Weekly mean salinity for 0, 10, 20, 35 m depths for the period 1969-74.

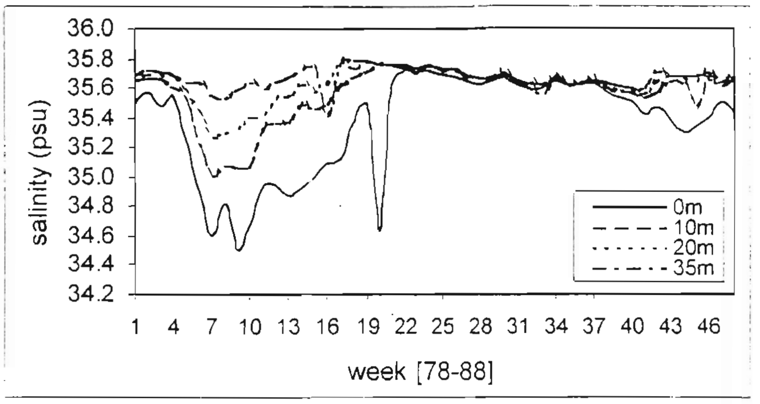


Figure 3-12: Weekly mean salinity for 0, 10, 20, 35 m depths for the period 1978-88.

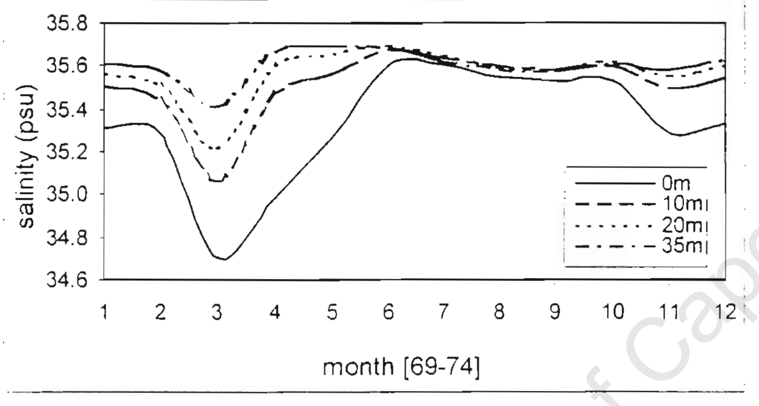


Figure 3-13: Monthly mean salinity for 0, 10, 20, 35 m depths for the period 1969-74.

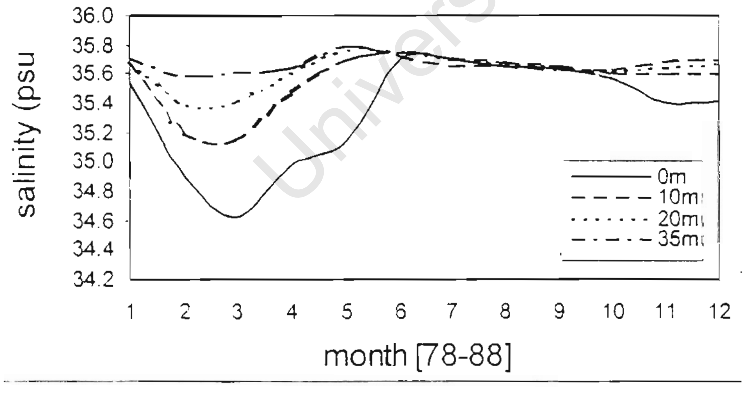


Figure 3-14: Monthly mean salinity for 0, 10, 20, 35 m depths for the period 1978-88.

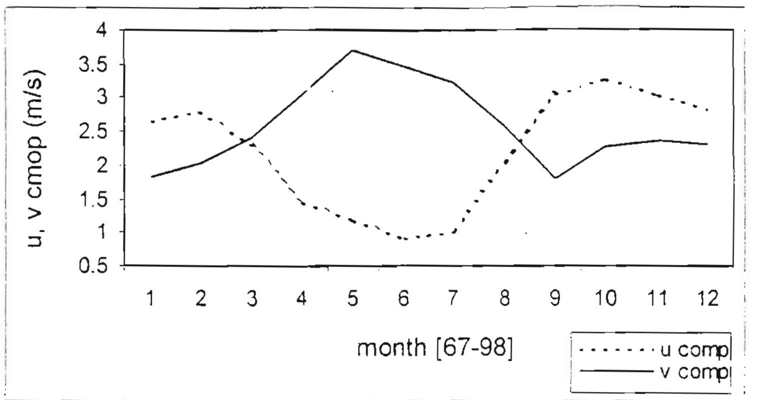


Figure 3-15: Seasonal pattern in u and v (wind) components extracted from the NCEP data from 12° 30S; 12° 30E for the period 1967-1998.

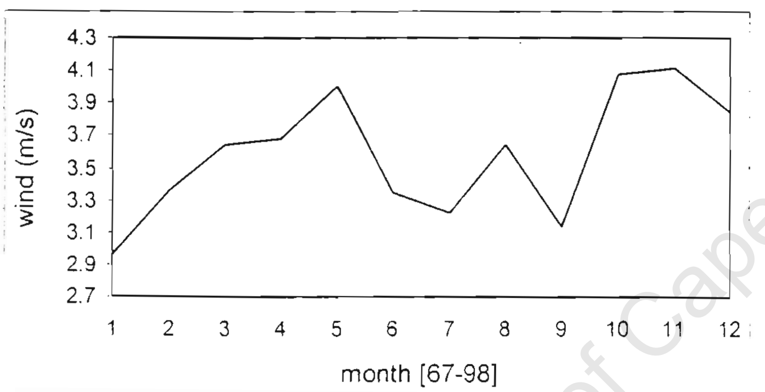


Figure 3-16: Seasonal pattern in surface wind speed extracted from the NCEP data from 12° 30S; 12° 30E for the period 1967-1998.

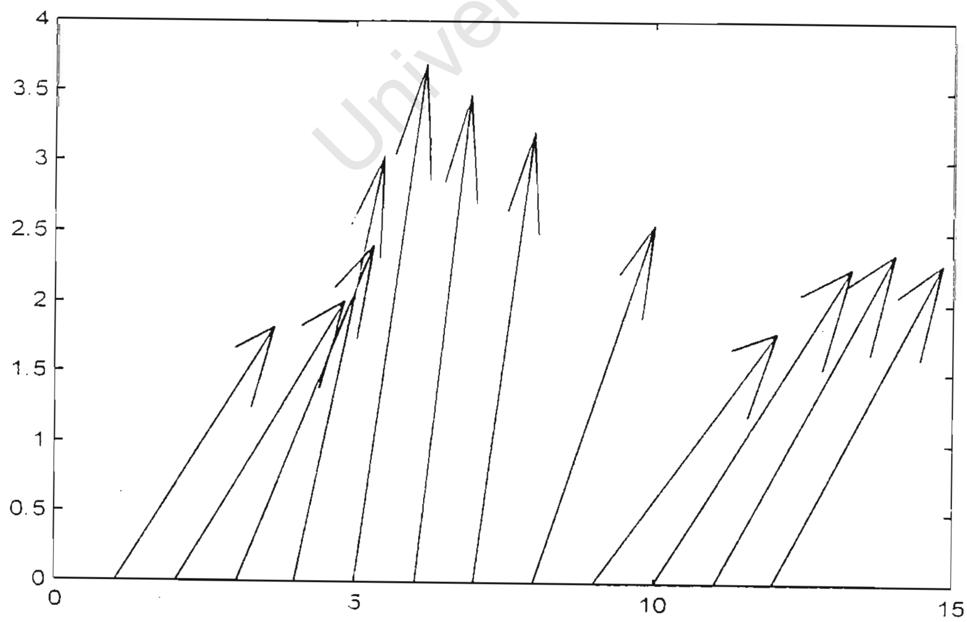


Figure 3-17 Feather plot displaying angles and magnitudes of the wind at 12 30S; 12 30E (off Lobito). Seasonal average was obtained within the 1967-1998 period i.e. over 32 years.

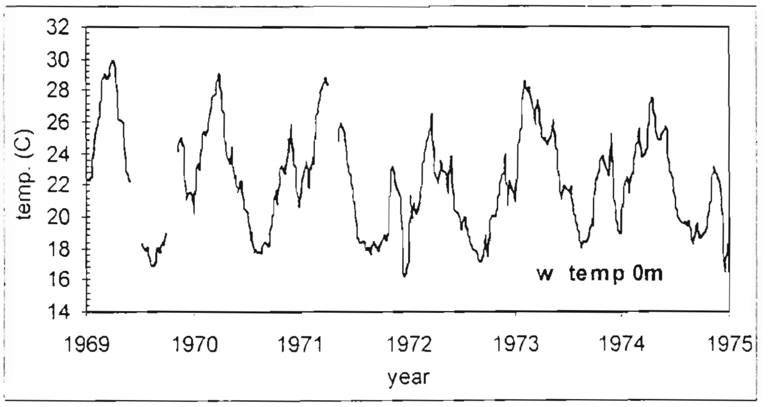


Figure 3-18: Temperature weekly values 0m for the 1969-74.

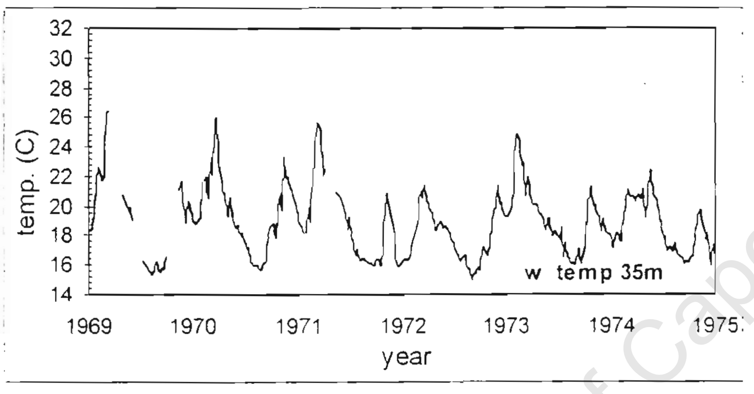


Figure 3-19: Temperature weekly values 35m for the 1969-74.

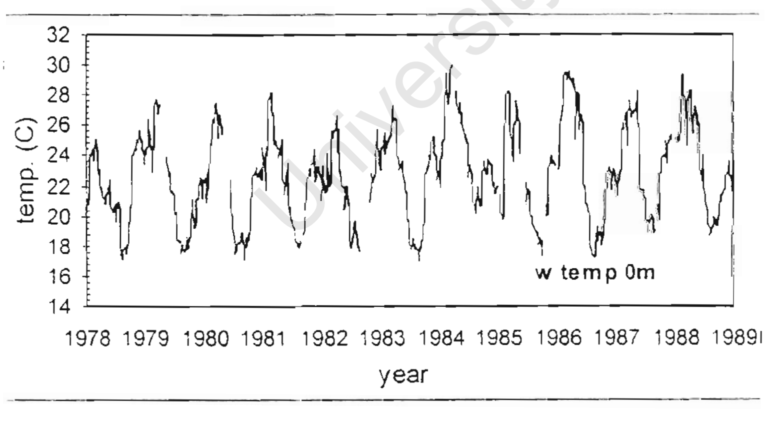


Figure 3-20: Temperature weekly values 0m for the 1978-88.

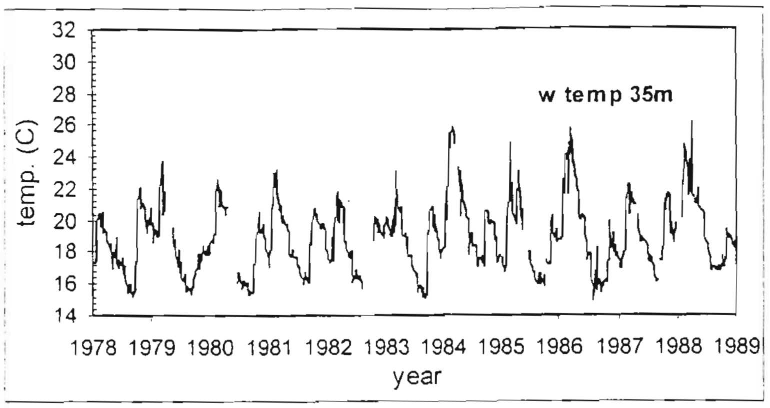


Figure 3-21: Temperature weekly values 35m for the 1978-88.

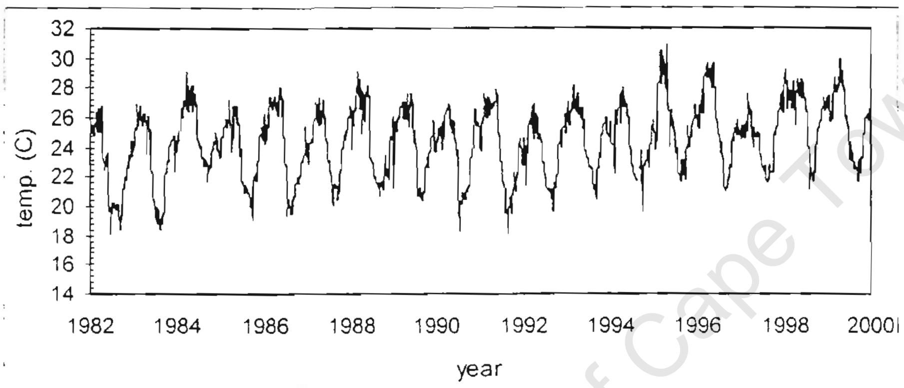


Figure 3-22: Satellite derived weekly SST for the period 1982-99

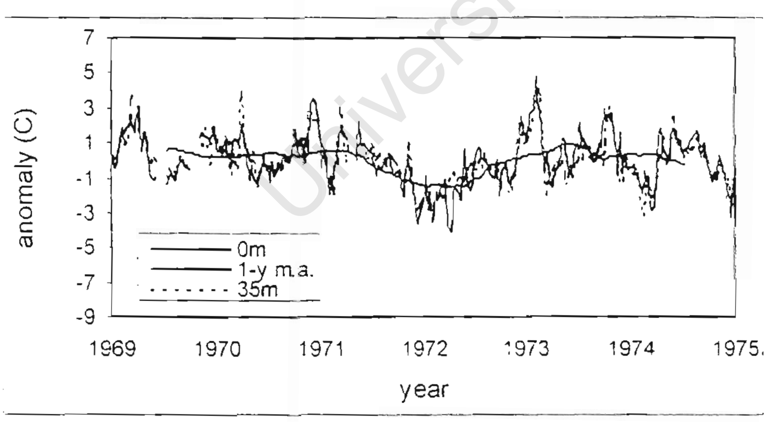


Figure 3-23: Weekly temperature anomalies 0 and 35m and one year moving average for the period 1969-74.

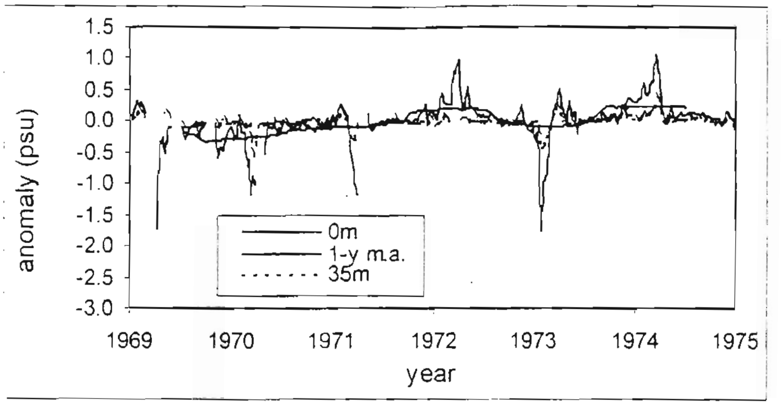


Figure 3-24: Weekly salinity anomalies 0 and 35m and one year moving average for the period 1969-74.

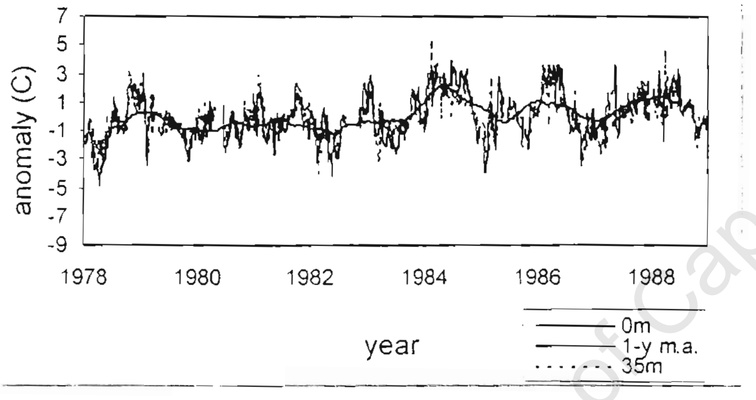


Figure 3-25: Weekly temperature anomalies 0 and 35m and one year moving average for the period 1978-88.

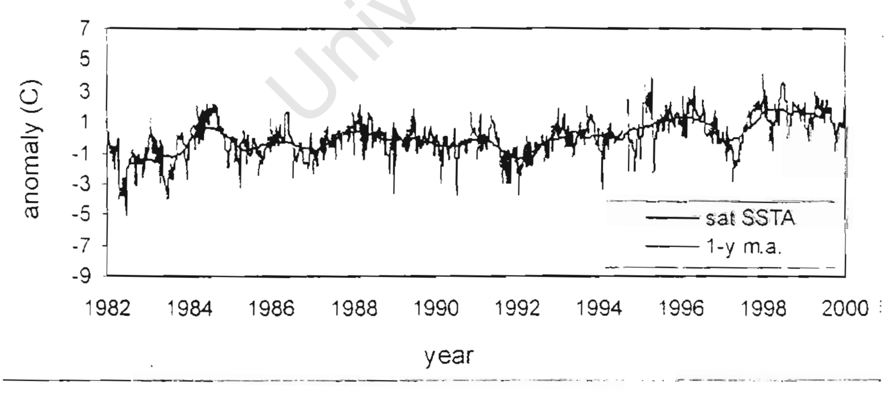


Figure 3-26: Satellite derived weekly SST anomalies and one year moving average for the period 1982-99.

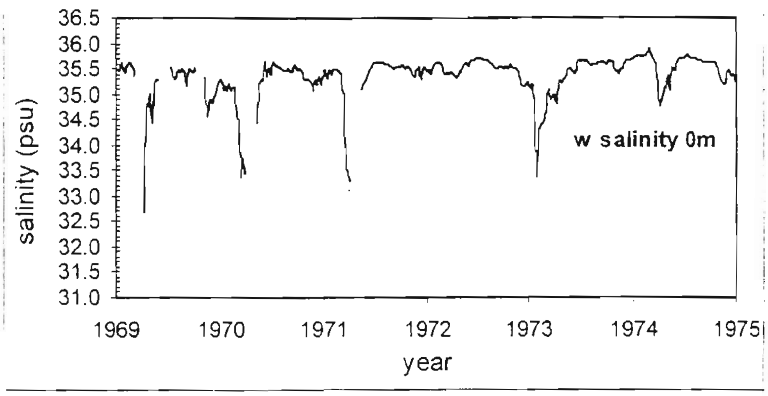


Figure 3-27: Salinity weekly values 0m for the 1969-74.

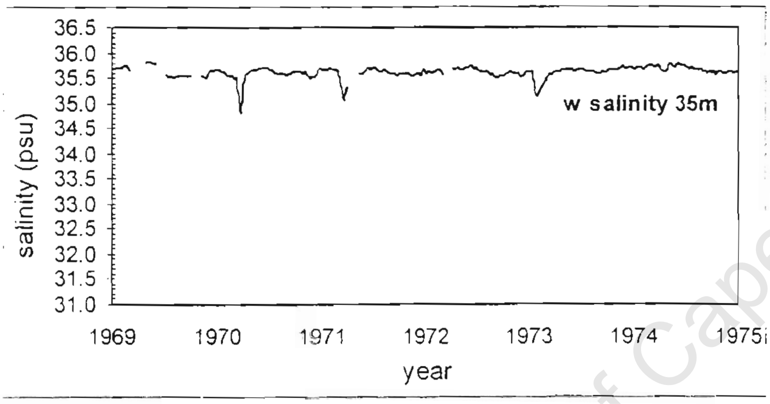


Figure 3-28: Salinity weekly values 35m for the 1969-74.

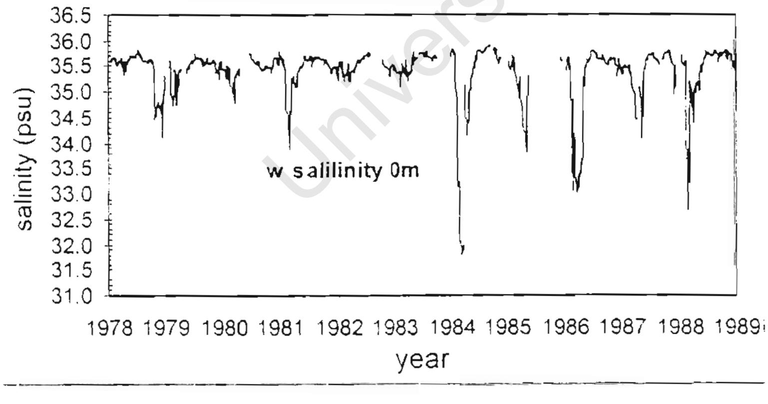


Figure 3-29: Salinity weekly values 0m for the 1978-88.

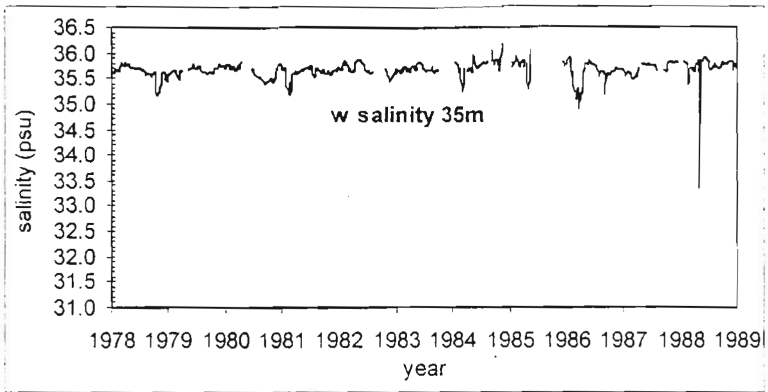


Figure 3-30: Salinity weekly values 35m for the 1978-88.

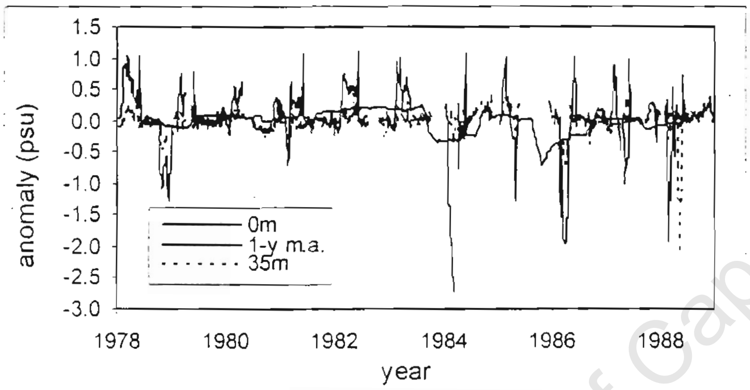


Figure 3-31: Weekly salinity anomalies 0 and 35m for the period 1978-88.

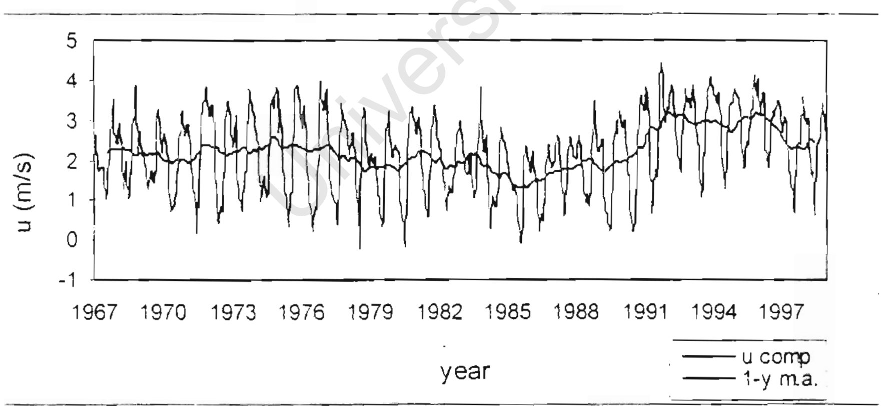


Figure 3-32: Monthly u (wind) component values for the 1967-1998 period; u component one-year moving average.

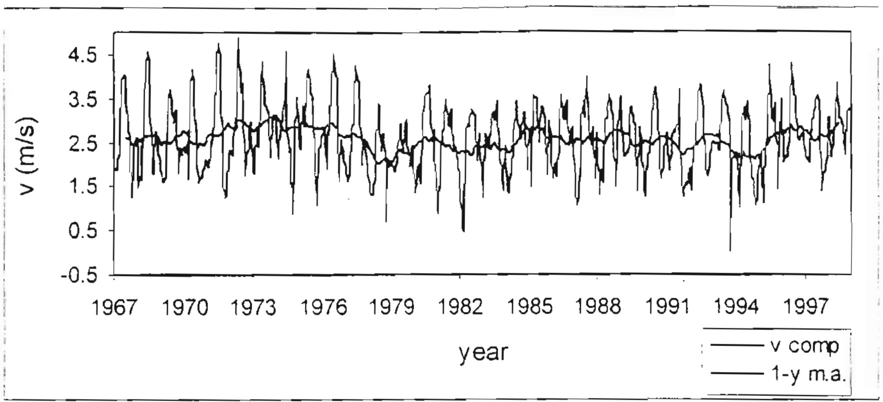


Figure 3-33: Monthly v (wind) component values for the 1976-1998 period; v component anomaly one-year moving average.

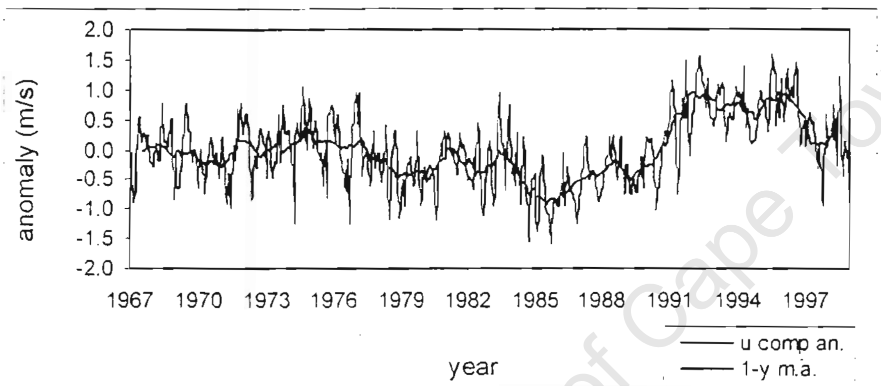


Figure 3-34: The thirty two-year monthly u (wind) component anomalies for the period 1967-1998; u (wina) component anomaly one-year moving average.

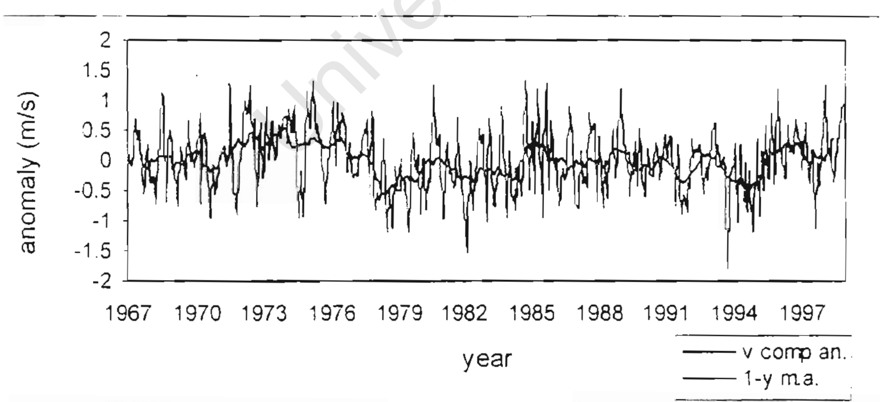


Figure 3-35: The thirty two-year monthly v (wind) component anomalies for the period 1967-1998;u (wind) component anomaly one-year moving average.

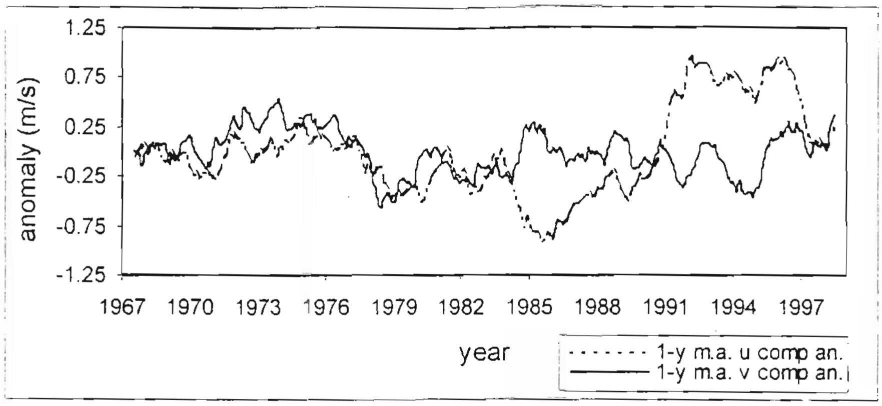


Figure 3-36: Monthly u and v (wind) components one-year moving average anomalies for the 1967 1998 period.

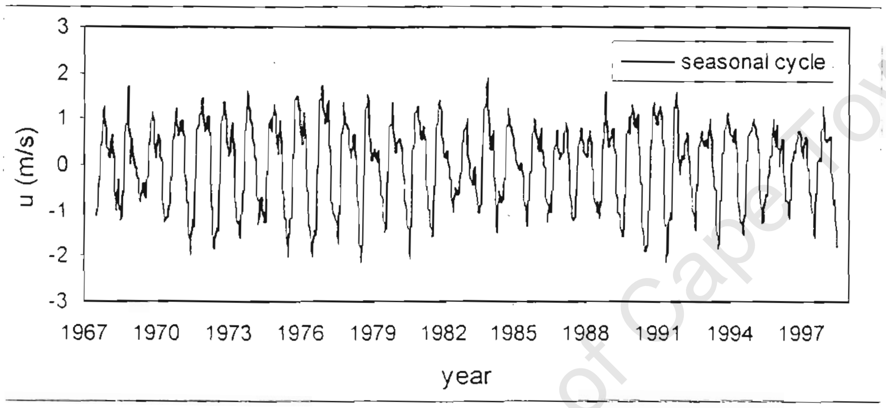


Figure 3-37: u (wind) component seasonal signal for the 1967-98 period.

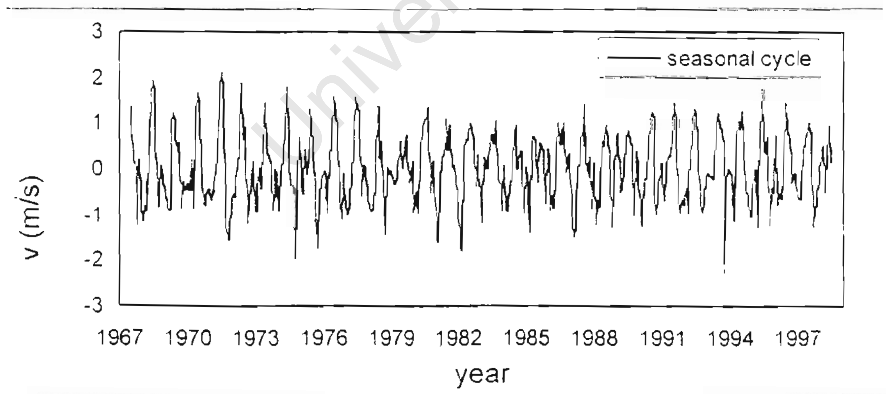


Figure 3-38: v (wind) component seasonal signal for the 1967-98 period.

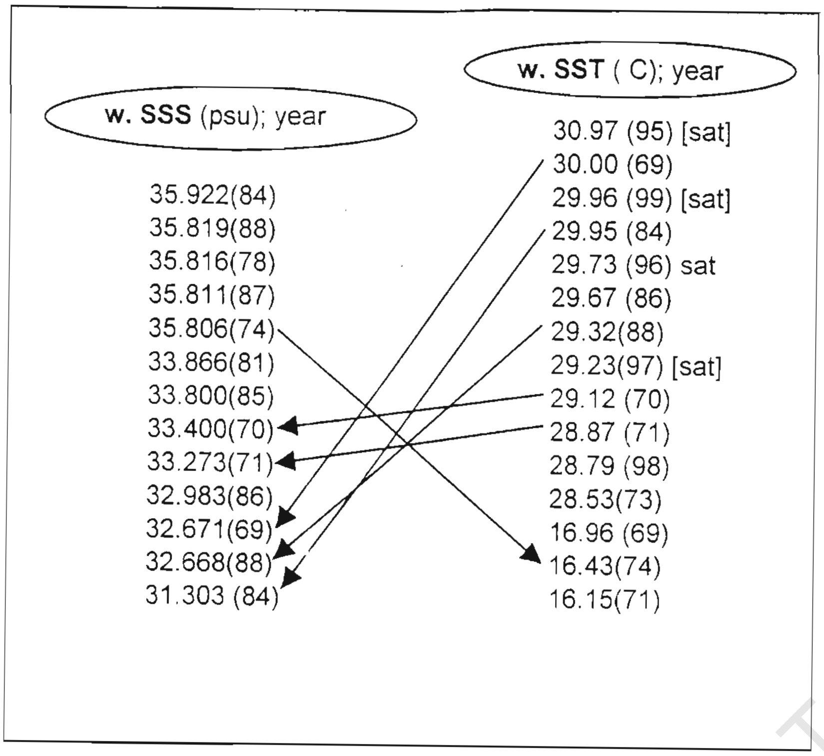


Figure 3-39 Scheme of weekly SST and SSS extreme values records.

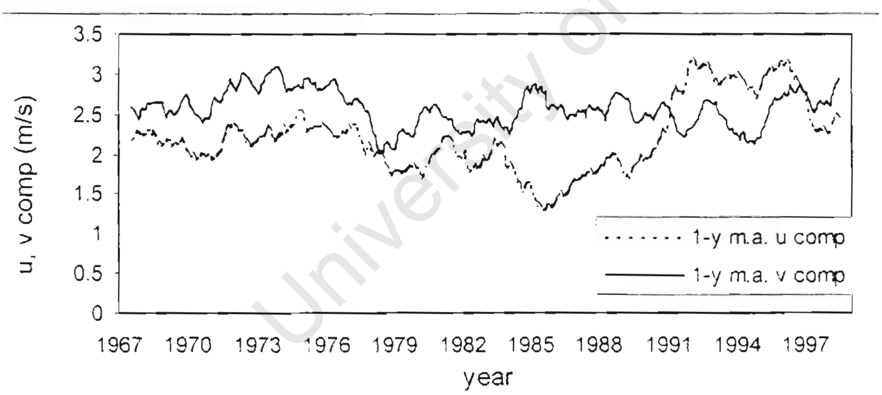


Figure 3-40: Monthly u and v (wind) components one-year moving average for the 1967-1998 period.

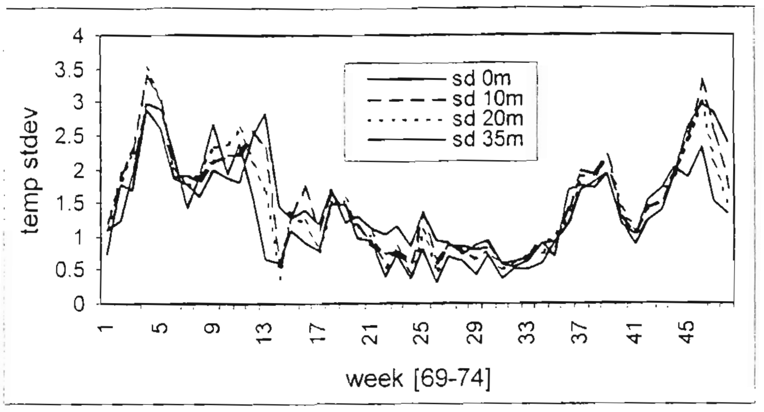


Figure 3-41: Weekly *in situ* temperature standard deviation for the 1969-1974 period at 12° 19S; 13° 34E.

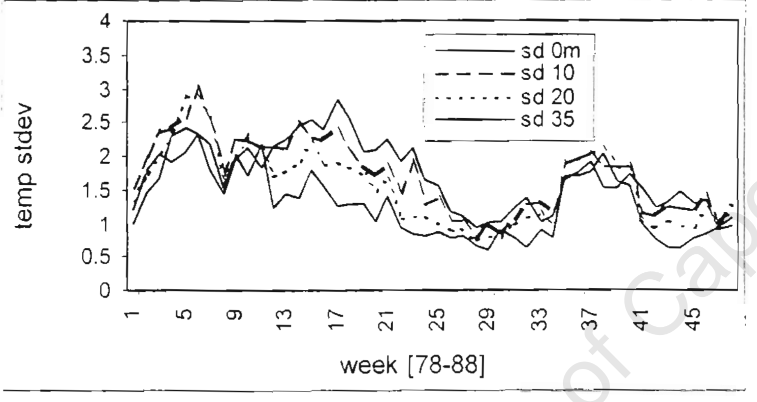


Figure 3-42: Weekly *in situ* temperature standard deviation for the 1978-1988 period at 12° 9S; 13° 34E.

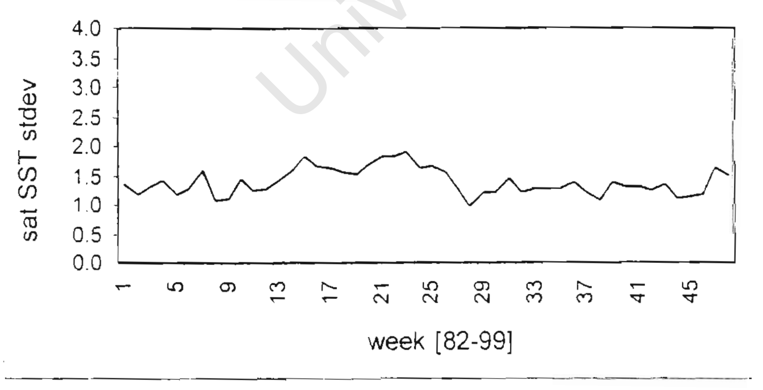


Figure 3-43: Weekly satellite-derived SST standard deviation for the 1982-1999 period at 11° 42S-12° 24S; 12° 48E-13° 24E.

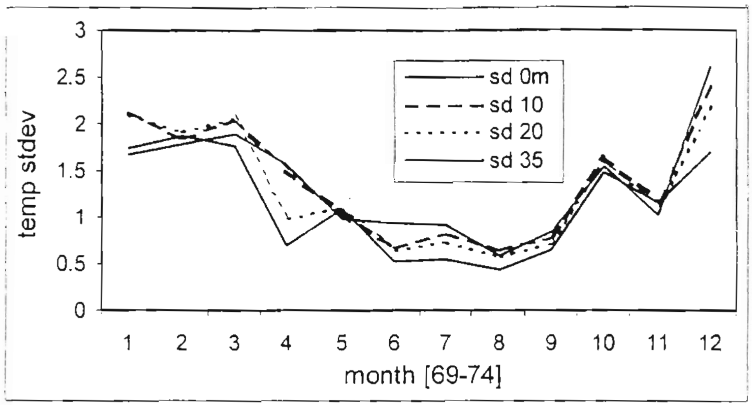


Figure 3-44: Monthly *in situ* temperature standard deviation for the period 1969-1974 at 12° 19S; 13° 34E.

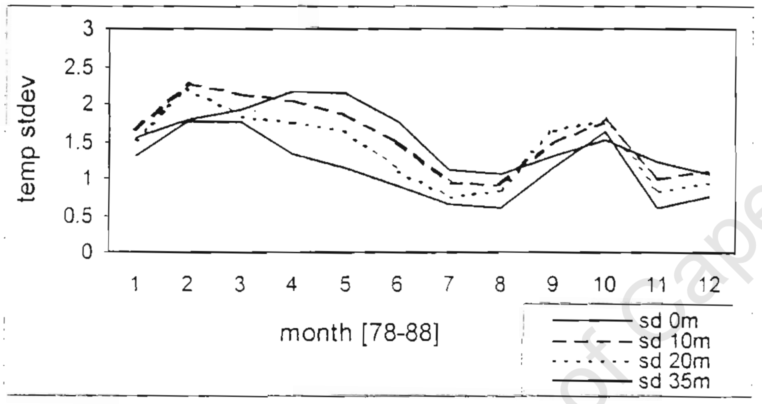


Figure 3-45: Monthly *in situ* temperature standard deviation for the period 1978-1988 at 12° 19S; 13° 34E.

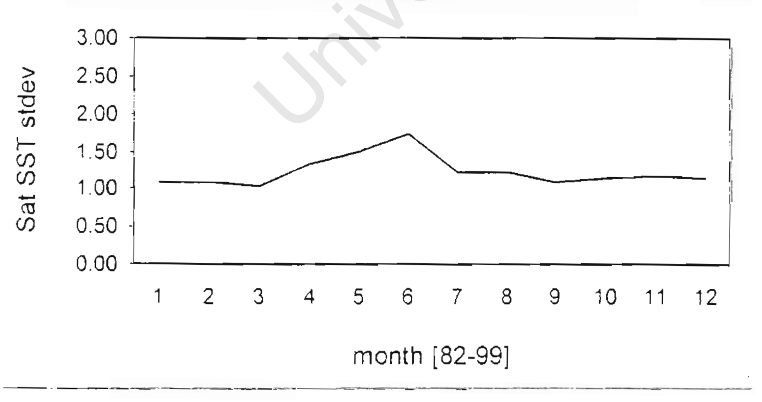


Figure 3-46: Monthly satellite-derived SST standard deviation for the 1982-1999 period at 11° 42S-12° 24S; 12° 48E-13° 24E.

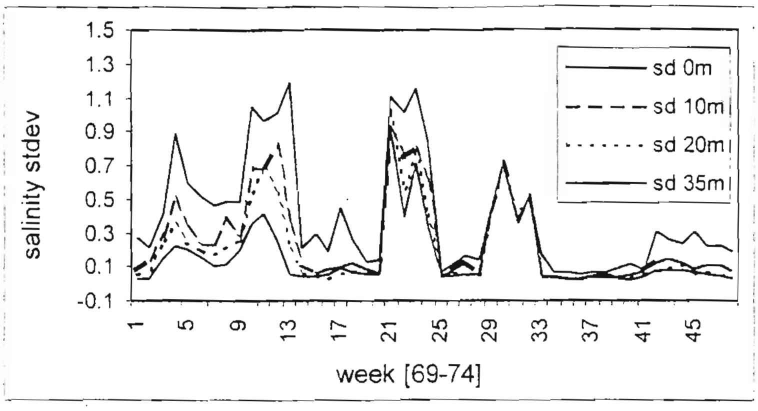


Figure 3-47: Weekly *in situ* salinity standard deviation for the 1969-1974 period at 12° 19S; 13° 34E.

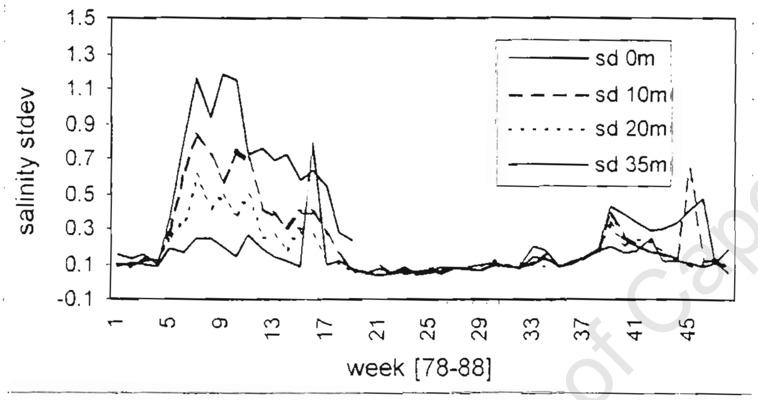


Figure 3-48: Weekly *in situ* salinity standard deviation for the 1978-1988 period at 12° 19S; 13° 34E.

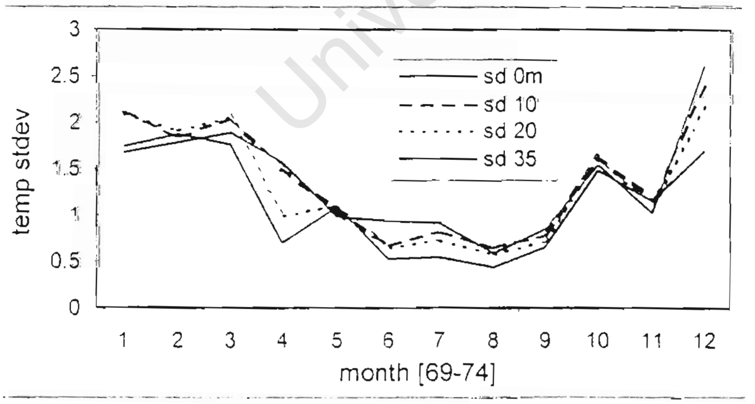


Figure 3-49: Monthly *in situ* salinity standard deviation for the period 1969-1974 at 12° 19S; 13° 34E.

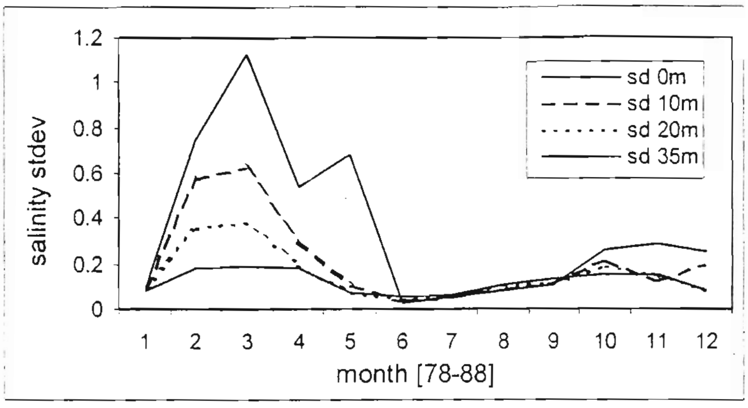


Figure 3-50: Monthly *in situ* salinity standard deviation for the period 1978-1988 at 12° 19S; 13° 34E.

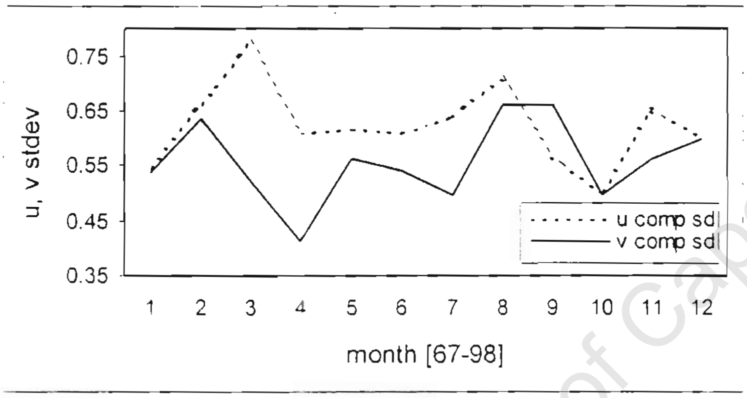


Figure 3-51: Monthly wind (u and v component) standard deviation for the 1967-1998 period.

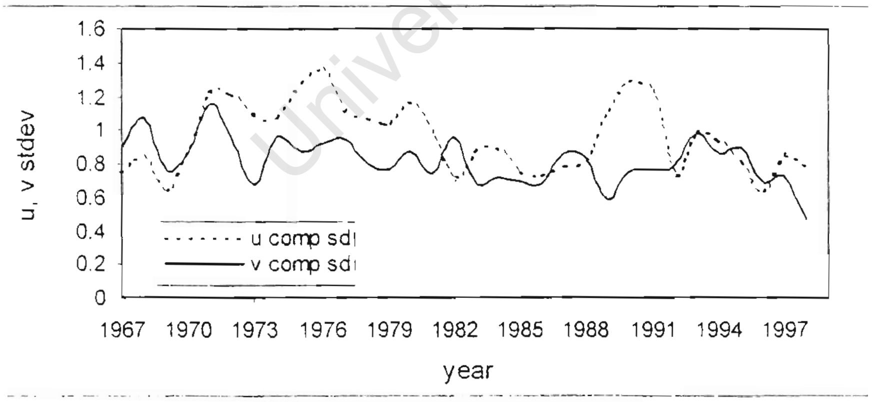


Figure 3-52: Annual wind (u and v component) standard deviation for the 1967-1998 period

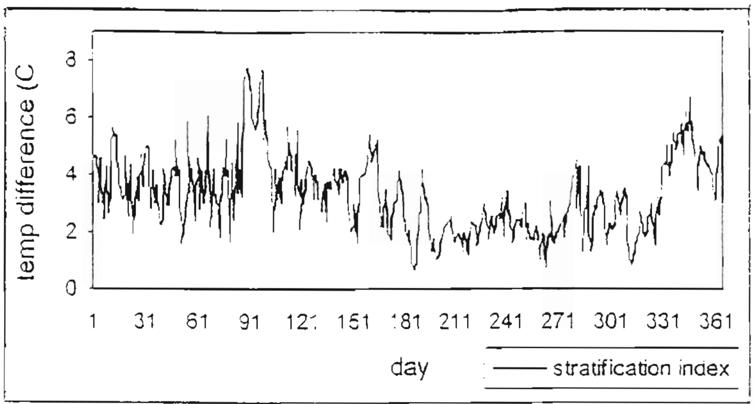


Figure 3-53: Index of stratification over 1970.

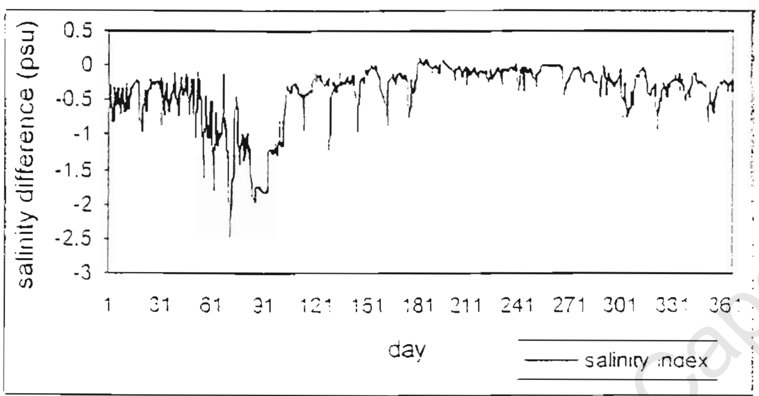


Figure 3-54: Salinity index.

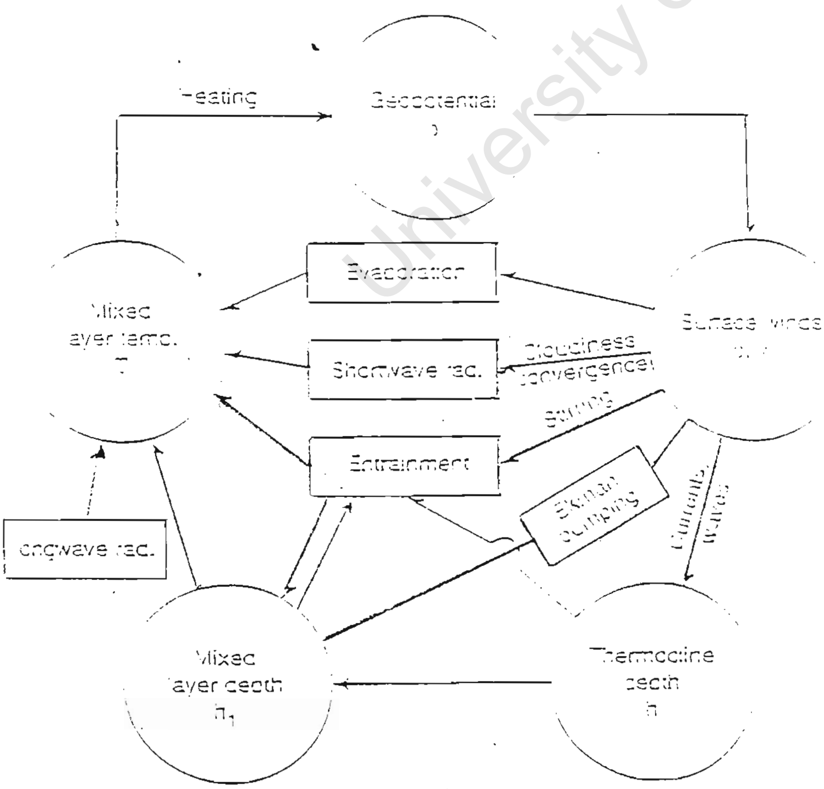


Figure 4-1: Schema of factors determining the mixed layer depth (MLD) and its changes (After Wang and Xie, 1997).

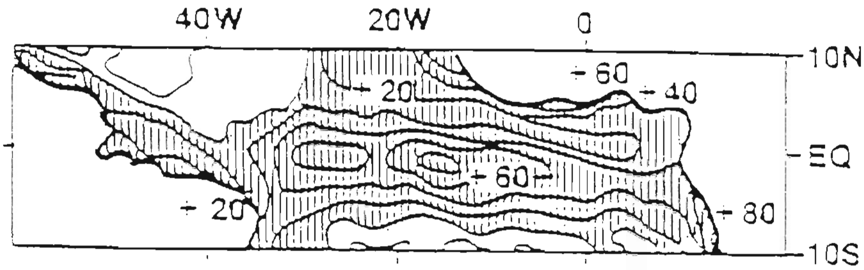


Figure 4-2: Mean annual net oceanic heat gain (W m^{2}). (After Hastenrath and Lamb 1978, chart 83).

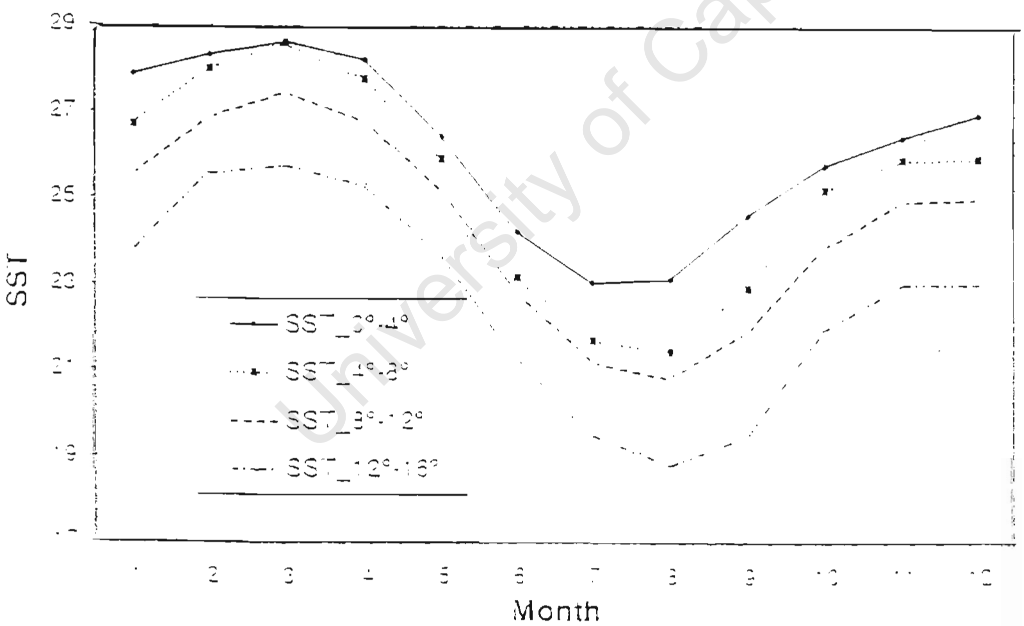


Figure 4-3: Seasonal pattern in sea sub-surface temperature (SST) extracted from the COADs database in four cells between 0 and 16 (After Servain and Lukas, 1990)

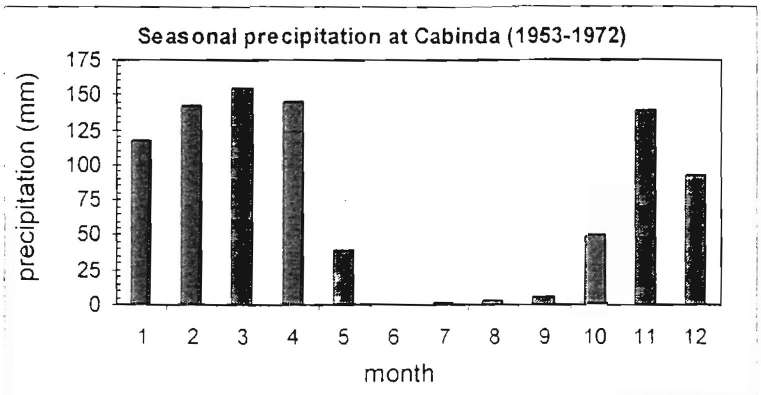
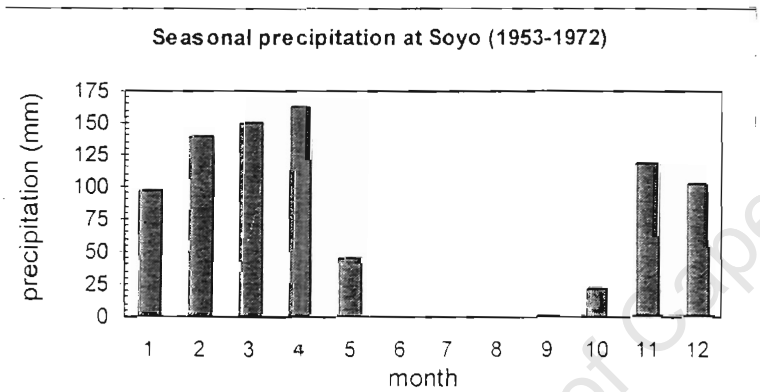
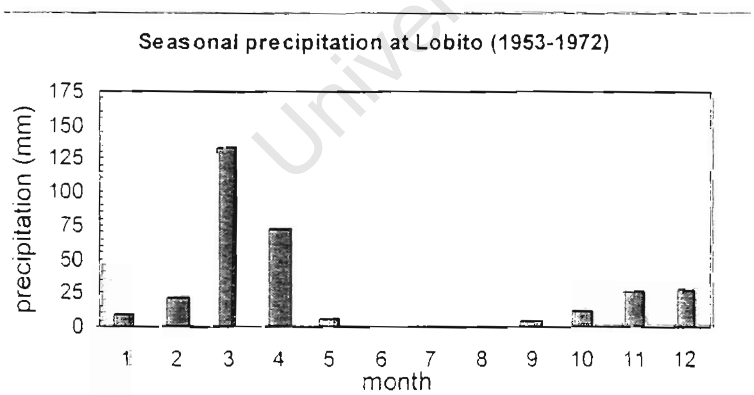


Figure 4-4: Seasonal precipitation at a) Cabinda (05 33S; 12 11E), b) Soyo (06° 06S; 12° 21E), c) Lobito (12° 22S; 13° 32E).



b)



c)

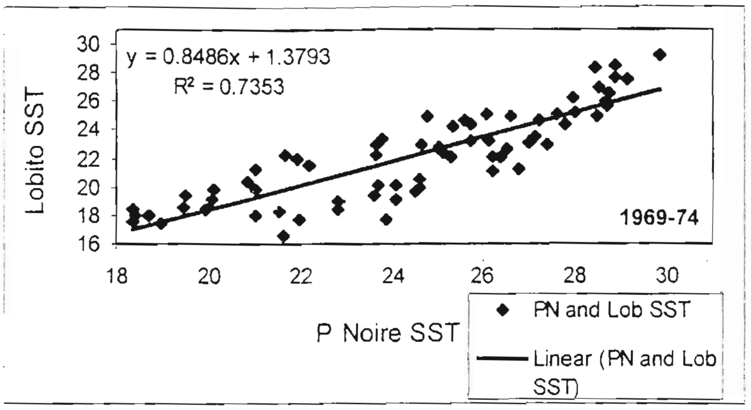
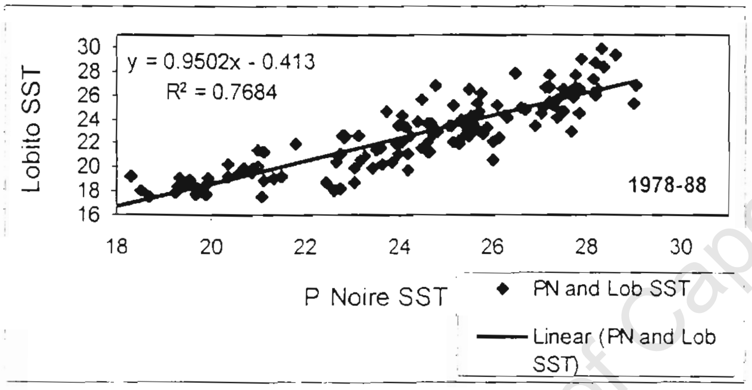


Figure 4-5: Scatterplot for Pointe-Noire and Lobito *in situ* SST anomalies a) 1969 -1974; b) 1978-1988



b)

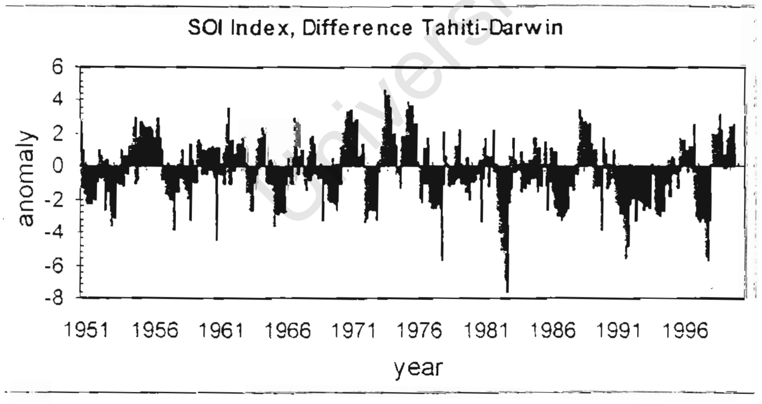


Figure 4-6: Graphic for Southern Oscillation Index (SOI), Sea Level Pressure (SLP) diferrence between Tahiti (17° 32S; 149° 34W) and Darwin (12° 23S; 130° 44E) in Pacific for the 1951-2000 period.

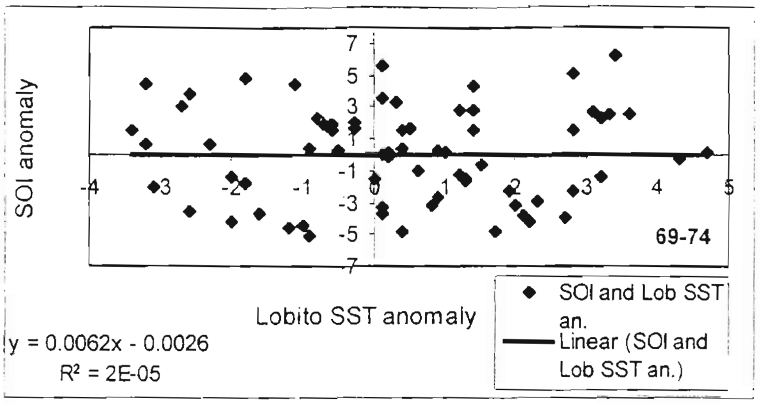
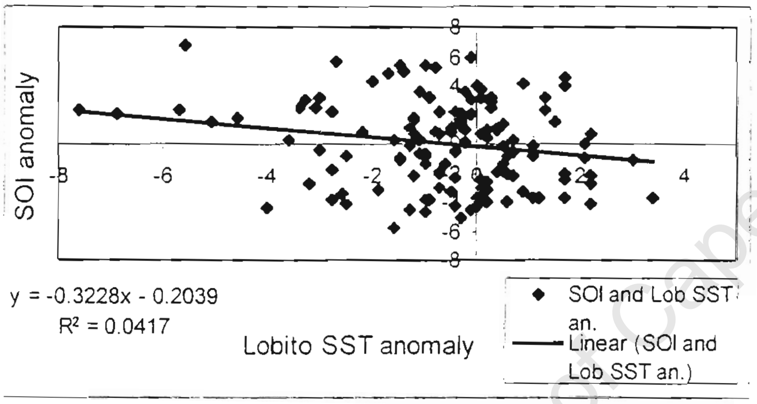


Figure 4-7: Scatterplot for Southern Oscillation Index (SOI) and Lobito *in situ* SST anomalies between a) 1969 and 1974; b) 1978-1988



b)

TABLES

Table 1-1: SST and SSS values off Angola. After Fidel and Filipe (1995)

	Warm	season	Cold	season
	SST (°C)	SSS (psu)	SST (°C)	SSS (psu)
North (5-9°S)	27.93 – 28.39	27.630 -	22.30 – 23.60	27.230 – 31.140
Center (9-13°S)	27.56 – 29.34	33.610 – 32.370	21.62 – 22.12	35.690 – 35.810
South (13-17°S)	22.30 – 23.60	35.020 – 35.980	15.56 – 16.08	35.600 – 35.630

Table 3-1 : Weekly mean temperature values for the periods (a) 1969-74 and (b) 1978-88

a)

	week 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0m	22.14	22.82	22.62	23.76	24.64	25.02	25.96	26.62	26.43	27.08	27.38	27.10	26.20	25.63	24.74	24.48
10m	20.15	20.89	20.75	22.02	22.92	23.52	24.61	25.69	24.42	25.34	24.87	24.64	23.51	22.73	22.19	22.12
20m	21.05	21.05	21.05	21.05	21.96	22.46	23.48	24.77	23.37	24.36	23.50	22.91	22.14	21.46	21.27	20.68
35m	18.07	18.40	18.85	19.92	20.75	20.85	21.30	22.91	22.67	22.70	21.97	21.47	20.36	20.24	19.83	19.40
week	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
0m	24.81	23.73	23.93	23.11	21.86	21.94	21.18	20.41	21.86	21.94	21.18	20.41	18.15	18.07	17.99	18.10
10m	22.64	21.94	22.10	21.69	20.36	19.91	20.00	19.16	18.93	18.06	17.96	17.48	17.16	17.05	16.95	16.73
20m	21.41	20.62	20.91	20.63	19.67	19.02	19.32	18.52	18.12	17.26	17.43	16.92	16.72	16.63	16.61	16.32
35m	20.02	19.74	19.90	19.39	18.92	18.25	18.47	17.59	17.35	16.49	16.68	16.33	16.22	16.18	16.14	15.87
week	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
0m	18.17	18.65	18.76	19.50	20.20	20.35	21.17	22.41	22.85	23.42	23.57	23.18	22.94	23.00	22.16	22.30
10m	17.03	17.23	17.24	18.15	19.00	18.65	19.89	21.14	21.37	22.14	21.70	21.74	21.08	20.91	20.41	20.29
20m	16.54	16.62	16.83	17.52	18.33	18.11	19.39	20.42	20.83	21.46	20.95	20.77	20.02	19.84	19.49	19.36
35m	16.05	16.11	16.36	16.91	17.77	17.61	18.51	19.58	19.94	20.56	19.80	19.32	18.734	18.61	18.36	18.17

b)

	week 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0m	23.02	22.67	23.32	24.42	25.22	26.41	26.71	27.16	26.74	26.51	26.08	25.88	26.02	25.41	25.16	24.53
10m	20.32	20.42	21.18	22.49	23.51	24.83	25.59	25.67	25.17	24.56	24.19	23.91	23.94	23.22	23.19	22.48
20m	19.27	19.49	20.18	21.26	22.29	23.50	24.40	24.35	23.66	23.55	22.96	22.40	22.63	21.83	21.85	21.29
35m	18.38	18.67	18.93	20.14	20.87	21.59	22.32	22.19	22.17	21.44	21.61	20.72	21.14	20.31	20.36	19.97
week	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
0m	24.63	24.14	23.88	23.31	21.97	21.57	20.81	20.39	19.96	19.57	19.16	18.62	18.33	18.34	18.65	18.71
10m	22.10	21.68	21.52	21.25	20.16	19.73	19.37	19.16	18.68	18.30	18.18	17.33	17.27	17.31	17.44	17.28
20m	20.74	20.71	20.17	20.01	19.25	18.84	18.35	18.45	17.93	17.57	17.55	16.74	16.75	16.83	16.74	16.73
35m	19.28	19.25	18.96	18.87	18.16	17.75	17.43	17.61	17.14	16.78	16.71	16.11	16.10	16.44	16.16	16.21
week	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
0m	18.76	19.19	19.41	20.62	21.50	21.57	22.40	22.42	23.02	23.16	23.41	23.51	23.40	22.92	22.57	22.91
10m	16.70	17.39	18.09	19.36	20.35	20.51	21.05	21.06	21.42	21.59	21.51	21.48	21.37	20.62	20.69	20.57
20m	16.39	16.97	19.04	18.80	19.78	19.90	20.42	20.42	20.67	20.65	20.60	20.40	20.18	19.69	19.60	19.36
35m	15.88	16.42	17.11	18.08	18.95	19.05	19.54	19.52	19.65	19.52	19.30	18.88	18.85	18.44	18.49	18.45

Table 2-1: Oceanographic and meteorological data inventory

Variable	Geographical location	Date range	Sampling interval	Units [accuracy/ precision]	Obs
T (temperature) S (salinity)	12° 19S; 13°34E (Lobito)	1968;1969;1970;1971;1972; 1973;1974;1975;1978;1979; 1980;1981;1982;1983;1985; 1986;1987;1988;1989;1990; 1991;1992;1995;1996;1997; 1998	Δt=24h	°C psu [± 0.1°C] [0.001 psu]	Data with some gaps
CORSA Sattelite SST derived	5°-18°S (Whole Angolan coast)	1982-1989 1990-1997	Weekly and monthly mean ~ 4.5 km	°C [<1°C]	Two volumes of CD-ROM set
CORSA satellite derived SST	Area: 1 Pixel bounded by 11° 42S; 12° 48E 11° 42S; 12° 48E 12° 24S; 13° 24E 12° 24S; 13° 24E (off Lobito)	1982;1983;1984;1985;1986; 1987;1988;1989;1990;1991; 1992;1993;1994;1995;1996; 1997;1998;1999	Weekly and monthly mean 1 Pixel ~ 4.5 km	°C	Two volumes of CD-ROM set
T (temperature)	04° 48S; 11°51E (Pointe-Noire)	1964;1965;1966;1967;1968; 1969;1970:1971;1972;1973; 1974;1975;1976;1977:1978; 1979;1980;1981;1982;1983; 1985;1986;1987;1988;1989; 1990;1991;1992;1993;1994; 1995;1996;1997;1998	monthly mean	°C [± 0.1°C]	
W (NCEP surface wind)	12°30S; 12°30E off Lobito	1967;1968;1969;1970;1971; 1972;1973;1974;1975;1976; 1977;1978;1979;1980;1981; 1982;1983;1984;1985;1986; 1987;1988;1989;1990;1991; 1992;1993;1994;1995;1996; 1997;1998	monthly mean	ms^{-1}	Available at Web site
SOI (Southern Oscillation Index)	17°S 32E; 149 ° 34W (Tahiti) 12°S 23E; 130° 44E (Darwin)	1951;1952;1953;1954;1955; 1956;1957;1958;1959;1960; 1961;1962;1963;1964;1965; 1966;1967;1968;1969;1970; 1971;1972;1973;1974;1975; 1976;1977;1978;1979;1980; 1981;1982;1983;1985;1986; 1987;1988;1989;1990;1991; 1992;1993;1994;1995;1996; 1997;1998;1999;2000	monthly mean anomalies	monthly mean anomalies index	Available at Web site
P (Precipitation)	5°33S; 12° 11E (Cabinda)	1953;1954;1955;1960;1961; 1962;1964;1965;1966;1967; 1968;1969;1972	Monthly mean	mm	Data with some gaps
P (Precipitation)	6°06S; 12° 21E (Soyo)	1953;1955;1956;1957;1960; 1961;1962;1964;1967;1968; 1969;1972	Monthly mean	mm	Data with some gaps
P (Precipitation)	8°51S; 13° 14E (Luanda)	1954;1955;1956;1957;1960; 1961;1962;1964;1965;1967; 1968;1969;1972	Monthly mean	mm	Data with some gaps
P (Precipitation)	12°22S; 13° 32E (Lobito)	1953;1954;1955;1956;1957; 1960;1961;1962;1964;1965; 1966;1967;1968;1969;1972	Monthly mean	mm	Data with some gaps

Table 2-2: Monthly numbers of temperature and salinity measurements made at Lobito oceanographic coastal station at 0 and 35 m depth for the periods 1969-1974 and 1978-1988.

	19 69				19 70				19 71				19 72		
	T		S		T		S		T		S		T		S
	0m	35 m	0m	35 m	0m	35 m	0m	35 m	0m	35 m	0m	35 m	0m	35 m	0m
January	26	26	26	25	26	26	26	26	26	26	26	26	26	26	26
February	23	23	23	23	24	24	24	24	24	24	24	24	25	25	25
March	13	1	13	1	22	22	22	22	27	27	27	27	27	27	27
April	24	-	24	-	26	26	26	26	25	25	25	25	25	25	25
May	27	27	27	25	26	26	26	26	26	26	26	26	25	25	25
June	-	-	-	-	26	26	26	26	26	26	26	26	26	26	26
July	27	27	27	27	27	27	27	27	27	27	27	27	25	25	25
August	26	26	26	26	25	25	25	25	26	26	26	26	27	27	27
Sept.	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26
October	-	-	-	-	25	25	25	25	25	25	25	25	25	25	25
Nov.	25	25	25	25	25	25	25	25	26	26	26	26	26	26	26
Dec.	26	26	26	26	26	26	26	26	25	25	25	25	25	25	25

	19 73				19 74				19 78				19 79		
	T		S		T		S		T		S		T		S
	0m	35 m	0m	35 m	0m	35 m	0m	35 m	0m	35 m	0m	35 m	0m	35 m	0m
January	27	27	27	27	27	27	27	27	16	16	15	15	26	26	26
February	24	24	24	24	24	24	24	24	22	22	22	22	24	24	24
March	26	26	26	26	25	25	25	25	26	26	26	26	16	16	16
April	25	25	25	25	21	21	21	21	21	21	21	21	-	-	-
May	27	27	27	27	25	25	25	25	25	25	25	25	24	24	24
June	26	26	26	26	24	24	24	24	26	26	26	26	25	25	25
July	26	26	26	26	26	26	26	26	25	25	25	25	22	22	22
August	26	26	26	26	26	26	26	26	27	27	27	27	18	18	18
Sept.	25	25	25	25	24	24	24	24	26	26	26	26	18	18	18
October	27	27	27	27	26	26.	26	26	25	25	24	24	27	27	27
Nov.	26	19	26	19	24	24	24	24	24	24	24	24	25	25	25
Dec.	25	25	25	25	24	24	24	24	20	20	20	20	21	21	21

	19 80				19 81				19 82				19 83		
	T		S		T		S		T		S		T		S
	0m	35 m	0m	35 m	0m	35 m	0m	35 m	0m	35 m	0m	35 m	0m	35 m	0m
January	24	24	24	24	24	24	24	24	24	24	24	24	23	23	23
February	23	23	23	23	23	23	22	21	21	21	21	21	22	22	22
March	25	25	25	25	25	25	25	25	26	26	26	26	25	25	25
April	7	7	7	7	25	25	25	25	23	23	23	23	25	25	25
May	-	-	-	-	24	24	24	24	25	25	24	25	17	17	17
June	18	18	18	18	25	25	23	23	26	26	26	26	25	25	25
July	26	26	26	26	26	26	26	26	26	26	26	26	26	26	19
August	20	20	20	20	21	20	20	20	2	2	-	-	21	21	21
Sep.	25	25	25	24	25	25	25	25	-	-	-	-	24	24	24
October	18	18	18	18	27	27	26	25	18	18	18	18	25	25	-
Nov.	24	24	24	24	24	24	24	24	24	24	24	24	24	24	-
Dec.	25	25	25	25	23	23	23	23	24	24	24	24	23	23	-

Table 2-2: continuation

	1984				1985				1986				1987		
	T		S		T		S		T		S		T		S
	0m	35 m	0m	35 m	0m	35 m	0m	35 m	0m	35 m	0m	35 m	0m	35 m	0m
January	25	25	25	25	26	26	20	31	25	25	24	25	18	18	18
February	21	21	21	21	21	19	21	21	20	20	20	19	20	20	20
March	10	10	10	10	22	22	21	22	22	22	22	22	20	20	20
April	22	22	22	22	20	20	18	18	22	22	22	22	15	15	15
May	23	23	21	20	6	6	5	5	25	25	25	25	15	15	15
June	16	16	11	11	18	18	-	-	24	24	24	24	22	22	22
July	25	25	25	25	24	24	-	-	24	24	24	24	22	22	22
August	25	25	10	10	21	21	-	-	16	16	16	16	18	18	18
Sept.	24	24	17	17	22	22	-	-	24	24	24	24	11	11	11
October	25	25	26	26	19	19	-	-	26	26	26	26	21	21	21
Nov.	25	25	10	10	24	24	8	9	22	22	22	22	19	19	19
Dec.	14	14	-	-	17	17	17	17	23	23	23	23	10	10	10
Total															

	1988			
	T		S	
	0m	35 m	0m	35 m
January	8	8	7	7
February	18	18	18	18
March	19	19	19	19
April	17	17	17	17
May	20	20	20	20
June	22	22	21	21
July	18	18	18	18
August	20	20	20	20
Sept.	21	21	21	21
October	20	20	19	20
Nov.	20	20	20	20
Dec.	21	21	21	21

Table 2-3: Format of a monthly oceanographic data file - Station # 0169 Daily Temperatures and Salinities and Depth

Jan-69					Coordinates Lat: 12 19' S Long:13 34' E			
	temperature (C)				***salinity (psu)***			
date	depht(m) :0	10	20	35	depht(m) :0	10	20	35
1								
2	21.30	19.30	18.70	18.00	35.577	35.546	35.546	35.648
3	21.80	20.80	19.50	18.30	35.546	35.596	35.650	35.681
4	22.20	19.30	18.60	18.03	35.478	35.595	35.626	35.684
5								
6	23.50	19.70	18.95	18.75	35.438	35.621	35.657	35.673
7	23.50	20.10	19.00	18.30	35.450	35.610	35.658	35.678
8	22.30	20.50	19.90	19.00	35.485	35.620	35.657	35.674
9	23.00	20.80	18.75	18.60	35.425	35.601	35.685	35.683
10	24.80	20.60	19.25	18.30	35.160	35.582	35.656	35.684
11	22.40	20.50	19.40	18.00	35.139	35.577	35.678	35.701
12								
13	21.00	20.20	19.50	19.20	35.619	35.655	35.680	35.679
14	22.80	19.70	19.10	18.30	35.595	35.670	35.680	35.680
15	20.20	19.10	18.90	18.00	35.692	35.690	35.690	35.704
16	21.80	20.50	20.00	19.00	35.470	35.590	35.635	35.691
17	21.90	21.00	20.20	19.05	35.627	35.654	35.670	35.683
18	22.40	21.45	20.95	19.20	35.646	35.660	35.666	35.673
19								
20	21.80	19.70	19.50	19.05	35.662	35.711	35.710	35.704
21	22.50	20.00	19.70	19.22	35.661	35.707	35.714	35.732
22	22.70	21.20	20.10	19.90	35.640	35.632	35.685	35.715
23	24.50	22.55	20.75	19.50	35.619	35.653	35.685	35.724
24	25.00	20.95	19.60	19.40	35.633	35.716	35.745	35.747
25	23.00	22.50	21.20	19.10	35.038	35.125	35.350	35.746
26								
27	24.20	21.10	20.50	19.70	35.625	35.705	35.720	
28	22.80	21.20	20.80	19.74	35.376	35.376	35.667	35.710
29	25.30	24.90	24.00	21.80	35.603	35.600	35.615	35.681
30	25.70	25.40	24.75	24.40	35.569	35.565	35.575	35.609
31	26.10	25.40	23.90	22.98	35.531	35.565	35.634	35.671

Average	23.02	21.09	20.21	19.34	35.512	35.601	35.651	35.690
min	20.20	19.10	18.60	18.00	35.038	35.125	35.350	35.609
max	26.10	25.40	24.75	24.40	35.692	35.716	35.745	35.747

Table 2-4: The simplified Knudsen table

d ml	S ‰	d ml	S ‰	d ml	S ‰	d ml	S ‰
1.0	1.89	7.0	12.88	13.0	23.68	19.0	34.33
.1	2.06	.1	13.06	.1	23.86	.1	34.51
.2	2.25	.2	13.24	.2	24.04	.2	34.68
.3	2.43	.3	13.42	.3	24.21	.3	34.86
.4	2.63	.4	13.60	.4	24.39	.4	35.04
.5	2.81	.5	13.79	.5	24.57	.5	35.21
.6	3.00	.6	13.97	.6	24.75	.6	35.39
.7	3.18	.7	14.15	.7	24.93	.7	35.56
.8	3.37	.8	14.34	.8	25.10	.8	35.74
.9	3.55	.9	14.52	.9	25.28	.9	35.91
2.0	3.73	8.0	14.70	14.0	25.46	20.0	36.09
.1	3.91	.1	14.89	.1	25.64	.1	36.27
.2	4.10	.2	15.07	.2	25.82	.2	36.45
.3	4.28	.3	15.25	.3	26.00	.3	36.62
.4	4.47	.4	15.43	.4	26.18	.4	36.80
.5	4.65	.5	15.61	.5	26.36	.5	36.97
.6	4.83	.6	15.79	.6	26.54	.6	37.15
.7	5.02	.7	15.97	.7	26.72	.7	37.32
.8	5.20	.8	16.15	.8	26.89	.8	37.50
.9	5.38	.9	16.33	.9	27.07	.9	37.67
3.0	5.57	9.0	16.51	15.0	27.25	21.0	37.84
.1	5.76	.1	16.69	.1	27.43		
.2	5.94	.2	16.87	.2	27.61		
.3	6.12	.3	17.05	.3	27.79		
.4	6.31	.4	17.23	.4	27.97		
.5	6.49	.5	17.41	.5	28.15		
.6	6.67	.6	17.58	.6	28.32		
.7	6.86	.7	17.76	.7	28.50		
.8	7.04	.8	17.94	.8	28.68		
.9	7.23	.9	18.12	.9	28.86		
4.0	7.41	10.0	18.30	16.0	29.03		
.1	7.59	.1	18.48	.1	29.21		
.2	7.77	.2	18.66	.2	29.38		
.3	7.96	.3	18.84	.3	29.56		
.4	8.14	.4	19.02	.4	29.74		
.5	8.32	.5	19.20	.5	29.92		
.6	8.51	.6	19.38	.6	30.09		
.7	8.69	.7	19.56	.7	30.27		
.8	8.87	.8	19.74	.8	30.45		
.9	9.06	.9	19.92	.9	30.63		
5.0	9.24	11.0	20.10	17.0	30.80		
.1	9.42	.1	20.28	.1	30.98		
.2	9.60	.2	20.46	.2	31.15		
.3	9.78	.3	20.64	.3	31.33		
.4	9.97	.4	20.81	.4	31.50		
.5	10.15	.5	20.99	.5	31.58		
.6	10.33	.6	21.17	.6	31.85		
.7	10.52	.7	21.35	.7	32.03		
.8	10.70	.8	21.53	.8	32.20		
.9	10.88	.9	21.71	.9	32.38		
6.0	11.06	12.0	21.89	18.0	32.56		
.1	11.24	.1	22.07	.1	32.74		
.2	11.42	.2	22.25	.2	32.91		
.3	11.61	.3	22.43	.3	33.09		
.4	11.79	.4	22.61	.4	33.27		
.5	11.97	.5	22.79	.5	33.44		
.6	12.15	.6	22.96	.6	33.62		
.7	12.34	.7	23.14	.7	33.80		
.8	12.52	.8	23.32	.8	33.97		
.9	12.70	.9	23.50	.9	34.15		

$\frac{d}{100}$ ml	$\frac{S ‰}{100}$
0.01	0.02
0.02	0.04
0.03	0.06
0.04	0.07
0.05	0.09
0.06	0.11
0.07	0.13
0.08	0.14
0.09	0.16

f · ½ (volume of $AgNO_3$ added) = d ml

Table 3-2: Maximum and minimum temperature and salinity climatological values and temperature and salinity differences between surface and bottom for two periods, (a) 1969-1974 and (b) 1978-1988

a)

	March	November	August	December
	max1	max2	min1	min2
1969-1974	26.99°C	23.25°C	18.08°C	22.60°C
1978-1988	26.48°C	23.28°C	18.44°C	23.04°C
T (0-35 m)				
1969-1974	4.98°C		1.98°C	
1978-1988	4.73°C		2.25°C	

b)

	May	December	March	November
	max1	max2	min1	min2
1969-1974	*35.698 psu*	*35.630 psu*	34.701 psu	35.287 psu
1978-1988	*35.789 psu*	*35.697 psu*	34.624 psu	35.406 psu
S (0-35 m)				
1969-1974	-0.095 psu		-0.714 psu	
1978-1988	-0.090 psu		-0.962 psu	

Table 3-3: Monthly mean temperature for the periods (a) 1969-1974 and (b) 1978-1988

a)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0m	22.84	25.56	26.99	25.26	23.90	21.35	19.08	18.08	18.77	21.03	23.25	22.60
10m	20.95	24.19	24.82	22.98	22.09	19.88	18.11	16.98	17.41	19.67	21.74	20.67
20m	19.96	23.17	23.54	21.56	20.89	19.13	17.43	16.57	16.88	19.06	21.00	19.67
35m	18.81	21.45	22.02	20.05	19.76	18.31	16.71	16.10	16.35	18.37	19.91	18.47

b)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0m	23.44	26.37	26.48	25.37	24.04	21.12	19.33	18.44	19.55	21.96	23.28	23.04
10m	21.13	24.90	24.65	23.25	21.73	19.54	18.12	17.25	17.96	20.73	21.50	20.91
20m	20.16	23.64	23.30	21.96	20.50	18.67	17.45	16.69	17.74	20.11	20.58	19.79
35m	19.10	21.74	21.66	20.48	19.15	17.69	16.68	16.19	16.93	19.24	19.34	18.52

Table 3-4: Weekly mean salinity values for the periods (a) 1969-1974 and (b) 1978-1978

a)

	week 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0m	35.392	35.374	35.366	35.135	35.252	35.333	35.332	35.232	35.115	34.598	34.632	34.458	34.397	35.124	35.152	35.264
10m	35.589	35.550	35.511	35.386	35.454	35.524	35.459	35.324	35.316	35.000	35.029	34.955	35.296	35.510	35.558	35.539
20m	35.625	35.604	35.554	35.493	35.521	35.568	35.523	35.440	35.432	35.135	35.133	35.196	35.488	35.596	35.618	35.645
35m	35.645	35.645	35.603	35.567	35.560	35.611	35.601	35.548	35.521	35.334	35.347	35.459	35.626	35.629	35.652	35.687
week	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
0m	34.982	35.281	35.405	35.380	35.587	35.572	35.640	35.604	35.660	35.622	35.570	35.558	35.572	35.544	35.551	35.525
10m	35.515	35.572	35.597	35.595	35.681	35.679	35.681	35.676	35.681	35.644	35.606	35.625	35.612	35.604	35.593	35.585
20m	35.633	35.660	35.661	35.685	35.701	35.695	35.695	35.698	35.683	35.644	35.632	35.623	35.610	35.602	35.593	35.580
35m	35.695	35.691	35.696	35.709	35.706	35.687	35.691	35.683	35.653	35.609	35.618	35.602	35.608	35.584	35.576	35.561
week	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
0m	35.472	35.540	35.548	35.552	35.566	35.559	35.536	35.452	35.385	35.201	35.228	35.335	35.299	35.297	35.348	35.370
10m	35.586	35.581	35.591	35.583	35.600	35.619	35.608	35.574	35.535	35.469	35.489	35.509	35.541	35.545	35.556	35.559
20m	35.586	35.583	35.586	35.592	35.612	35.625	35.622	35.622	35.562	35.530	35.560	35.556	35.599	35.593	35.609	35.615
35m	35.570	35.567	35.574	35.584	35.607	35.603	35.623	35.621	35.598	35.561	35.591	35.585	35.615	35.596	35.667	35.642

b)

	week 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0m	35.488	35.570	35.477	35.546	35.257	34.883	34.595	34.825	34.501	34.673	34.938	34.939	34.867	34.924	34.992	35.095
10m	35.654	35.673	35.669	35.611	35.513	35.198	35.009	35.075	35.065	35.085	35.335	35.361	35.369	35.486	35.469	35.486
20m	35.661	35.702	35.703	35.663	35.569	35.420	35.276	35.298	35.327	35.415	35.416	35.539	35.553	35.634	35.576	35.632
35m	35.682	35.725	35.710	35.696	35.644	35.637	35.556	35.534	35.584	35.642	35.601	35.639	35.675	35.720	35.743	35.410
week	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
0m	35.118	35.367	35.489	34.628	35.622	35.721	35.701	35.747	35.718	35.724	35.664	35.668	35.663	35.668	35.619	35.581
10m	35.617	35.670	35.717	35.771	35.766	35.773	35.739	35.769	35.743	35.734	35.696	35.672	35.679	35.703	35.663	35.628
20m	35.783	35.738	35.779	35.775	35.773	35.764	35.734	35.759	35.738	35.712	35.693	35.669	35.664	35.712	35.628	35.644
35m	35.776	35.796	35.790	35.769	35.762	35.741	35.714	35.727	35.697	35.681	35.653	35.630	35.655	35.681	35.625	35.597
week	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
0m	35.607	35.641	35.612	35.630	35.628	35.581	35.539	35.505	35.427	35.461	35.381	35.299	35.343	35.395	35.500	35.426
10m	35.635	35.683	35.632	35.634	35.665	35.608	35.575	35.577	35.537	35.579	35.647	35.635	35.460	35.655	35.614	35.651
20m	35.621	35.685	35.624	35.645	35.644	35.629	35.594	35.587	35.561	35.647	35.691	35.671	35.647	35.683	35.644	35.684
35m	35.559	35.663	35.611	35.642	35.663	35.644	35.616	35.608	35.606	35.707	35.679	35.680	35.690	35.710	35.662	35.692

Table 3-5: Monthly mean salinity values for the periods (a) 1969-1974 and (b) 1978-1988

a)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0m	35.317	35.287	34.701	34.984	35.262	35.601	35.603	35.548	35.528	35.528	35.287	35.328
10m	35.509	35.440	35.069	35.472	35.570	35.679	35.639	35.599	35.585	35.600	35.500	35.550
20m	35.569	35.513	35.217	35.600	35.660	35.697	35.645	35.596	35.587	35.620	35.552	35.604
35m	35.615	35.580	35.415	35.671	35.698	35.692	35.621	35.582	35.573	35.614	35.584	35.630

b)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0m	35.532	34.890	34.624	34.981	35.138	35.700	35.693	35.646	35.630	35.560	35.406	35.416
10m	35.657	35.199	35.151	35.462	35.695	35.761	35.711	35.680	35.654	35.605	35.606	35.601
20m	35.690	35.391	35.410	35.607	35.771	35.756	35.703	35.675	35.651	35.613	35.644	35.669
35m	35.709	35.593	35.617	35.649	35.789	35.734	35.665	35.654	35.628	35.632	35.681	35.697

Table 3-7: Annual amplitudes of the weekly satellite derived SST for the periods 1982-1999

Satellite derived SST (C)			
year	*Max*	*Min*	*Amplitude*
1989	27.59	20.23	7.36
1990	26.96	18.25	8.71
1991	27.87	18.11	9.76
1992	26.97	19.53	7.44
1993	28.20	20.37	7.83
1994	28.07	19.57	8.50
1995	30.97	21.59	9.38
1996	29.74	20.99	8.75
1997	29.23	21.53	7.70
1998	28.64	21.11	7.53
1999	29.96	21.59	8.37

Table 3-6: Annual amplitudes of the weekly temperature and salinity for the periods 1969-1974 and 1978-1988

year	T-0m Max	T-0m Min	T (C) Amplitude	S-0m Max	S-0m Min	S (psu) Amplitude
1969	30.00	16.96	13.04	35.630	32.671	2.959
1970	29.12	17.71	11.41	35.659	33.400	2.259
1971	28.87	16.15	12.72	35.632	33.273	2.359
1972	26.35	17.04	9.31	35.707	35.144	0.563
1973	28.53	17.94	10.59	35.667	33.359	2.308
1974	27.50	16.43	11.07	35.890	34.758	1.132
	T-35m	T-35m	Amplitude	S-35m	S-35m	Amplitude
1969	26.40	15.34	11.06	35.830	35.495	0.335
1970	26.04	15.65	10.39	35.710	34.776	0.934
1971	25.65	15.85	9.80	35.717	35.034	0.683
1972	21.48	14.94	6.54	35.728	35.485	0.243
1973	24.79	15.98	8.81	35.725	35.123	0.602
1974	22.45	15.92	6.53	35.772	35.544	0.228
	T-0m	T-0m	Amplitude	S-0m	S-0m	Amplitude
1978	25.71	17.10	8.61	35.816	34.146	1.670
1979	27.73	17.48	10.25	35.773	34.744	1.029
1980	27.55	17.10	10.45	35.779	34.789	0.990
1981	28.10	17.73	10.37	35.726	33.866	1.860
1982	26.77	17.59	9.18	35.805	35.206	0.599
1983	27.32	16.89	10.43	35.787	35.082	0.705
1984	29.95	20.05	9.90	35.922	31.781	4.141
1985	20.23	17.28	2.95	35.706	33.800	1.906
1986	29.67	17.24	12.43	35.798	32.989	2.809
1987	28.32	18.74	9.58	35.811	34.075	1.736
1988	29.32	18.69	10.63	35.819	32.668	3.151
	T-35m	T-35m	Amplitude	S-35m	S-35m	Amplitude
1978	22.14	15.14	7.00	35.825	35.151	0.674
1979	23.72	15.25	8.47	35.784	35.454	0.330
1980	22.61	15.30	7.31	35.813	35.398	0.415
1981	23.80	15.86	7.94	35.738	35.162	0.576
1982	21.87	15.70	6.17	35.876	35.448	0.428
1983	23.12	14.96	8.16	35.811	35.581	0.230
1984	25.86	17.10	8.76	36.194	35.233	0.961
1985	24.94	15.77	9.17	36.080	35.274	0.806
1986	25.81	14.93	10.88	35.902	34.880	1.022
1987	22.18	15.97	6.21	35.845	35.457	0.388
1988	26.15	16.74	9.41	35.895	33.346	2.549

Table 3-8: Weekly in situ SST, SSS and satellite derived SST extreme records

Parameter	year	month	week	weekly SSS (psu)	sea water condition
SSS	**1969**	**April**	**1st**	**32.671**	**extremely fresh**
SSS	1970	March	2nd	33.400	fresh
SSS	1970	March	3rd	33.762	fresh
SSS	1970	March	4th	33.448	fresh
SSS	1971	March	2nd	33.602	fresh
SSS	1971	March	3rd	33.466	fresh
SSS	1971	March	4th	33.273	fresh
SSS	1973	January	4th	33.359	fresh
SSS	1974	February	3rd	35.806	salty
SSS	1974	February	4th	35.890	salty
SSS	1978	July	2nd	35.816	salty
SSS	1981	February	3rd	33.866	fresh
SSS	1982	July	2nd	35.805	salty
SSS	1984	January	1st	35.844	salty
SSS	1984	February	2nd	33.127	fresh
SSS	1984	February	3rd	33.226	fresh
SSS	**1984**	**February**	**4th**	**32.532**	**extremely fresh**
SSS	**1984**	**March**	**1st**	**31.781**	**extremely fresh**
SSS	**1984**	**March**	**2nd**	**31.970**	**extremely fresh**
SSS	1984	June	3rd	35.800	salty
SSS	1984	August	2nd	35.879	salty
SSS	1984	Sept.	1st	35.878	salty
SSS	**1984**	**Sept.**	**2nd**	**35.922**	**extremely salty**
SSS	1984	Sept.	4th	35.812	salty
SSS	1984	October	1st	35.869	salty
SSS	1984	October	3rd	35.845	salty
SSS	1984	October	4th	35.809	salty
SSS	1985	April	3rd	33.991	fresh
SSS	1985	April	4th	33.800	fresh
SSS	1986	February	3rd	33.042	fresh
SSS	1986	March	1st	33.363	fresh
SSS	**1986**	**March**	**2nd**	**32.983**	**extremely fresh**
SSS	1986	March	3rd	33.038	fresh
SSS	1986	March	4th	33.122	fresh
SSS	1986	April	1st	33.235	fresh
SSS	1986	April	2nd	33.418	fresh
SSS	1987	October	3rd	35.811	salty
SSS	**1988**	**February**	**3rd**	**32.668**	**extremely fresh**
SSS	1988	March	1st	33.253	fresh
SSS	1988	October	3rd	35.819	salty
Parameter	**year**	**month**	**week**	**weekly SST (C)**	**condition**
SST	**1969**	**February**	**4th**	**29.85**	**extremely warm**
SST	**1969**	**March**	**1st**	**29.00**	**extremely warm**
SST	1969	March	2nd	28.66	warm
SST	1969	March	3rd	28.95	warm
SST	**1969**	**March**	**4th**	**30.00**	**extremely warm**
SST	**1969**	**April**	**1st**	**29.32**	**extremely warm**
SST	1969	**August**	**1st**	**17.00**	**extremely cool**
SST	1969	**August**	**2nd**	**16.96**	**extremely cool**
SST	**1970**	**March**	**3rd**	**29.01**	**extremely warm**

Table 3-8: continuation

Parameter	year	month	week	weekly SST (C)	sea water condition
SST	1970	March	4th	29.12	extremely warm
SST	1971	March	2nd	28.87	warm
SST	1971	March	3rd	28.76	warm
SST	1971	March	4th	28.28	warm
SST	1971	Dec.	1st	16.53	extremely cool
SST	1971	Dec.	2nd	16.15	extremely cool
SST	1971	Dec.	3rd	16.45	extremely cool
SST	1973	January	4th	28.40	warm
SST	1973	February	1st	28.53	warm
SST	1974	Dec.	2nd	16.43	extremely cool
SST	1981	February	3rd	28.00	warm
SST	1983	August	3rd	16.89	extremely cool
SST	1984	February	1st	28.40	warm
SST	1984	February	2nd	29.47	extremely warm
SST	1984	February	4th	29.23	extremely warm
SST	1984	March	1st	29.68	extremely warm
SST	1984	March	2nd	29.95	extremely warm
SST	1984	April	1st	28.32	warm
SST	1986	February	2nd	28.94	warm
SST	1986	February	3rd	29.42	extremely warm
SST	1986	February	4th	29.24	extremely warm
SST	1986	March	1st	28.90	warm
SST	1986	March	2nd	29.63	extremely warm
SST	1986	March	3rd	29.67	extremely warm
SST	1986	March	4th	28.89	warm
SST	1986	April	1th	28.49	warm
SST	1986	April	2nd	29.02	extremely warm
SST	1988	February	2nd	28.89	warm
SST	1988	February	3rd	29.32	extremely warm
SST	1988	March	4th	28.36	warm
Sat. der. SST	year	month	week	weekly sat SST (C)	sea water condition
Sat. der. SST	1995	February	1st	28.49	warm
Sat. der. SST	1995	February	2nd	29.53	extremely warm
Sat. der. SST	1995	February	3rd	30.44	extremely warm
Sat. der. SST	1995	March	1st	29.44	extremely warm
Sat. der. SST	1995	March	2nd	30.15	extremely warm
Sat. der. SST	1995	March	3rd	29.29	extremely warm
Sat. der. SST	1995	April	2nd	30.97	extremely warm
Sat. der. SST	1995	April	3rd	30.14	extremely warm
Sat. der. SST	1996	February	4th	29.06	extremely warm
Sat. der. SST	1996	March	1st	28.75	warm
Sat. der. SST	1996	March	2nd	29.73	extremely warm
Sat. der. SST	1996	March	3rd	28.57	warm
Sat. der. SST	1996	March	4th	28.98	warm
Sat. der. SST	1996	April	1st	29.24	extremely warm
Sat. der. SST	1996	April	3rd	28.88	warm
Sat. der. SST	1996	April	4th	29.74	extremely warm
Sat. der. SST	1996	May	1st	28.53	warm
Sat. der. SST	1997	Dec.	4th	29.23	extremely warm
Sat. der. SST	1998	January	1st	28.34	warm

Table 3-8: continuation

Parameter	year	month	week	weekly sat SST (C)	sea water condition
Sat. der. SST	1998	January	4th	28.43	warm
Sat. der. SST	1998	March	2nd	28.31	warm
Sat. der. SST	1998	April	3rd	28.64	warm
Sat. der. SST	1998	March	3rd	28.59	warm
Sat. der. SST	1999	March	1st	28.79	warm
Sat. der. SST	1999	**April**	**1st**	**29.36**	**extremely warm**
Sat. der. SST	1999	**April**	**2nd**	**29.96**	**extremely warm**
Sat. der. SST	**1999**	**April**	**4th**	**29.11**	**extremely warm**
Sat. der. SST	1999	May	1st	28.84	warm
Sat. der. SST	1999	May	2nd	28.76	warm

Table 3-9: Weekly and monthly temperature, salinity and u, v (wind) components standard deviation values.

1. Weekly *in situ* temperature for the periods (a) 1969-74 and (b) 1978-1988
2. Weekly *in situ* salinity for the periods (c)1969-74 and (d) 1978-1988
3. Monthly *in situ* temperature for the periods (e) 1969-74 and (f)1978-1988
4. Monthly *in situ* salinity for the periods (g) 1969-74 and (h)1978-1988
5. Weekly satellite derived SST for the period 1982-1999.
6. Monthly satellite derived SST for the period 1982-1999.
7. u (wind) component for the period 1967-1998.
8. v (wind) component for the period 1967-1998.

3-9.1 a)

	week 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0m	0.71	1.76	1.68	2.87	2.6	1.85	1.79	1.59	1.98	1.85	1.8	2.49	2.84	1.45	1.26	1.38
10m	1.19	1.92	2.29	3.37	2.97	1.89	1.93	1.83	2.1	2.23	2.24	2.54	2.28	0.54	1.32	1.7
20m	1.12	1.83	2.24	3.49	3.02	1.99	1.74	1.92	2.33	2.36	2.6	2.06	1.65	0.38	1.37	1.2
35m	1.09	1.23	1.91	2.98	2.9	2.25	1.41	1.88	2.68	1.94	2.38	1.55	0.67	0.62	1.08	0.89
week	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
0m	1.18	1.7	1.2	1.28	1.11	1.01	1.15	0.84	1.35	0.92	0.89	0.73	0.88	0.93	0.56	0.54
10m	1.12	1.63	1.41	1.14	0.91	0.74	0.8	0.6	1.33	0.61	0.87	0.86	0.82	0.85	0.59	0.62
20m	0.77	1.52	1.53	1	1.02	0.55	0.8	0.41	1.06	0.48	0.94	0.83	0.65	0.8	0.52	0.61
35m	0.79	1.46	1.47	0.95	0.92	0.39	0.71	0.35	0.81	0.29	0.69	0.64	0.43	0.71	0.37	0.51
week	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
0m	0.62	0.89	0.7	1.7	1.74	1.7	1.91	1.2	0.89	1.23	1.38	1.88	2.63	2.95	2.84	2.39
10m	0.68	0.89	0.93	1.38	1.99	1.93	2.16	1.28	1.04	1.42	1.54	1.89	2.49	3.29	2.51	1.72
20m	0.73	0.75	1.03	1.22	1.91	1.88	2.14	1.39	1.06	1.38	1.54	1.9	2.45	2.99	2.01	1.44
35m	0.50	0.6	0.91	1.17	1.69	1.79	1.91	1.18	1.01	1.54	1.7	2.02	1.86	2.31	1.51	1.32

b)

	week 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0m	1.19	1.79	2.02	1.92	2.07	2.32	1.79	1.44	1.97	2.11	1.81	2.14	2.23	2.45	2.53	2.38
10m	1.53	1.99	2.36	2.42	2.56	3.02	2.51	1.72	2.28	2.24	2.14	2.15	2.13	2.48	2.29	2.22
20m	1.30	1.74	2.04	2.34	2.91	2.88	2.55	1.61	1.96	2.3	2.13	1.7	1.77	1.92	2.22	1.89
35m	0.99	1.46	1.68	2.3	2.42	2.33	2.19	1.53	2.02	1.69	2.17	1.22	1.44	1.36	1.8	1.55
week	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
0m	2.82	2.55	2.06	2.1	2.24	1.9	2.11	1.65	1.56	1.17	1.1	0.93	1.03	1.02	1.22	1.39
10m	2.40	2.06	1.84	1.71	1.84	1.44	1.91	1.3	1.38	1.04	1.06	0.77	0.99	0.84	1.03	1.28
20m	1.91	1.86	1.74	1.47	1.64	1.08	1.1	1.09	1.02	0.89	0.91	0.74	0.8	0.77	0.98	1.08
35m	1.26	1.28	1.27	1.02	1.39	0.91	0.85	0.8	0.88	0.77	0.82	0.66	0.59	0.88	0.77	0.63
week	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
0m	1.00	1.1	1.64	1.76	1.91	1.53	1.52	1.72	1.53	1.23	1.32	1.46	1.3	1.33	0.9	0.97
10m	1.32	1.15	1.9	1.98	2.04	1.85	1.84	1.84	1.17	1.11	1.25	1.24	1.2	1.39	0.99	1.21
20m	1.14	0.96		1.94	2.05	2.08	1.86	1.8	1.05	0.92	1.05	0.95	0.94	1.2	0.98	1.17
35m	0.88	0.76	1.69	1.71	1.77	2.03	1.6	1.55	1	0.74	0.64	0.64	0.78	0.83	0.91	1.07

Table 3-9.2: continuation

c)

	week 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0m	0.2684	0.2153	0.4158	0.8875	0.598	0.5031	0.466	0.4885	0.4797	1.045	0.962	1.0144	1.1885	0.2096	0.2989	0.1876
10m	0.0793	0.1337	0.2845	0.5	0.3352	0.2288	0.2397	0.374	0.2765	0.6913	0.6917	0.8141	0.3569	0.1122	0.0711	0.0893
20m	0.0509	0.0842	0.2492	0.3404	0.2431	0.1941	0.1743	0.2048	0.2544	0.5332	0.6842	0.5298	0.2035	0.0672	0.0524	0.0314
35m	0.0305	0.0357	0.1517	0.2234	0.1944	0.1504	0.0997	0.1183	0.1983	0.3492	0.416	0.2439	0.0499	0.0432	0.0399	0.0586
week	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
0m	0.450	0.255	0.132	0.139	1.109	1.014	1.154	0.845	0.066	0.112	0.167	0.133	0.434	0.712	0.372	0.510
10m	0.109	0.131	0.094	0.067	0.910	0.743	0.796	0.602	0.049	0.082	0.121	0.056	0.434	0.712	0.372	0.510
20m	0.072	0.080	0.072	0.061	1.023	0.552	0.798	0.407	0.050	0.062	0.057	0.055	0.434	0.712	0.372	0.510
35m	0.090	0.062	0.053	0.054	0.924	0.390	0.710	0.346	0.043	0.047	0.053	0.052	0.434	0.712	0.372	0.510
week	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
0m	0.17	0.067	0.0719	0.0575	0.0692	0.0677	0.0918	0.1134	0.083	0.3107	0.2597	0.2391	0.3096	0.2242	0.219	0.1832
10m	0.0451	0.0479	0.0372	0.029	0.0448	0.0404	0.0426	0.06	0.0753	0.1322	0.1484	0.1239	0.0937	0.1186	0.1138	0.0845
20m	0.042	0.0435	0.0349	0.0314	0.0422	0.0409	0.0333	0.0254	0.0582	0.0821	0.0955	0.1113	0.0514	0.0819	0.0604	0.0555
35m	0.0403	0.0408	0.0326	0.0373	0.0419	0.0542	0.0371	0.0234	0.038	0.0736	0.0803	0.0744	0.0615	0.058	0.0395	0.0309

d)

	week 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0m	0.1491	0.1316	0.1557	0.0909	0.3615	0.8045	1.1527	0.9337	1.1815	1.1419	0.7203	0.7574	0.6832	0.7204	0.5785	0.627
10m	0.1015	0.0993	0.1173	0.1273	0.2798	0.6284	0.8211	0.7171	0.5633	0.7506	0.6936	0.4107	0.3832	0.3033	0.3929	0.3943
20m	0.1069	0.0841	0.135	0.1015	0.252	0.344	0.6002	0.4095	0.4816	0.3756	0.48	0.259	0.2492	0.1721	0.2874	0.2498
35m	0.0875	0.1095	0.0912	0.0858	0.1882	0.1631	0.2403	0.241	0.1958	0.1357	0.2674	0.1901	0.1397	0.1222	0.0845	0.791
week	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
0m	0.5445	0.2813	0.2339		0.0899	0.0438	0.0793	0.0356	0.0503	0.0636	0.0869	0.0758	0.0579	0.0984	0.0937	0.0696
10m	0.2604	0.1474	0.0771	0.0655	0.0387	0.0454	0.0666	0.0554	0.0667	0.0532	0.0851	0.0675	0.0762	0.0986	0.0933	0.0836
20m	0.103	0.1155	0.0544	0.0536	0.0512	0.044	0.0499	0.0498	0.0805	0.0668	0.0871	0.0763	0.0966	0.1253	0.0971	0.1002
35m	0.095	0.1159	0.0766	0.0541	0.0701	0.052	0.0535	0.047	0.0587	0.0782	0.0881	0.0853	0.0979	0.1003	0.0783	0.0848
week	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
0m	0.1407	0.1322	0.0865	0.1014	0.1373	0.1808	0.4206	0.3759	0.3316	0.287	0.3027	0.3298	0.3982	0.4724	0.1031	0.1882
10m	0.1007	0.1446	0.0896	0.1037	0.1415	0.1785	0.3773	0.2523	0.2029	0.1782	0.1666	0.1397	0.6325	0.1215	0.1296	0.0803
20m	0.1065	0.1667	0.094	0.1011	0.1281	0.1846	0.3247	0.2078	0.2408	0.2328	0.1608	0.1379	0.089	0.0994	0.1373	0.0776
35m	0.1937	0.1744	0.0879	0.1152	0.1319	0.1733	0.1985	0.1602	0.1765	0.2374	0.121	0.113	0.1039	0.0788	0.1052	0.0527

Table 3-9: continuation

3 e)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0m	1.68	1.79	1.89	1.57	0.98	0.93	0.92	0.59	0.84	1.55	1.03	2.60
10m	2.13	1.85	2.05	1.51	1.04	0.68	0.83	0.65	0.79	1.63	1.17	2.40
20m	2.10	1.91	2.08	0.99	1.11	0.65	0.74	0.59	0.72	1.61	1.12	2.16
35m	1.73	1.87	1.77	0.70	1.09	0.52	0.54	0.44	0.66	1.47	1.15	1.70

f)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0m	1.54	1.77	1.91	2.16	2.13	1.76	1.10	1.06	1.28	1.51	1.22	1.06
10m	1.61	2.27	2.15	2.06	1.86	1.49	0.95	0.93	1.49	1.74	0.99	1.11
20m	1.51	2.21	1.84	1.75	1.64	1.11	0.76	0.85	1.66	1.79	0.83	0.95
35m	1.29	1.75	1.75	1.32	1.14	0.89	0.66	0.59	1.15	1.61	0.59	0.77

4.g)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0m	0.417	0.486	0.86	0.464	0.229	0.092	0.117	0.076	0.08	0.07	0.2	0.213
10m	0.235	0.263	0.608	0.124	0.086	0.044	0.073	0.042	0.04	0.04	0.105	0.095
20m	0.175	0.19	0.47	0.078	0.069	0.033	0.053	0.041	0.04	0.03	0.072	0.058
35m	0.102	0.132	0.279	0.071	0.063	0.028	0.047	0.038	0.03	0.03	0.056	0.038

h)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0m	0.092	0.74	1.126	0.538	0.683	0.03	0.05	0.085	0.11	0.26	0.285	0.253
10m	0.09	0.577	0.631	0.291	0.11	0.038	0.054	0.094	0.11	0.22	0.129	0.195
20m	0.093	0.355	0.386	0.199	0.067	0.043	0.064	0.104	0.12	0.19	0.155	0.085
35m	0.079	0.179	0.186	0.183	0.072	0.051	0.066	0.103	0.14	0.15	0.153	0.079

Table 3-9: continuation

9.5

week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
sd	1.33	1.16	1.31	1.4	1.19	1.27	1.59	1.06	1.11	1.46	1.23	1.28	1.41	1.58	1.84	1.66
week	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
sd	1.625	1.54	1.53	1.68	1.82	1.82	1.89	1.64	1.64	1.56	1.28	0.98	1.22	1.21	1.45	1.2
week	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
sd	1.261	1.29	1.26	1.38	1.22	1.06	1.38	1.33	1.31	1.25	1.35	1.1	1.15	1.17	1.62	1.47

9.6

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1.08	1.08	1.05	1.33	1.48	1.72	1.23	1.23	1.08	1.14	1.16	1.14

9.7

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
sd u	0.54	0.66	0.78	0.61	0.62	0.61	0.64	0.71	0.56	0.50	0.65	0.60
sd v	0.54	0.64	0.52	0.41	0.56	0.54	0.49	0.66	0.66	0.50	0.56	0.60

9.8

	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
sd u	0.75	0.84	0.63	0.89	1.23	1.22	1.09	1.08	1.27	1.37	1.12	1.07	1.04	1.17	0.99	0.70
sd v	0.90	1.08	0.77	0.86	1.16	0.94	0.67	0.95	0.88	0.92	0.95	0.80	0.77	0.87	0.74	0.96
	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
sd u	0.87	0.89	0.75	0.73	0.79	0.81	1.11	1.29	1.23	0.72	0.99	0.94	0.8	0.63	0.85	0.78
sd v	0.68	0.71	0.69	0.68	0.86	0.84	0.58	0.75	0.76	0.79	0.97	0.86	0.9	0.7	0.72	0.46

Table 3-10: Index of stratification values over 1970

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	4.37	5.00	2.40	7.40	3.86	2.60	1.62	1.92	1.88	2.62	3.40	3.91
2	4.62	4.55	4.55	6.25	3.14	1.58	2.10	1.70	1.58	1.80	3.10	4.68
3	4.57	3.42	3.42	6.14	3.00	3.62	1.19	1.26	1.78	2.57	2.55	5.52
4	3.40	2.82	2.82	5.81	3.72	3.98	0.69	2.02	2.45	2.75	3.35	4.88
5	3.00	4.16	4.16	5.60	4.28	4.00	0.65	1.85	2.34	3.00	3.50	5.42
6	4.60	2.97	2.97	5.85	4.48	4.08	0.73	1.63	2.40	3.64	2.74	5.40
7	2.40	3.63	3.63	6.51	4.18	4.08	0.90	1.13	2.17	4.06	1.98	5.40
8	2.53	2.45	6.10	7.75	3.16	4.44	2.52	2.39	3.00	4.40	1.28	5.80
9	4.30	2.20	2.20	7.30	3.84	5.40	2.73	2.30	2.60	2.80	0.80	4.64
10	2.66	2.80	2.80	5.18	4.00	4.41	4.25	2.20	1.71	3.76	1.00	6.22
11	4.10	4.20	4.20	5.92	3.66	4.71	3.15	2.15	2.30	4.18	1.32	5.50
12	4.50	3.73	3.73	4.90	2.78	4.93	3.20	1.50	1.74	1.35	1.85	6.70
13	5.64	3.10	3.10	4.34	2.68	5.18	3.19	1.65	1.80	2.40	2.10	6.50
14	5.28	2.92	2.92	4.20	3.68	4.70	2.85	2.05	1.69	3.00	2.68	5.48
15	5.39	4.10	1.80	1.98	2.34	2.21	1.40	2.40	2.24	4.30	2.40	4.92
16	3.63	4.29	4.29	4.14	3.76	2.57	1.32	3.00	1.48	2.85	2.22	4.24
17	3.48	3.94	3.94	3.52	3.70	2.12	1.77	2.35	1.87	1.30	1.78	3.42
18	3.10	5.21	5.21	3.17	3.49	3.53	0.97	1.80	1.00	1.80	2.00	5.00
19	3.64	3.91	3.91	3.90	4.18	2.33	1.10	1.74	1.90	2.92	2.77	4.74
20	4.65	4.13	4.13	3.01	4.20	1.68	1.45	2.10	1.80	2.82	2.93	4.80
21	3.39	1.62	1.62	4.48	3.52	1.80	1.60	2.54	0.70	3.40	3.00	4.74
22	2.48	2.10	4.40	4.20	3.30	2.08	1.77	1.92	1.96	3.45	1.90	4.31
23	4.34	2.43	2.43	5.70	4.22	2.84	1.97	2.20	1.81	3.25	1.57	4.38
24	1.94	4.27	4.27	4.17	4.20	3.07	2.20	2.69	3.10	3.35	3.22	4.15
25	3.00	5.84	5.84	5.12	3.69	3.15	2.30	2.87	1.98	2.75	2.57	4.00
26	3.95	3.42	3.42	4.40	4.12	4.15	2.40	2.46	1.60	1.47	3.53	3.08
27	3.72	4.19	4.19	4.02	3.84	3.50	2.40	3.25	1.90	2.29	4.55	3.50
28	3.07	3.30	3.30	3.27	2.10	3.08	2.55	1.80	2.00	2.28	4.30	3.12
29	4.74		7.10	5.60	2.00	2.33	1.70	3.35	2.20	2.10	4.80	4.89
30	3.58		7.50	2.05	2.48	2.40	1.63	3.40	2.40	2.42	5.03	5.37
31	4.90		7.80		3.00		1.92	2.16		2.86		4.71

Table 3-11: Salinity index values over 1970

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	-1.195	-0.200	-0.530	-1.828	-0.230	-0.030	0.024	-0.152	-0.368	-0.060	-0.650	-0.379
2	-0.289	-0.417	-0.528	-1.833	-0.132	0.003	0.030	-0.070	-0.021	-0.045	-0.566	-0.207
3	-0.817	-0.737	-1.810	-1.707	-0.180	-0.043	0.011	-0.033	-0.054	-0.022	-0.371	-0.371
4	-0.680	-0.272	-0.658	-1.348	-0.150	0.006	0.006	-0.155	-0.101	-0.110	-0.572	-0.510
5	-0.305	-0.679	-1.149	-1.200	-0.297	-0.086	0.098	-0.196	-0.065	-0.224	-0.169	-0.332
6	-0.575	-0.441	-0.958	-1.230	-0.300	-0.156	-0.007	-0.091	-0.130	-0.247	-0.147	-0.390
7	-0.327	-0.296	-0.995	-1.284	-0.254	-0.210	-0.035	-0.090	-0.202	-0.166	-0.157	-0.453
8	-0.705	-0.100	-0.120	-1.084	-0.168	-0.475	-0.051	-0.093	-0.305	-0.110	-0.050	-0.188
9	-0.304	-0.116	-0.150	-1.306	-1.185	-0.430	-0.101	-0.100	-0.210	-0.101	-0.033	-0.117
10	-0.672	-0.704	-1.346	-0.782	-0.800	-0.569	0.010	-0.087	-0.116	-0.082	-0.096	-0.123
11	-0.510	-0.739	-1.210	-0.981	-0.232	-0.871	0.003	-0.264	-0.081	-0.170	-0.080	-0.297
12	-0.268	-0.159	-2.467	-1.159	-0.325	-0.288	-0.050	-0.054	-0.007	-0.244	-0.284	-0.230
13	-0.634	-0.426	-1.806	-1.147	-0.369	-0.212	-0.123	-0.018	0.000	-0.215	-0.475	-0.280
14	-0.312	-0.228	-1.384	-0.417	-0.113	-0.180	0.080	-0.186	0.004	-0.300	-0.407	-0.293
15	-0.310	-0.120	-1.000	-0.275	-0.092	-0.100	0.044	-0.140	-0.039	-0.385	-0.310	-0.298
16	-0.246	-0.203	-0.427	-0.394	-0.280	-0.302	0.042	-0.075	-0.018	-0.470	-0.270	-0.313
17	-0.200	-0.735	-0.749	-0.347	-0.235	-0.102	0.034	-0.017	-0.039	0.005	-0.273	-0.819
18	-0.380	-0.259	-1.438	-0.318	-0.245	-0.110	-0.032	-0.104	-0.010	-0.110	-0.932	-0.381
19	-0.576	-0.200	-0.999	-0.248	-0.140	-0.076	-0.050	-0.278	-0.030	-0.254	-0.465	-0.650
20	-0.931	-1.033	-1.148	-0.256	-0.286	-0.133	-0.052	-0.041	-0.010	-0.444	-0.535	-0.680
21	-0.958	-0.093	-1.376	-0.341	-0.105	-0.190	-0.103	-0.093	-0.005	-0.108	-0.225	-0.683
22	-0.348	-0.100	-1.250	-0.471	-0.144	-0.128	-0.216	-0.061	-0.091	-0.260	-0.400	-0.306
23	-0.665	-0.258	-0.966	-0.410	-0.142	-0.249	-0.082	-0.075	-0.033	-0.225	-0.457	-0.327
24	-0.193	-0.688	-1.357	-0.938	-0.580	-0.751	-0.064	-0.024	-0.040	-0.316	-0.269	-0.241
25	-0.240	-1.636	-1.725	-0.490	-0.964	-0.307	-0.008	-0.020	-0.420	-0.220	-0.325	-0.280
26	-0.348	-0.435	-1.973	-0.400	-0.304	-0.191	-0.075	-0.021	-0.277	-0.090	-0.199	-0.197
27	-0.234	-1.048	-1.903	-0.402	-0.169	-0.398	-0.174	-0.076	-0.215	-0.059	-0.222	-0.360
28	-0.278	-1.015	-1.750	-0.353	-0.252	-0.350	-0.013	0.021	-0.155	-0.056	-0.106	-0.376
29	-0.218		-1.746	-0.366	-0.070	-0.165	-0.035	-0.379	-0.015	-0.744	-0.250	-0.387
30	-0.231		-1.748	-0.120	-0.060	0.122	-0.274	-0.213	-0.089	-0.249	-0.103	-0.238
31	-0.883		-1.790		-0.150		-0.059	-0.024		-0.747		-0.218

Declaration

I hereby declare that unless otherwise stated this thesis represent my own work, both in concept and execution. Local team at Lobito carried out the data collection and on three occasions I have flown to Lobito from Luanda to introduce data from the original archives into my Laptop. The SST satellite derived data are from the Envifish project in which Angola is a member.

I carried out all computations and drew all figures for the analysis.

In all respects I lay claim to uncited ideas, concepts, hypotheses or conclusions contained in this thesis.

Name: Quilanda Fidel   Date: 16 August 2001