NANCEP 1995

Nansen Courses in Environmental Physics

Alte Brücke, Swakopmund Namibia, November 15 - December 13 1995

Editor

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I M R

Institute of Marine Research
Division for Fisheries Development Research
NANSEN PROGRAMME

1996

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List of Participants

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Sylvia Dorothea Elizabeth Andreas	" "	Namibia
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NatMIRC	National Marine Information and Research Center P.O. box 912, Swakopmund, 9000 Namibia
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PREFACE

Within the The Nansen Programme[1] oceanographic environmental data have been collected in Mozambican, Namibian and Angolan waters over the last decade or so. Realising that important oceanographic processes are controlled by the atmosphere, and that teaching in environmental physics is literally absent in many of the countries in the region, we found it useful to set up a course in environmental physics in the area, with participants from various institutions like Fishery Research Institutes, Universities, Meteorological and Hydrological Institutes and so on. This gave us the opportunity to study various environmental parameters from the area simultaneously, their interactions and relative importance.

Among the basic long term goals are a better understanding of the environmental influence on the variability of the fish stocks in the area, the impact of the global warming, and the roles of the bays near the largest cities as waste recipients. The studies reported here will in most cases be followed up by more profound investigations.

Bergen April 1996 T.G.

[1]The Nansen programme is supported by the Norwegian Agency for Development Cooperation (NORAD), The Food and Agriculture Organization of the United Nations (FAO), and the United Nations Development Programme (UNDP)

INTRODUCTION

The first NANCEP course took place in Namibia for a 4 week period in November-December 1995, with participants from Angola; Mozambique and Namibia (see participant list Table I) The objectives of the course were several:

Actualize Universities in the region in environmental teaching and research
Stimulate environmental research at the fishery research institutions
Acquire and work up historical data
Give the particpants a platform for understanding environmental dynamics
Stimulate institutional cooperation within each country
Initiate regional and international cooperation

CONTENTS OF THE COURSE

The course was divided in 3 parts, lectures, exercises, and an individual research topic for each fellow.

a. Lectures

As a basis for the lectures we used the book "Introductory Dynamical Oceanography" by Pond and Pickard. Time did only allow to discuss the first 9 chapters. The lectures were dominated by the mathematical developments of the theories, which only are briefly mentioned in the book.

The following topics were lectured: Density of ocean water, Classifications of forces and motions, The continuity equation, Static stability, The eqution of motion, Reynolds stresses and eddy viscosity, Inertial motion, Geostrophic equation, Wind driven Circulation (Ekman and Sverdrup theories), Westward intensification, Vorticity, Stommels inertial theory for the Gulf Stream.

b. Excercises

The exercises distributed during the course are given in Appendix 1. As may be seen they do mainly deal with applying the mathematical theories on various processes in the ocean.

c. Fellows' Reports

All the participants got a data set during the first week of the course to work up, analyse and report. This resulted in many long nights work and busy weekends. The fellows' contributions are given here, and constitutes the main bulk of this report. As may be seen several institutions have contributed with data in addition to those represented by the participants, especially meteorological and hydrological institutions.

The fellows contributions should be considered as a progress report, and thus not be cited without prior reference to the author. In many cases these preliminary reports will be follwed up by the authors, and hopefully some of them may end up as publishable papers.

It should be mentioned that reference lists given in the reports are incomplete in most cases.

THE VOLUME Of THE COURSE

It may be of interest for universities and research institutions where the fellows are potential applicants to know how much credit should be given to this course.

Totally 40 hours lectures were given. Tutored exercises was about 20 hours. In addition comes the work with the research topics. Using the standard from the University of Bergen, Norway, this will be equivalent to about 3 to 4 credits. (A full University year study is 20 credits).

VARIOUS APPLICATIONS OF THE COURSE

For the participants there where a variety of motives to attend the course. For some it was directly related to a formal university course, and at least one will have to pass an examination as a part of a Master degree. A few of the participants are already teaching at a University level. For them a major motivation was to use the NANCEP as a basis for their own teaching in environmental physics. Some of the participants have permanent positions at fishery research institutions, where they are involved in environmental research, without the adequate educational level. For them this course was an introduction or brush-up of their knowledge in the field, training in research and scientific reporting, and may also be used in the future in a formal educational setup.

ACKNOWLEDGEMENTS

The following institutions contributed to the NANCEP-95 through manpower, data, specially adjusted computer-programs or equipment:

University of Namibia, Windhoek, Namibia
Universidade Eduardo Mondlane, Maputo, Mozamique
Universidade Augostinho Neto, Luanda, Angola
University of Bergen, Norway
Instituto Investigação Pesqueira, Maputo, Mozamique
Instituto Investigação Pesqueira, Luanda, Angola
National Marine Information and Research Center (NatMIRC) Swakopmund, Namibia
Institue of Marine Research, Bergen, Norway
Inamet (The National Meteorological Institute), Luanda, Angola
Department of Water Affairs, Division Hydrology, Windhoek, Namibia
Weather Service, Windhoek, Namiba
National Institute of Meteorolgy (INAM), Maputo, Mozambique

We are greatful to NatMIRC which helped us with computer and copying fascilities, as well as access to the library. They also invited the fellows to give their oral presentations in their beautiful new auditorium, which gave the students a valuable experience in giving a talk to a representative, international audience.

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NANSEN COURSE IN ENVIRONMENTAL PHYSICS
Swakopmund, Namibia, 14 Nov - 15 Dec 1995

SEASONAL, YEAR-TO-YEAR AND LONG TERM TRENDS IN NAMIBIAN WATERS

By

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Abstract

A 17-year time series of temperature, salinity and dissolved oxygen measurements from three defined blocks off Central Namibia (23°00'S) has been analysed for seasonal, annual and longterm variability. Temperature and salinity anomalies clearly identify 1984 and 1995 as anomalous periods.

INTRODUCTION

The Namibian coastline stretches from the Cunene River at 17°15'S in the north to the Orange River at 28°40'S in the south with a total distance of around 1400km (Boyd, 1987). The Benguela current, Namibia's western boundary together with the west coast currents of Peru, California, and North West Africa are the four main eastern boundary current regions. Although the oceanography of all four is dominated by upwelling, the Benguela, unlike the others, is bounded in both the north and the south by warm water regimes (Shannon and Nelson, 1995). These coastal upwelling regions are amongst the richest fishing grounds in the world.

The Benguela current flows northerly following the coast between 34°S and 23°S, while north of latitude 23°S it tends to move away from the coast. The current consists of the cool upwelled water found within 150km of the west coast between latitude 15°S and 34°S (Shannon 1970). The main upwelling period in northern Namibia extends from about March to November, with a peak around August and September (Shannon, 1985).

DATA, MATERIALS AND METHODS

Data

The oceanographic data being used in this study covers a time scale of 18 years, from June 1978 to March 1995, and was collected on 140 cruises. Much of the oceanographic data was collected in the pre-independence period by the South African Sea Fisheries Research Institute. Data collection took place on a routine monthly basis covering a fixed station grid on the central Namibian shelf region (fig. 1), consisting of 3 sections each having a maximum of 9 stations, spaced at intervals of 2 nautical miles (nm), 5nm, 10nm, 15nm, 25nm, 35nm, 45nm, 55nm and 65nm from the coast.

Temperature, salinity and dissolved oxygen measurements were recorded from water samples collected at standard depths using Nansen-Petersen water bottles.

Between January 1990 and March 1995 CTD data was collected on 28 scientific cruises conducted by the Namibian Ministry of Fisheries and Marine Resources, the Dr. Fridtjof Nansen Programme and the Japanese O.F.C.F. Programme. These cruises took place onboard the research vessels Benguela, Welwitschia, Dr. Fridtjof Nansen and the Matsuyama Maru.

Various instruments were used for the data collection. A Niel Brown conductivity temperature and depth profiler (CTD) was used onboard the Namibian research vessels, this CTD was replaced with a Seabird SBE19 instrument in 1993.

The Dr. Fridtjof Nansen made use of Nansen-Petersen water bottles and a SD200 CTD which was also replaced by a Seabird instrument in 1994.

Data collection onboard the Matsuyama Maru started in 1994 and a Seabird SBE19 CTD was used.

Water samples collected on all cruises were mainly for calibration purposes and for dissolved oxygen determinations.

The Seabird CTD instruments were equipped with oxygen sensors and oxygen titrations were mainly done for sensor calibration.

All the data used in this project is considered to have an accuracy better than 0.1 °C, 0.05 psu and 0.1 ml/l for temperature, salinity and dissolved oxygen concentration respectively.

Materials and Methods

The temperature, salinity and oxygen data obtained with different instruments and methods was reformatted into a standard format with a series of FORTRAN programmes developed for this purpose. A data file containing all the temperature, salinity and oxygen values collected during a period of 1 month was created for every month of every year. All these files containing the average monthly values of the measured parameters were used to create the database.

A number of FORTRAN programmes were developed to extract data from the database in time, area and depth.

In section 2 (off Walvis Bay) three boxes were defined from which data has been extracted for analysis. These boxes are illustrated in figure 2. Boxes **A** and **B** cover the surface layer, 0 to 10m depth, at an inshore and offshore region; box **C** covers an offshore region between the depths of 50 and 100m. These three boxes were chosen to investigate the variability of parameters in space, time and intensity.

The monthly means for every box were calculated by averaging all data points covered by the particular box.

Seasonal variations were done by computing the monthly average for all parameters over the 17-year period.

Anomalies for the parameters were calculated by subtracting the longtime monthly average from the monthly average for every box.

An index for upwelling was constructed by subtracting the seasonal temperature averages of box **C** from those of box **A**.

Calculations and graphing were done with an Excel spreadsheet.

Vertical and horizontal sections of the various parameters were created with Surfer.

RESULTS

Seasonal variation

Temperature

Figure 3 shows the seasonal variation in temperature in the various boxes. These seasonal variations were obtained by averaging the monthly values for the period covered by the time series. In box **A** (fig. 3a) there is a clear seasonal cycle for the temperature, with a maximum value of about 16°C in late summer. The minimum temperature value occurs in spring and it ranges between 12° and 13°C.

For box **B** (fig. 3b) the seasonal pattern for temperature has similar characteristics although the temperature maximum is a month earlier than at box **A**. The temperature values are somewhat higher in box **B** than in box **A,** ranging between 13.5° and 17.5°C for the minimum and maximum respectively.

In box **C** (fig. 3c) the seasonal temperature values varied less than in boxes **A** and **B**, however the same pattern is still very clear. Temperatures for box **C** range between 12° and 13.5°C.

Salinity

Figure 4 shows the seasonal salinity variation for boxes **A**, **B** and **C**. A salinity maximum occurs earlier in box **A** (fig. 4a) than in boxes **B** and **C** (fig. 4a and c). In box **A** values >35.2psu occur from around March to August whereas in boxes **B** and **C** these values occur only from around May to August. Salinity values < 35.1psu occur between September and December in boxes **A** and **B** and during November in box **C**. In general the salinity values for box **C** show less variation than the values for boxes **A** and **B**.

Oxygen

Figure 5a shows that the maximum oxygen level for box **C** occurs from July to October, where after it starts to decrease again and reach a minimum around June.

The maximum level is around 2.7 ml/l and the minimum level at about 1.5 ml/l

Annual variations

Temperature

Figure 6 shows the year-to-year temperature variation for the various boxes. From the temperature values for boxes **A** and **B** (fig. 6a and b) the seasonal variation is very clear in all years, however some years such as 1984 and 1995 has higher maximum temperatures. Box **C** (fig. 6c) also shows seasonal variation but the temperatures are on average around 3° to 5°C lower than in the surface boxes. The maximum and minimum variation is also less in box **C**.

Salinity

Salinity values in Figure 7 show very little variation between the surface boxes **A** and **B** (fig. 7a and b) and box **C** (fig. 7c). Periods 1979, 1980, 1984 and 1995, as in the case of temperature, have the highest maximum salinity values.

Oxygen

Figure 5c shows the annual oxygen variation. No clear pattern is evident, however a minimum around May-June can be seen for some years.

Anomalies

Temperature

The magnitude of the anomalies in the surface boxes, **A** and **B** (figure 8a and b), are larger than the ones in box **C** (fig. 8c). Year-to-year variation in the anomalies showing colder and warmer periods is quite clear in all the boxes.

Very high positive anomalies for 1984 and 1995 are clear in box **A**.The 1984 anomaly also shows strong in box **B**.A relatively strong negative temperature anomaly for 1987 shows clearly in boxes **A** and **B**.

Salinity

Salinity anomalies are shown in figure 9. Years such as 1979, 80, 84 and 1995 stand out as positive anomalous periods in box **A** and **B** (fig. 9a and b) with exception of 1995 which does not show in box **B**.The magnitude of the anomalies does not vary much between the different boxes, except for the period 1995 where the anomaly shows only in box **A**.

Oxygen

Oxygen anomalies in box **C** (fig. 5c) show a distinct year to year variation. Periods of lower oxygen levels in the early eighties and periods of higher oxygen during the late eighties show some oscillation.

Upwelling

Maximum temperature variation between the surface and bottom layer occurs in Summer and Autumn with a minimum difference of about 0.2°C in September.

Figure 10 shows the monthly average temperature difference between box **A** and **C**. These values were calculated from the long term averages.

DISCUSSION

The temperature maximum shown by the seasonal variation of around February and March can be described by the slackening of upwelling favourable wind stress. The difference in temperatures for boxes **A** and **C** (fig. 10) is a clear indication that the water column is well stratified in late summer and autumn (December-April).

During spring upwelling is at it's maximum, which results in a well mixed water column, this is clearly visible in the low surface temperatures around September.

Figure 10 shows the seasonal upwelling intensity for the central Namibian shelf region.

Salinity variation in the central Namibian shelf region corresponds well with the water temperature, although the variation is small.

Temperature anomalies show two very distinct periods (1984 and 1995) of very high positive anomalous conditions. These abnormally high water temperatures and salinities have very similar characteristics in both 1984 and 1995.The warm water intrusion in 1984 has been described by various authors, such as Shannon et al. (1986), as a Benguela-Nino, similar to the El-Nino phenomenon of the Pacific ocean.

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Shannon LV, Boyd AJ, Brundrit GB, J Tautuon-Clark (1986) On the existence of an El Nino-type phenomenon in the Benguela system. *J Mar Res* 44(3): 495-520

Shannon LV And G Nelson (in press) Large scale features and processes and system variability

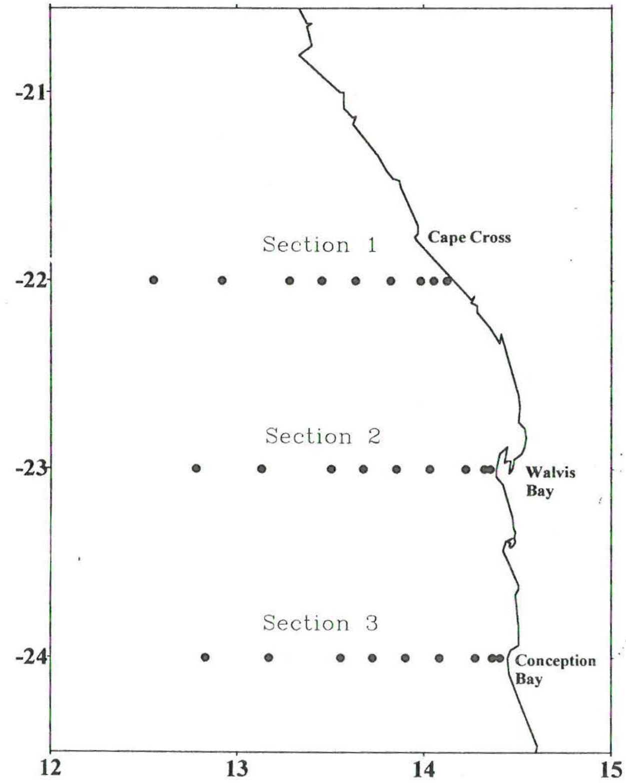


Figure 1. Station grid for the central Namibian shelf region

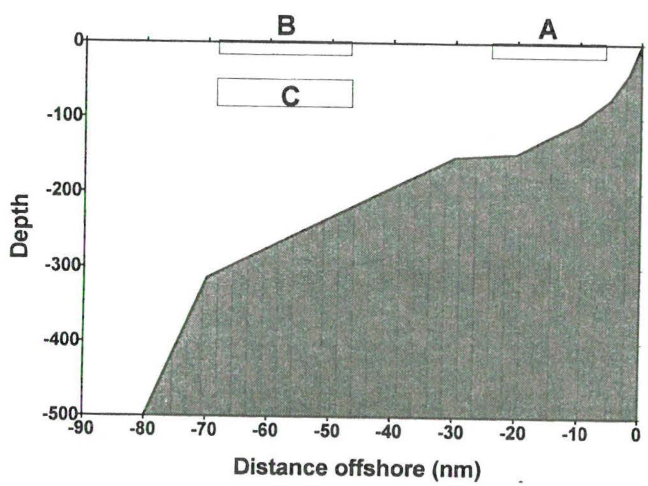


Figure 2. Vertical section off Walvis Bay (23°00'S) showing boxes A,B and C

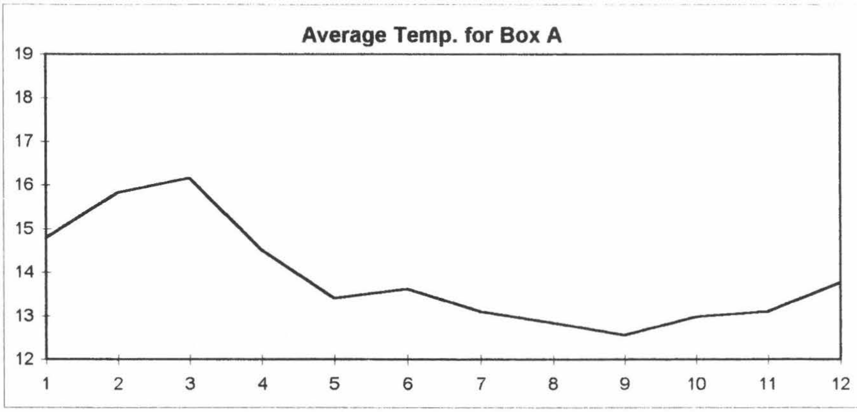


Figure 3a

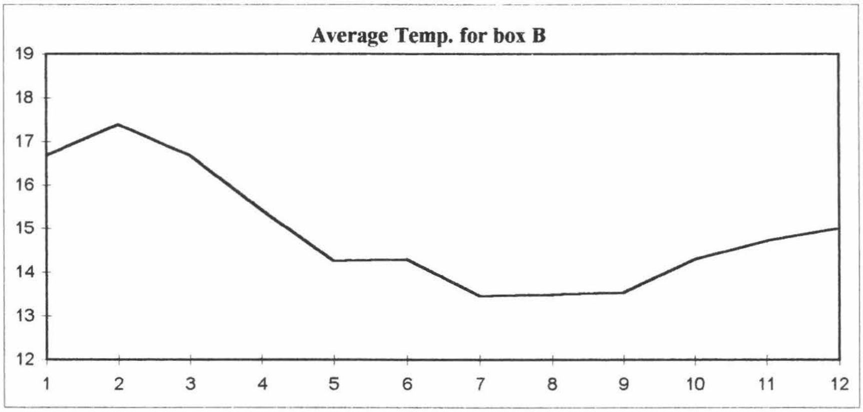


Figure 3b

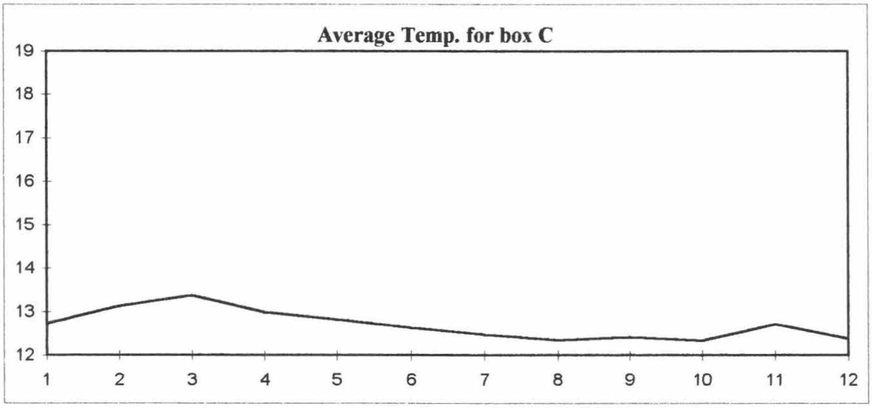


Figure 3c

Figure 3. Mean monthly average temperatures for a) Box A, b) Box B and c) Box C

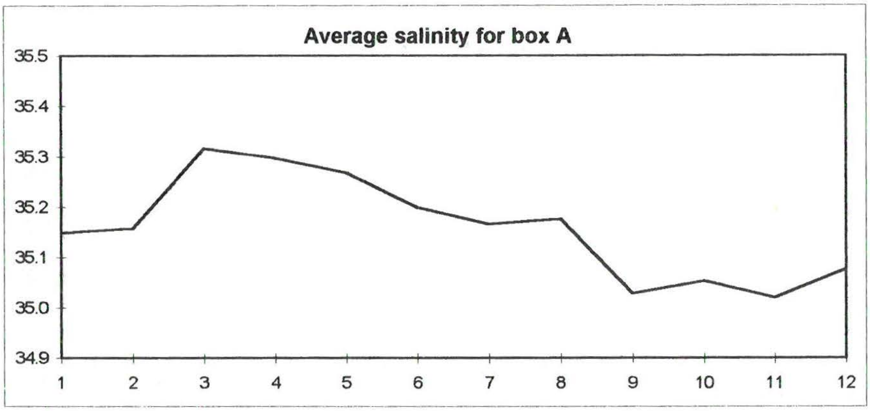


Figure 4a

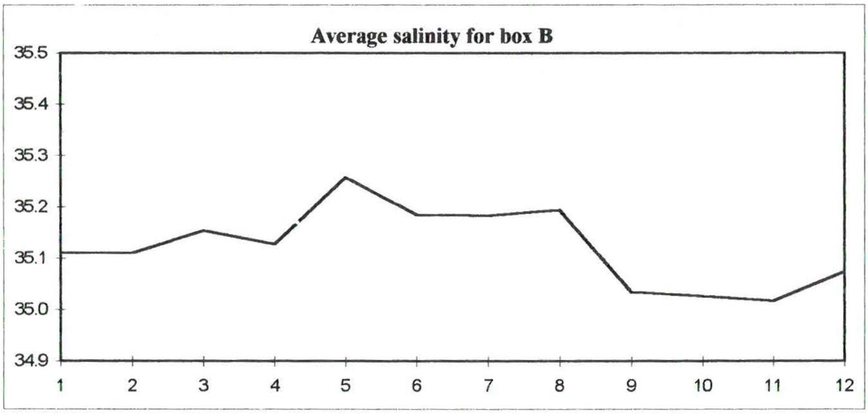


Figure 4b

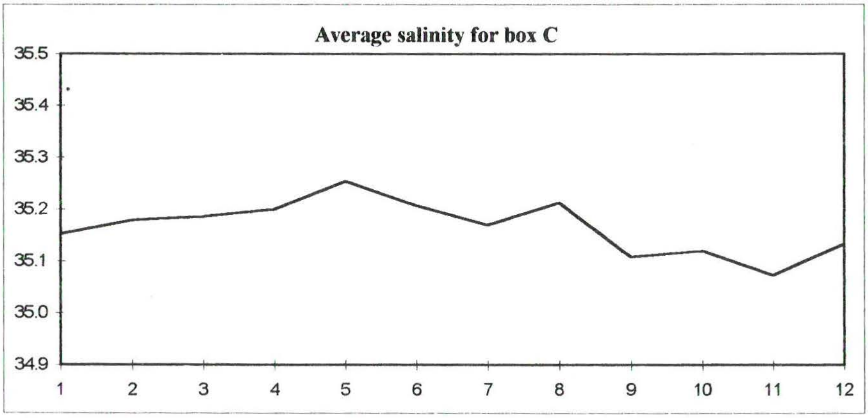


Figure 4c

Figure 4. Mean monthly average salinities for a) Box A, b) Box B and c) Box C

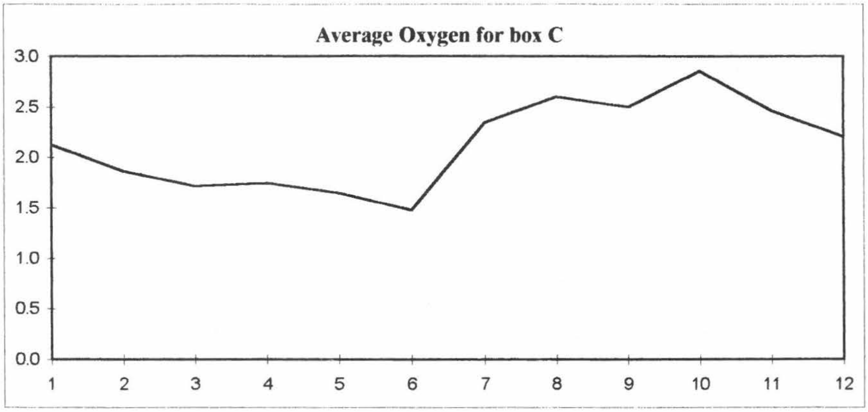


Figure 5a

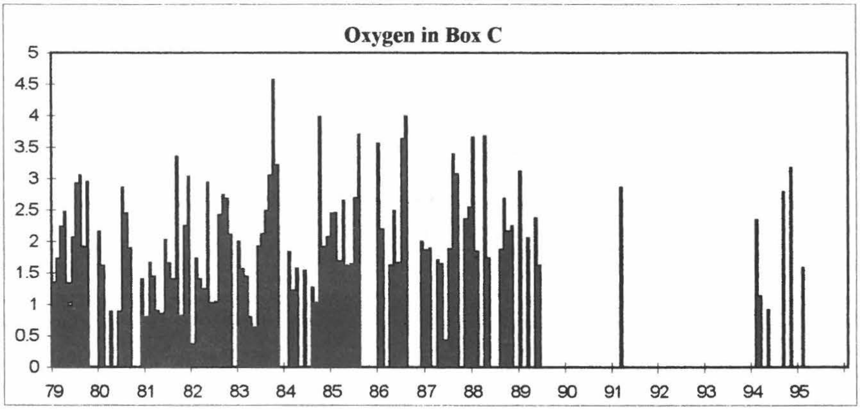


Figure 5b

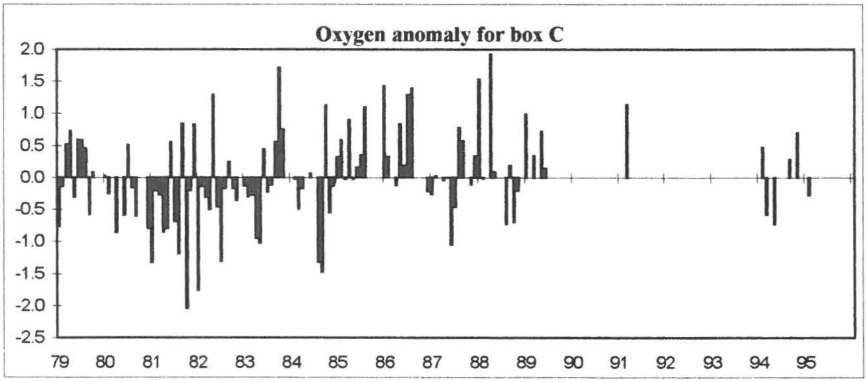


Figure 5c

Figure 5. Oxygen consentration in Box C: a) Mean monthly average b) Monthly averages and c) monthly anomalies.

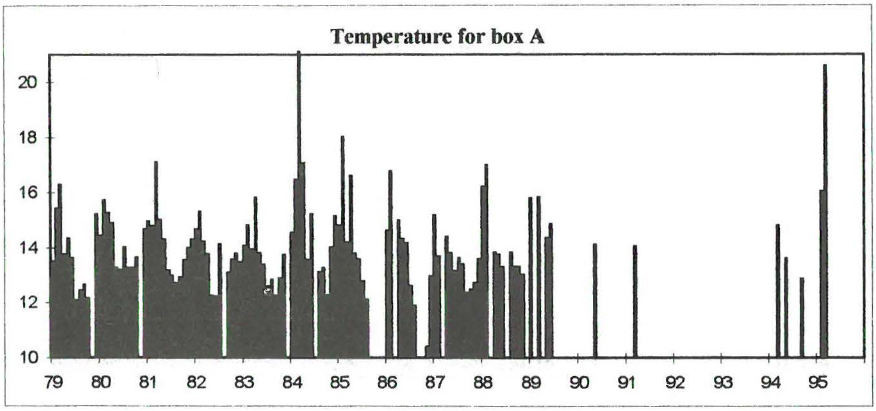


Figure 6a

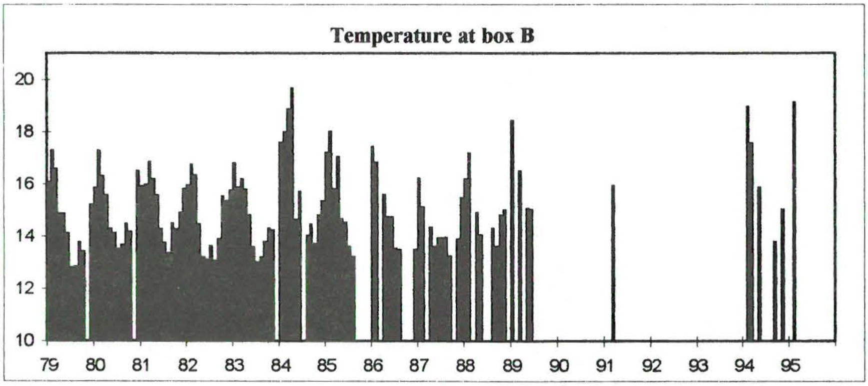


Figure 6b

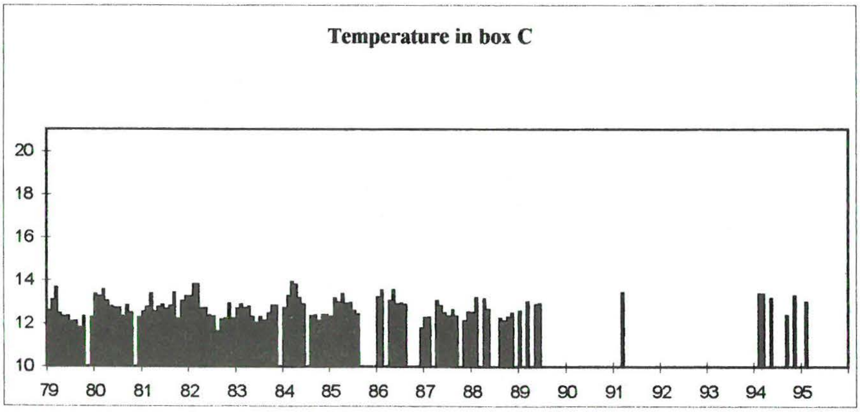


Figure 6c

Figure 6. Monthly average temperatures for a) Box A, b) Box B and c) Box C

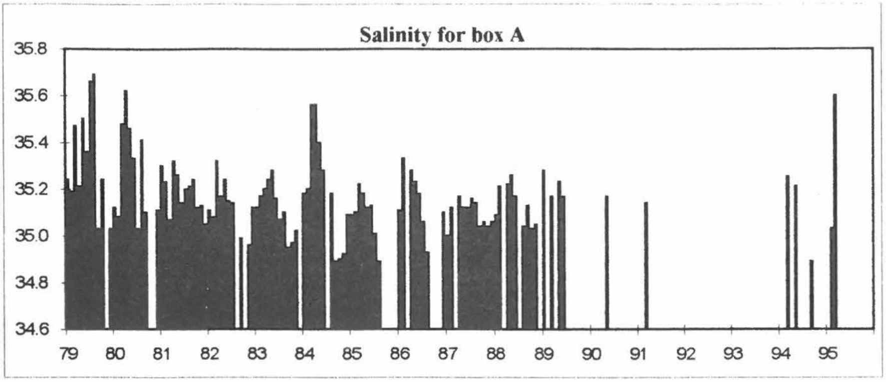
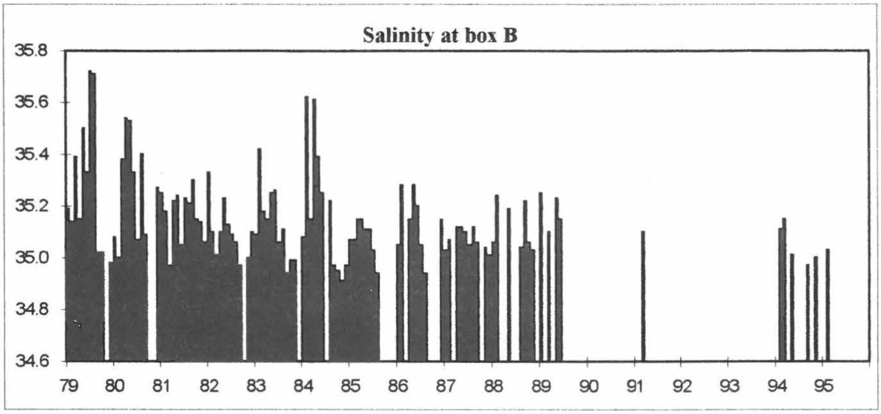


Figure 7a



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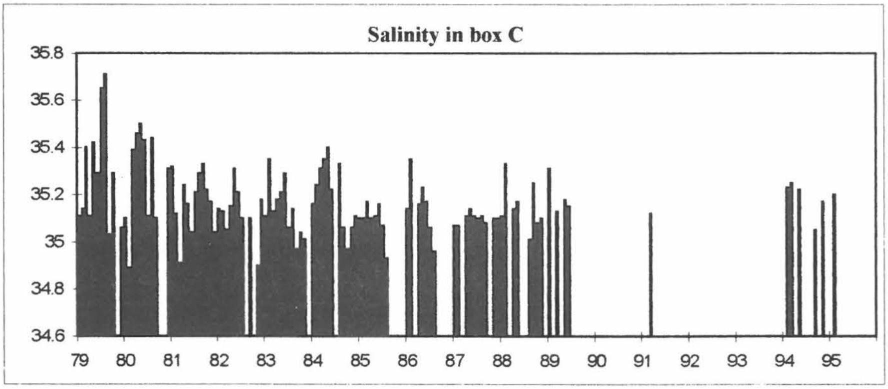

Figure 7c

Figure 7. Monthly average salinities for a) Box A, b) Box B and c) Box C

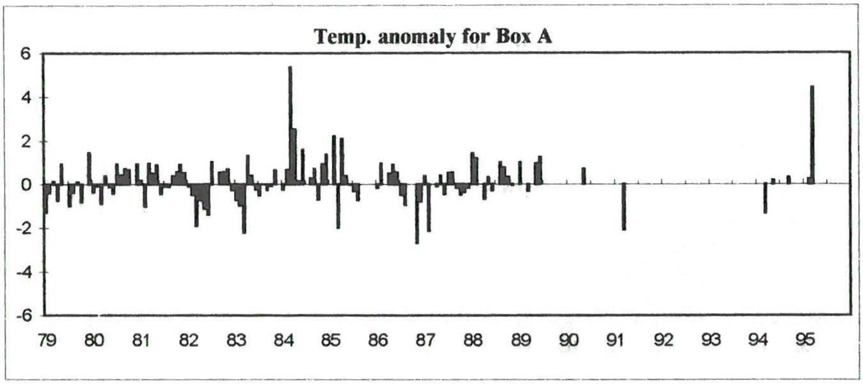

Figure 8a

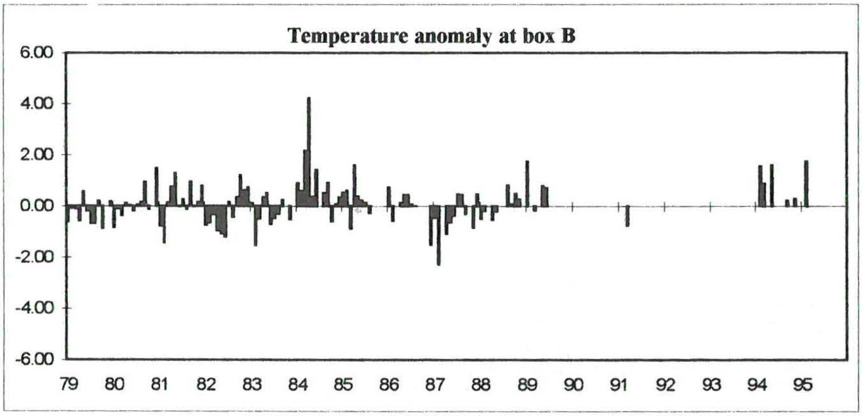

Figure 8b

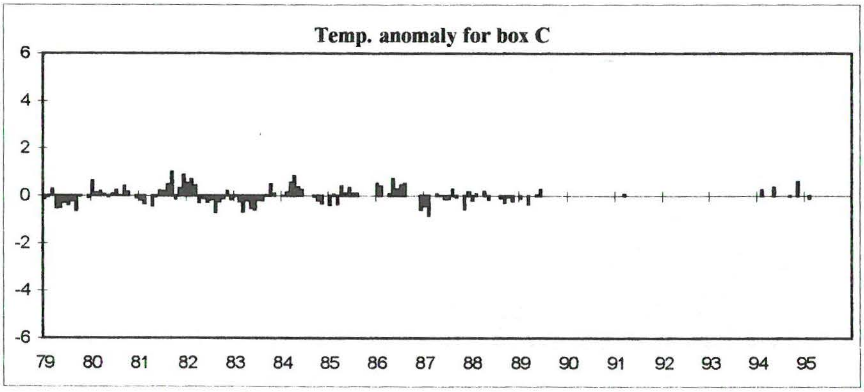

Figure 8c

Figure 8. Monthly temperature anomalies for a) Box A, b) Box B and c) Box C

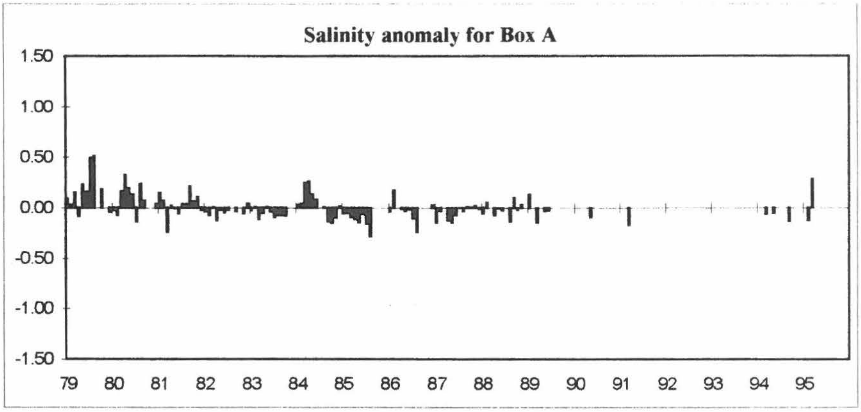

Figure 9a

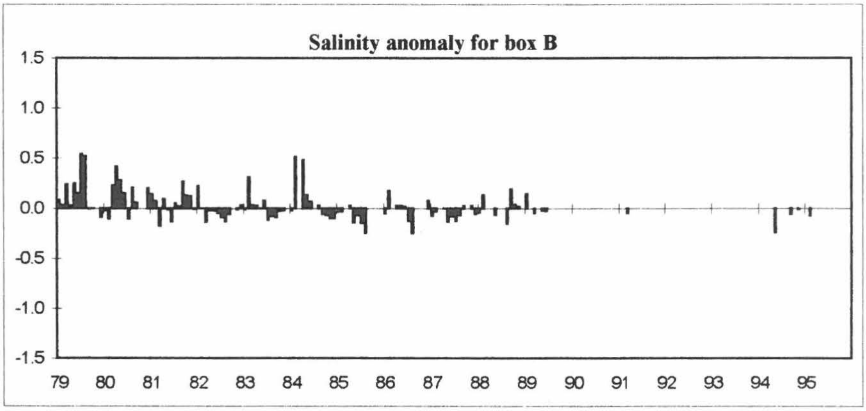

Figure 9b

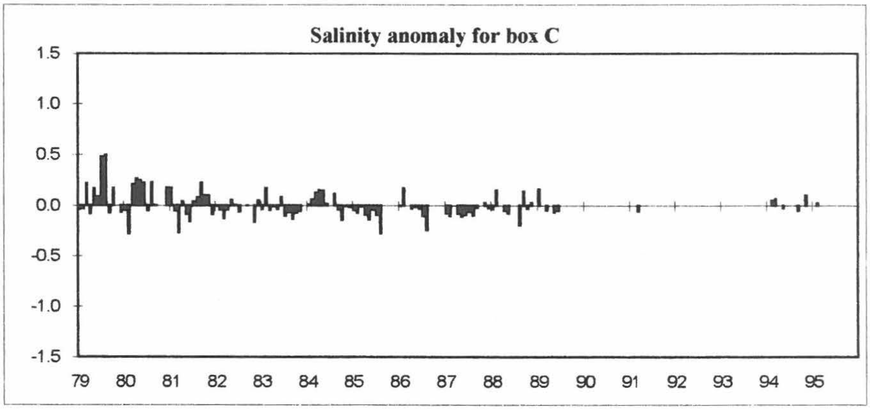

Figure 9c

Figure 9. Monthly salinity anomalies for a) Box A, b) Box B and c) Box C

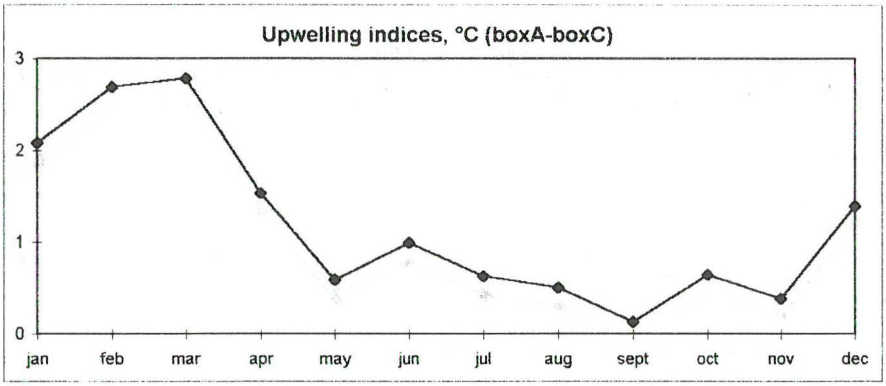

Figure 10

Figure 10. Mean seasonal variation of upwelling index

NANSEN COURSE IN ENVIRONMENTAL PHYSICS
Swakopmund, Namibia, 14 Nov - 15 Dec 1995

HYDROLOGICAL CLIMATE VARIATIONS OBSERVED AT THE LOBITO FIXED STATION, ANGOLA

by

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Angola

Abstract

In this work the historical data (time series) of temperature and salinity of the fixed station of Lobito (12° 19'S, 13°34'E) is presented and analysed. The observations started in February 1968 and ended in May 1992 for the temperature, and for salinity the period is February 1968 to November 1991. Seasonal and year to year variations are discussed.

INTRODUCTION

The systematic occupation of a fixed coastal station in Angola began in 1968 at a location outside Lobito (12° 19'S, 13°34'E) at 40m depth. The main objective was to study the coastal hydro-climate of Angola. The Angolan coast is 1650km long. The climatic and oceanographic conditions of this coast are very variable.

The warm currents of Angola, the cold currents of Benguela, and the trade winds coming from sub-tropical regions and going towards equatorial regions have all large impact on the physical conditions of Angolan waters, and therefore the fisheries in the Angolan economical zone.

Angola is characterized by a variety of climatic conditions: from rain-forest in the north to desert climate in the south. However, the biggest area of the territory belongs to the tropical climate influence, with a warm and wet season (summer) and cold and dry season (winter).

From the study of the temperature and salinty characteristics of surface waters of inter-tropical oriental zone of the Atlantic, Wauthy (1977) (Berrit,1961) observed that the year is divided into two periods, one cold (T<24°C) and one warm (T>27°C).

MATERIAL AND METHODS

Observations at the fixed station of Lobito were carried out at 08 GMT during week days, Saturdays, Sundays and holidays excluded. The observation depths were at 0, 5, 10, 20 and 35 metre. The samples were taken using NANSEN bottles with reversing thermometers. Water samples were analysed for salinity using a Beckman salinometer.

The original records are stored as paper notes and formes at Angolan Institute of Marine Research station at Lobito (the former MEBPA).

Data were collected from 1968 to 1992, but unfortunately there are some intervals when the data are missing: from 1968 to 1979 there are no observations taken at 5m depth, between 1982 and 1985 there were no salinity data available at 20m depth, during 1992 salinity was not measured. The weekly mean values were calculated as simple arithmetic means of the daily observations (usually 5 days).

A series of computer programs written in Quick Basic were developed to compute monthly means for the whole period (1968-1992), average monthly means, and monthly anomalies.
The following formulas were used:

M(m) = SVS/NS;
M(an)=SVM/NS;
ANOM=M(m)-M(an)
where:
M(m) is the monthly means
SVS: sum of observed values (T or S) at a specific level
NS: number of observed weeks
M(an): yearly means
SVM: sum of observed monthly values (at a specific level)
NM: number of observed months
ANOM: monthly anomalies (68-92).

RESULTS

Seasonal variations

Temperature

The temperature varies according to the season of the year, therefore the maximum temperature at the surface (26.56 °C) is observed in March, and the minimum surface temperature (18.52 °C) is found in August, see Fig. 1a. Note that there is no lag between the surface and the bottom layer; the maximum and minimum temperatures occur at all levels simultaneously.

The extreme temperatures from the whole series as seen from the original weekly averages was found to be 29.93 °C for the maximum temperature which occurred at the surface in the second week of Match, 1984, and the minimum (15.16 °C) was observed in the bottom layer (35m) the third week of August, 1983.

Note that the temperature variations not are simple sinusoidal, at all levels there is a secondary minimum in December-January. This may also be seen in the isopleth-diagrams by Dias et al (1983).

Salinity

The maximum variations of the salinity are found at the surface layer, see Fig. 1b. In the surface layer the minimum salinity (34.699 psu) occurs during the rainy season in March. The maximum salinity (35.651 psu) was found in July, but the salinity varies little during the dry season (June-October). As for the temperature variations, there seem to be very little lag between surface and bottom layer, so the minimum salinity at 35m (35.456 psu) was also found in March. However, the maximum bottom salinity (35.727 psu), occurred as early as in May.

From the original weekly averages, the maximum salinity (37.760) for the whole data set occurred at 10m in April, 1982, and the minimum (31.930) at the surface on the second week in March, 1984.

Year to year variations (1968-1982)

Temperature anomalies

From Fig.2 it is obvious that the temperature anomalies vary in the same manner at all levels from surface to the bottom layer at 35m depth. Cold periods occurred in 1971-1972, 1974-1975 and 1978 and 1992. The most pronounced warm periods occurred in 1984 and 1986-1987.

Salinity anomalies

The amplitudes of the salinity anomalies are maximum at the surface, decreasing with depth, see Fig.3. Pronounced low salinities occurred in the surface layers in 1984 and 1986. Maximum salinity anomalies occurred in 1974 and 1978.

According to the water categories defined by Gallordo (1966), a presence of brackish water exist along the coast in the wet season, while in the dry (cold) season upwelling may bring more saline sub-surface water to the surface.

DISCUSSION

Values of temperature and salinity varies according to the season of the year, with maximum temperatures during hot season and low temperatures in the cold season, and maximum salinities in the cold (dry) season and minimum salinities during hot (wet) season. The average yearly temperature and salinity amplitudes for the surface layer (see Fig.1) are about 7.5°C and 1 psu respectively. Looking up the original data we find maximum range of temperature variations of order 15°C and salinity variations of the order 7 psu.

Year to year variations of salinity is much smaller at 35m than at the surface layer. The two most important rivers in the region are the Congo river in the north and the Kwanza river in Central Angola. The south going Angolan current may carry fresh water from these river influencing the Lobito station. Ekman transport driven by upwelling favourable wind from south-east may bring subsurface more saline water to the surface.

The anomalies that was observed in 1984 with warm and fresh surface layers, coincides with the Benguela Niño 1984 (Shannon et al. 1984).

There is a need to try to prolong the data series after 1992 using the observations when research vessels have operated in the neighbourhood of the Lobito fixed stations. Of particular interest is to learn about the characteristics of the Benguela Niño 1995 (Gammelsrød et. al 1995).

Observations carried out in time series at this fixed station let us know and follow the formation of the hydrological regime in this area where an important fishery takes place. The environmental influence on the fish stocks and fish behaviour may therefore be studied by this data series, which in turn may be an important information to obtain a sustainable management of the fishery. It is therefore utterly important that the Lobito fixed station observation series is continued in the future.

Acknowledgement

My acknowledgements to the scientific team of the former MEPBA guided by Eng. C. Afonso Dias for creating the fixed station of Lobito for hydro climatic studies, to the actual Director of the IIP/Lobito station Sr. R. Garrocho and to the director of the IIP in Luanda.

I also thank the NANSEN program and NANCEP supported by NORAD for elaborating this paper guided by professor Tor Gammelsrød and tutors Antonio Mubango Hoguane, Detlof von Oertzen and Gunhild Schreiber.

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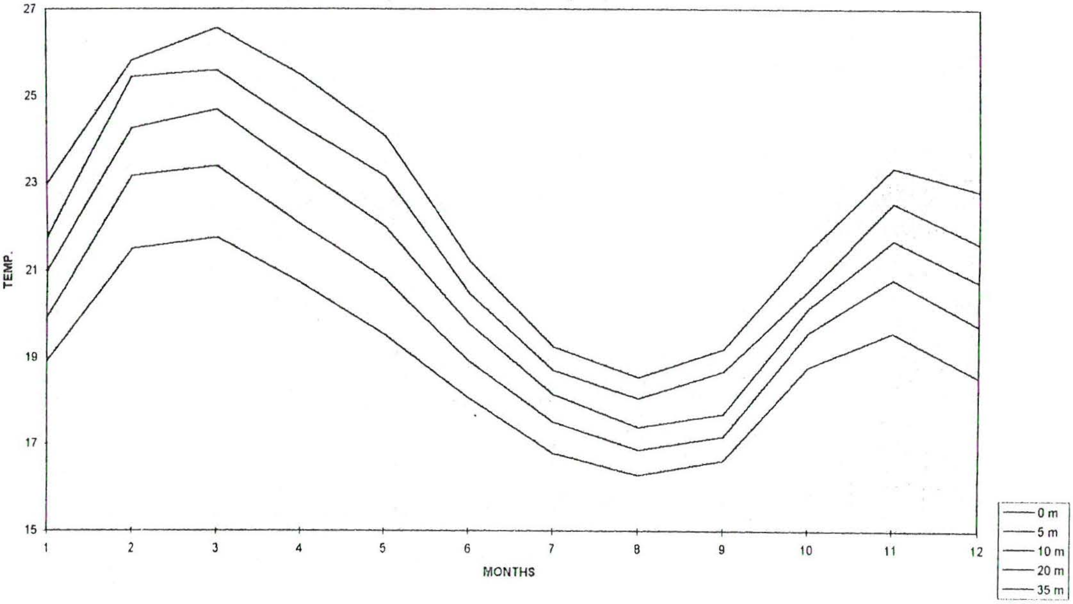
Wauthy B. (1977): Revision de la classification des eaux de surface du Golfe de Guinnee Berrit (1961).Cahiers ORSTOM, serie oceanographie, vol.XV,3.

AVERAGE SEASONAL VARIATION TEMP. IN LOBITO FIXED STATION (1968-1992)



AVERAGE SEASONAL VARIATION SAL. IN LOBITO FIXED STATION (1968-1991)

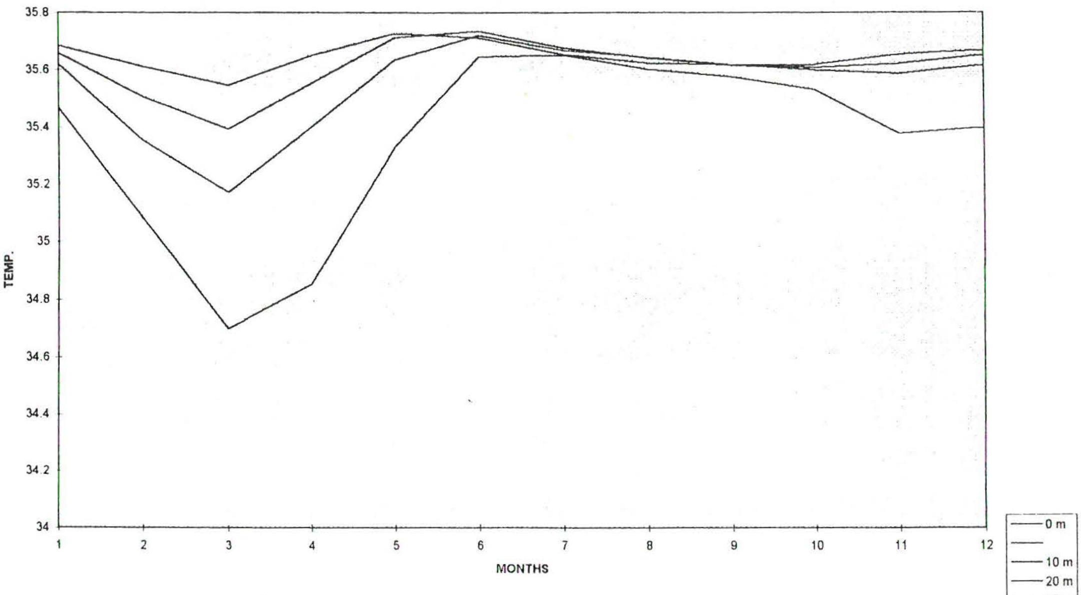
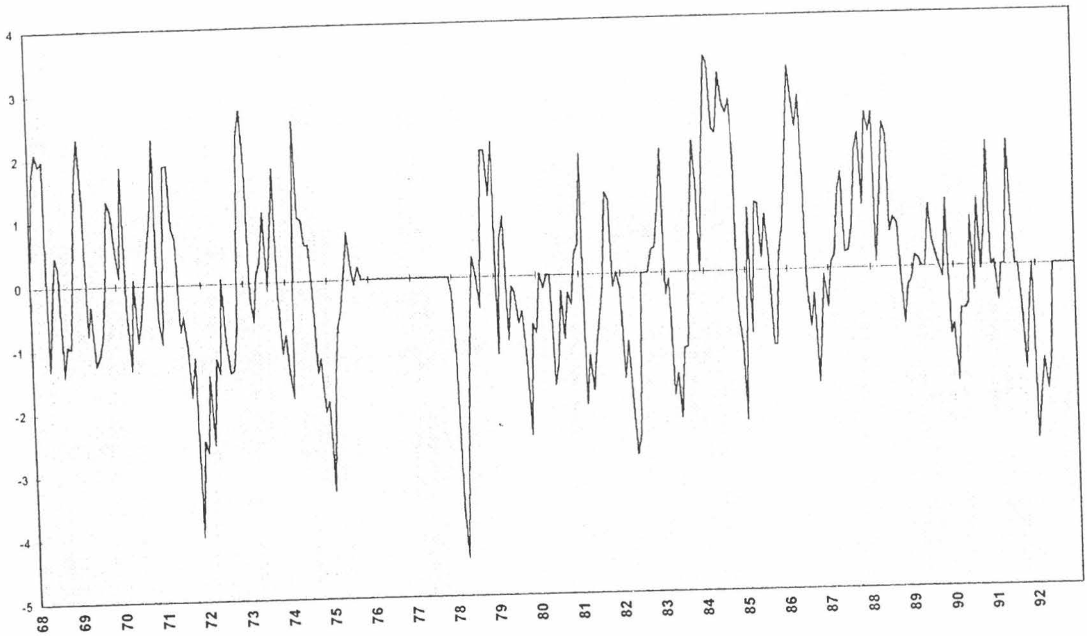


Fig. 1A and1B

TEMPERATURE ANOMALY 0 m



TEMPERATURE ANOMALY 10 m

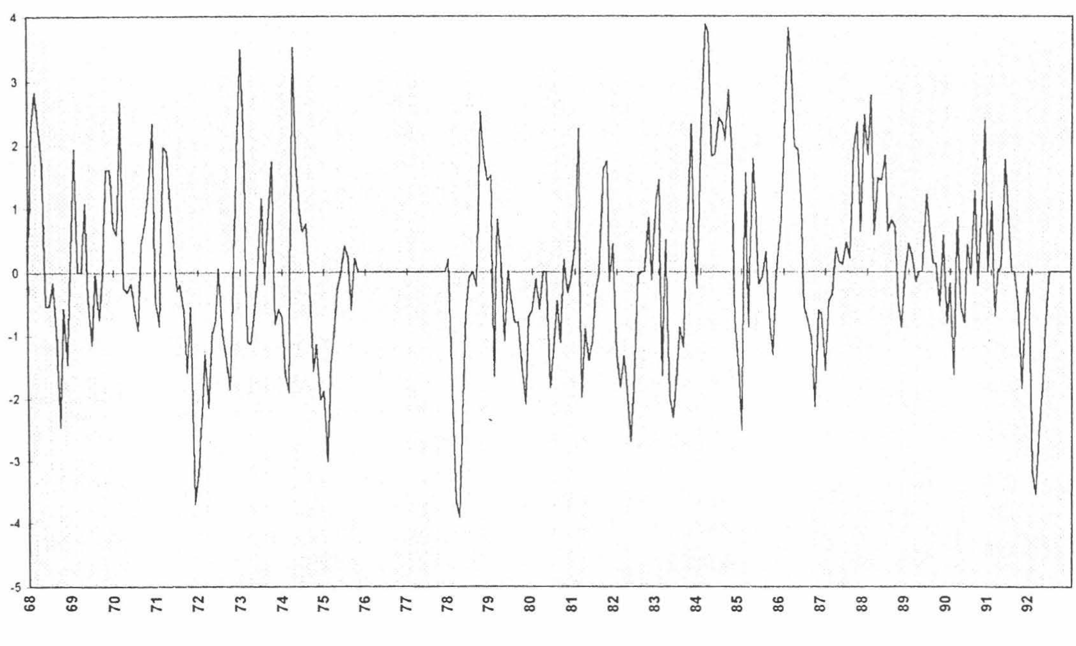
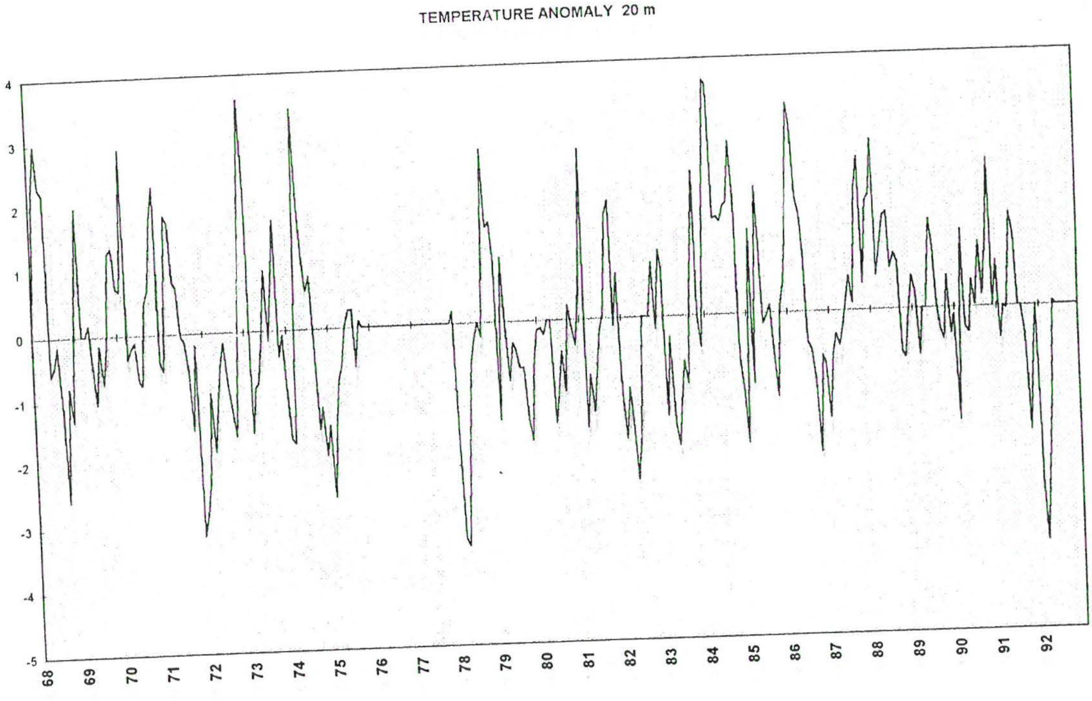


Fig. 2A and2B


TEMPERATURE ANOMALY 20 m
4
3
2
1
0
-1
-2
-3
-4
-5
68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92

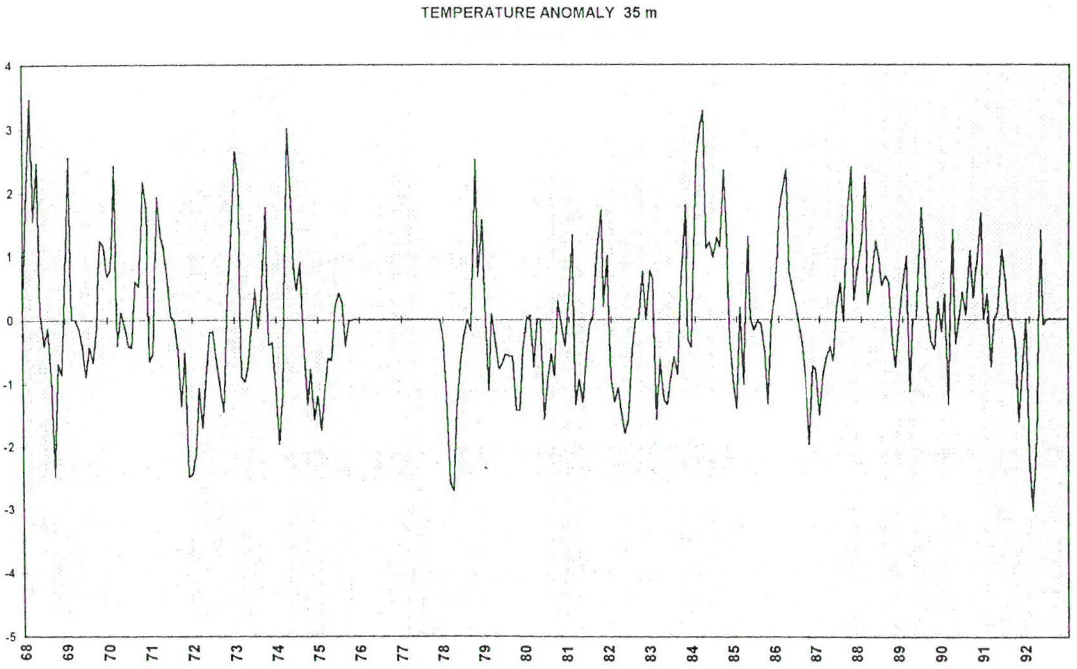
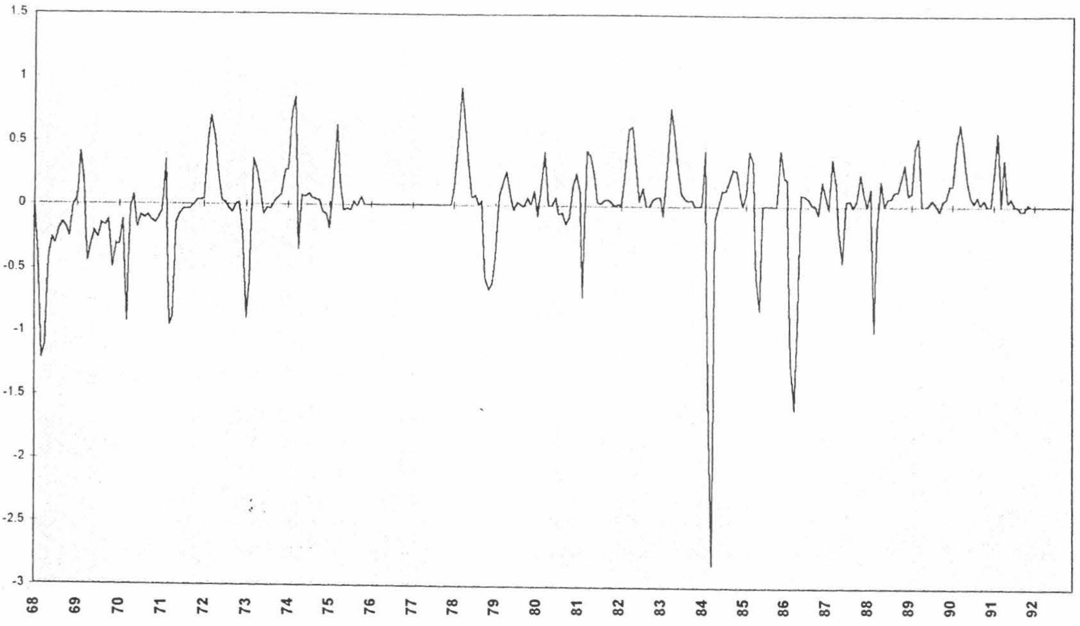

TEMPERATURE ANOMALY 35 m
4
3
2
1
0
-1
-2
-3
-4
-5
68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92

Fig. 2C and2D

SALINITY ANOMALY 0 m



SALINITY ANOMALY 10 m

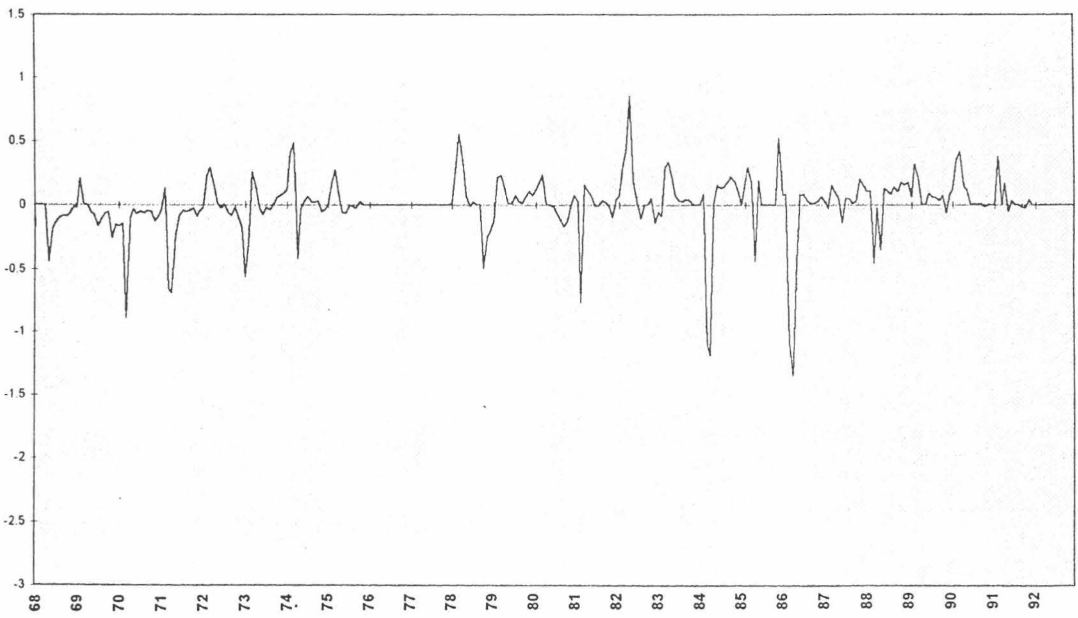
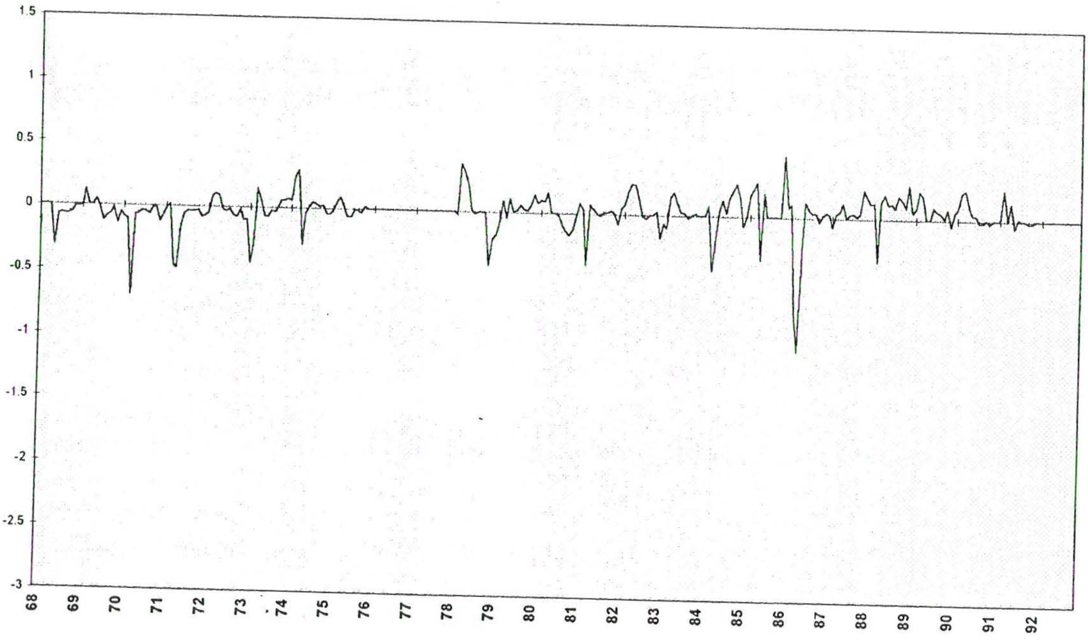


Fig. 3A and 3C

SALINITY ANOMLY 20 m



SALINITY ANOMALY 35 m

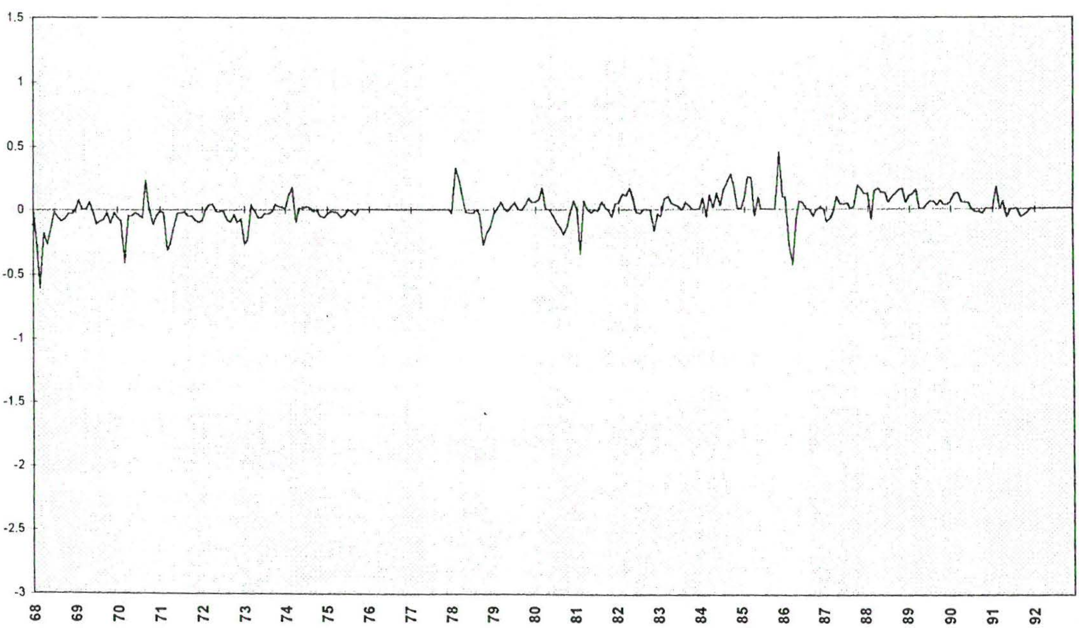


Fig. 3C and3D

NANSEN COURSE IN ENVIRONMENTAL PHYSICS
Swakopmund, Namibia, 14 Nov - 15 Dec 1995

BENGUELA NIÑOS AS SEEN FROM THE COASTAL METEOROLOGICAL STATIONS IN ANGOLA.

By

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Abstract

Meteorological data were taken from five coastal cities of Angola: Cabinda, Luanda, Porto-Amboim, Benguela and Namibe in order to study the Benguela Niños which have stricken the Angolan waters through the years. The seasonal variations of temperature are discussed. The temperature decreases with increasing latitude. As to the precipitation, the situation is the same. It rains more in Cabinda, which is near the equator, than in Namibe, which is near the Kalahari desert.

Year to year variations both for the temperature and precipitation, are also dicussed. Benguela Niño 84 and 95 were more intense and had more impact on the weather. It has also been observed a slight but gradual warming from 1980s due probably to the general warming of the earth.

INTRODUCTION

The main purpose of this paper is to study from meteorological data the Niños occurences observed in the Angolan waters through the years.These data have been taken from five stations all along the coast of Angola: Cabinda, Luanda, Porto-Amboim, Benguela and Namibe, for locations, see map in Fig.1. The time series covers the period from 1951 until 1995.

The seasonal, year to year and long term trends are discussed. Of particular interest are the so called Benguela Niño events, the South-East Atlantic counterpart of the most well known El Niño effect in the Pacific, (Shannon et al 1986).

The Niños have a detrimental influence on the fisheries, and are thought to occur in the Benguela region about once per decade (Shannon et al 1986, Shannon & Nelson 1995). A significant Benguela Niño event was also observed in the first quarter of 1995 (Gammelsrod et al 1995).

DATA, METHODS AND INSTRUMENTS

Data

The precipitation, the maximum and minimum temperature of the atmosphere were obtained from the National Institute of Meteorology of Angola in Luanda.

All these data were recorded daily and the monthly average has been computed.The overview of the data and the timespans used in this study is shown in table 1.

Table 1. Time series from coastal stations of Angola

STATIONS	PRECIPI-TATION	MAXIMUM TEMPERATURE	MINIMUM TEMPERATURE	MISSING DATA
CABINDA	***1953-1995***	***1953-1995***	***1953-1995***	
LUANDA	***1951-1995***	***1953-1994***	***1953-1995***	May & June ,1958(precip.)
PORTO-AMBOIM	***1961-1994***	***1961-1990***	***1961-1990***	Prec.Mar.-May,1980;May-Dec.,1981;Apr.-June,1987;Oct.-Nov,1989;1990(all the year)
BENGUELA	***1961-1994***	***1981-1994***	***1981-1994***	
NAMIBE	***1951-1995***	***1953-1994*** (temperature average)		

Instruments

The maximum and minimum temperatures measured from the five stations were obtained using two thermometers:one records the maximum temperature and the other records the minimum temperature.These thermometers are of mercury in glass.

As to the precipitation, pluviometer which consists of a container with a funnel, is used. The rain water is dropped in special glass scaled in mm.

In meteorology 1mm of precipitation means the height which the rain water would reach if the soil was impervious. Quantitatively 1mm of precipitation represents 1 l of water over square meter.

Methods

The monthly averages were computed both for the precipitation and for the temperature from 1951 until 1995 for each station. These averages allowed me to asses the magnitude of the rain which falls each month within the five coastal cities.These calculations were made through a program written in Quick-Basic. The averages were computed for both the temperature and precipitation using the following formulas:

$\mathbf{T}mj=\mathbf{SUM\ T}ij/\mathbf{n}$ for $i=1...n$ for temperature average.

$\mathbf{P}mj=\mathbf{SUM\ P}ij/n$ for $i=1....n$ for precipitation average

where

$j=1......12$ is the month

$i=1........n$ is the year

$\mathbf{T}mj$ is the mean monthly average of temperature

$\mathbf{P}mj$ is the mean monthly average of precipitation

Tij is the temperature of i year and of j month

Pij is the precipitation of i year and of j month

n is the number of years.

From these results, curves were plotted in Excel showing the mean values of precipitation and temperature for each month.

Then from these mean values, monthly anomalies were computed using another program in Quick-Basic and finally draw a plot which allowed me to detect and to identify the hottest and the most rainy years. Anomalies were computed by means of the following expressions:

$\mathbf{T}aj=\mathbf{T}ij\text{-}\mathbf{T}mj$

$\mathbf{P}aj=\mathbf{P}ij\text{-}\mathbf{P}mj$

where

$\mathbf{T}aj$ is the temperature anomaly

$\mathbf{P}aj$ is the precipitation anomaly

RESULTS

Seasonal Variations

The seasonal variations of precipitation from the various stations are shown in the Fig.2a, and the variations of maximum and minimum temperature from Luanda in Fig. 2b. Table 2 gives an overview of the mean monthly average for temperature and for precipitation .

Table2: Averages of maximum and minimum temperature and precipitation from the coastal stations of Angola.

STATIONS	PRECIPITATION (mm)	MAXIMUM TEMPERATURE (° C)	MINIMUM TEMPERATURE (° C)
CABINDA	reaches 190 in March which is the maximum value.The decline of the precipitation in May shows the beginning of the dry season until September.	32 in February and March.	17.5 in June.
LUANDA	reaches 90 April.	32 in March and April	18 in July
PORTO-AMBOIM	reaches 100 in April.	31 in February until March.	17 in July
BENGUELA	reaches 70 in April	31 in March & April.	17 in July
NAMIBE	reaches only 20 in March	25 in March	17 in July

Table 2 and Fig.2 show that the monthly precipitation decreases with the latitude from 190 mm in Cabinda, which is near the equator, to 20 mm in Namibe near the Namibian desert, southern Angola.

As to the average maximum temperature, it is almost the same in Cabinda and in Luanda with 32°C in March and April; 31°C in Porto-Amboim and Benguela and it decreases to 25°C in Namibe.

As to the average minimum temperature, it is about 17°C along the entire coast, see Table 2.

Year to year variations

The monthly anomalies for the maximum and minimum temperatures in Luanda is shown in Fig.3.

The coldest year seems to have been 1958, and the warmest year 1984. For the minimum temperature anomalies we note that a long term warming seems to take place.

From Namibe only average temperatures are available, and the anomalies are shown in Fig.4. Again we recognise the cold year in 1958, and the warm year in 1984. Also note the higher temperatures during the 1980's.

The precipitation anomalies from Cabinda are shown in Fig. 5 and from Luanda in Fig.6. As the average precipitation in Cabinda is higher than Luanda, we note that the anomalies in Luanda is generally positive, while the high average precipitation in Cabinda also allows for large negative anomalies.

DISCUSSION

" El Niño" is a climatic fluctuation of the ocean-atmosphere system. It is not known whether the pertubations originate in the atmosphere or in the ocean. Here is a brief explanation of what happens in the atmosphere during an " El Niño" event:

> The strength of the wind depends on the difference in the surface atmospheric pressure between the subtropical high pressure of South -East Atlantic (Southern Africa) where cool dry air converges and subsides and the low pressure over South-West Atlantic (Brazilian Coast) where warm, moist air rises producing cumulonimbus clouds and heavy rainfalls.

During an " El Niño" event, the South-West Atlantic low has anomalously high pressure and moves eastwards into the Atlantic while the South-East Atlantic high becomes anomalously low. This climatic fluctuation occured for the first time along the Peruvian Coast. (Ocean Circulation, Open University).

The Benguela Niños occured in 1910, 1920, 1934, 1949, 1963, 1974, 1985 and in 1995. 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, (Shannon & Nelson, 1995).

During the first quarter of 1995, the R/V "Dr Fridtjof Nansen" has covered the Angolan Coast from Cabinda until Lobito. Then it went back to Luanda trying to study the time development of the phenomenon called "Benguela Niño".

Table 3. Year to year variations for maximum and minimum temperature and precipitation. The conditions during Nino years are indicated.

STATIONS	**MAXIMUM TEMPERATURE ANOMALIES** (o C)	**MINIMUM TEMPERATURE ANOMALIES** (o C)	**PRECIPITATION ANOMALIES** (mm)
CABINDA	period:1951-1980 1963-1964 :+1.5 1972-1973: +0.5-1.0	period:1951-1980 From 1965,we can observe a gradual increase of temperature.	Period :1951-1994 It is a rainy region. Some increases were recorded in 1950s & 1974 with 150 to 200
LUANDA	period:1953-1995 1962-1964:+2 1972-1974:+1.5 1983-1984:+3 1995 :+2	period:1953-1995 It is constant from 1953 - 1980 with a gradual increase from 1981 with + 0.5 -2.5	period:1953-1995 1955:+300 1963-1964:-150 1972-1974:+100 1983-1984:+200 a real increase 1995:250
PORTO-AMBOIM	period:1961-1990 1962-1963:+1.5 1973-1973:+1.5 1983-1984:+2.5		period:1961-1990 1962-1963:+150 1971:+350 1972-1973:+150 1983-1984:+100
BENGUELA	period:1981-1994 1983-1984:+3	period:1981-1994 1983-1984:+2	1983-1984:+50 1985-1986:+250 1994:+150
NAMIBE	period:1953-1995 1962-1963:+4 1983-1984:+5 1995:+2.5 From 1980,there is a real warming of the atmosphere.		It is a dry town with some increases in 1973-1974:+100 1984:+20 1995:+60

During this cruise, it has been observed an increase of water temperature for about 8°C and a decrease of the salinity for about 5 psu relatively to the previous year. The maximum salinity differences were found at the surface, but the temperature deviations were maximum at typically 30m to 50 m depth.The thermocline was found at 20 to 30 m greater depths than usual.

A decline of the biomass abundance has been recorded during this quarter (Gammelsrod et al 1995).

In Table 3 we have indicated the conditions during " El Niño" years. There are indications of a little warming in1963-1964 for all stations of about 1.5°C. The same situation occured in1974, but in 1984 the effect of " El Niño" was tremendous. It stroke the Angolan coast strongly as we can see in Table 3: an increase of more than 3°C in Luanda and Benguela and up to 5°C in Namibe. About the precipitation, 200 mm in Luanda, 100 mm in Porto-Amboim, 250 mm in Benguela and finally 20mm in Namibe which is twice the average value.

In 1995, the atmospheric temperature in Luanda has increased of +2°C and Namibe of +2.5°C. Then with the precipitation it was 250mm in Luanda and 60 mm in Namibe three times the average value.

It is obvious that some increases of temperatures and of precipitation are due to other factors than the Benguela Niños .

The minimum temperature anomalies show a gradual warming from 1965 in Cabinda,1981 in Luanda, and 1980 in Namibe due probably to the general warming of the earth. The increase of CO_2 in the atmosphere may cause this warming.

Acknowledgements
I am very grateful to Professor Tor Gammelsrod who is the organiser of Nancep, for his advices and his cooperation during the Nancep course and while I was writing this paper. Also I will be grateful to Mr Antonio Mubango Hoguane to have helped me to write the two programs in Quick-basic, to the Fisheries Research Institute in Swakopmund for letting me using their fascilities as for instance the copy machine, and finally to Mr Mabika, the meteorologist from the National Institute of Meteorology in Angola for the data I got from him.

I am also indebted to all persons whom directly or indirectly helped to the achievement of the Nancep Course and particularly of this paper.

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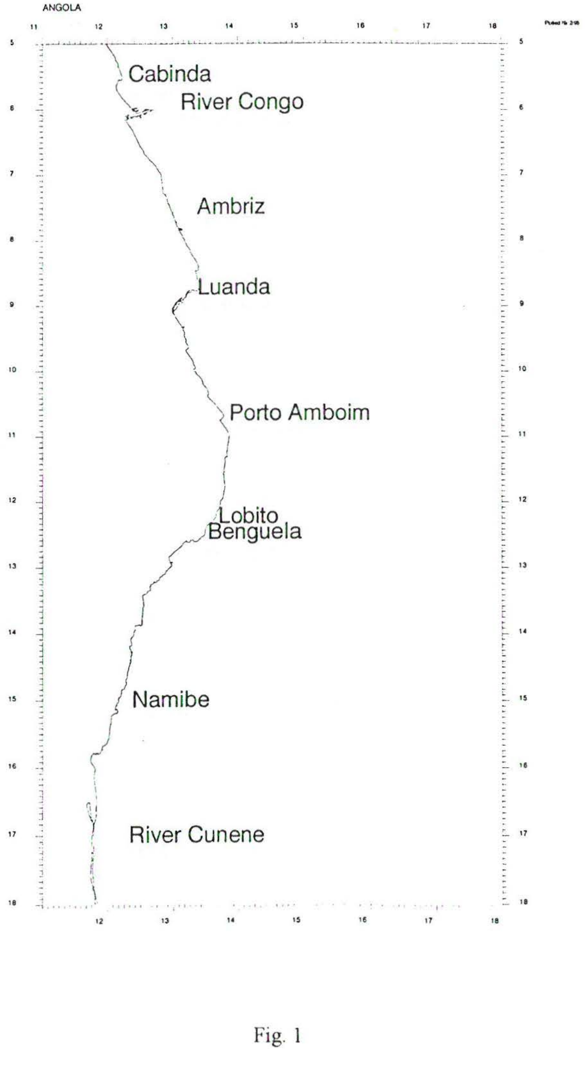
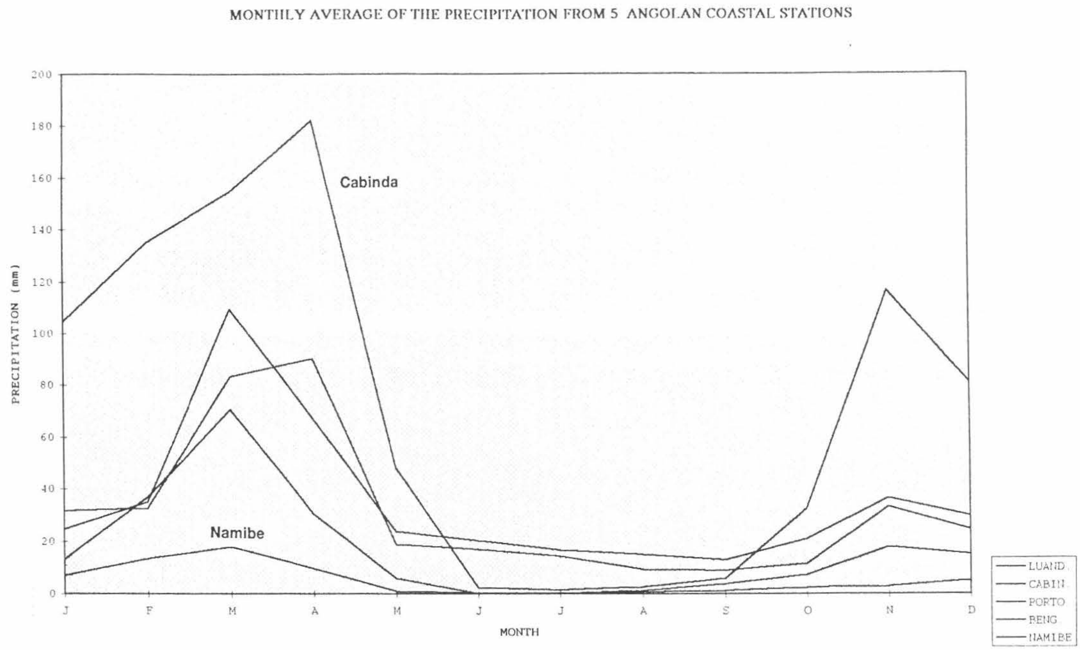


Fig. 1


MONTHLY AVERAGE OF THE PRECIPITATION FROM 5 ANGOLAN COASTAL STATIONS
200
180
160
140
120
100
80
60
40
20
0
PRECIPITATION (mm)
Cabinda
Namibe
J
F
M
A
M
J
J
A
S
O
N
D
MONTH
LUAND.
CABIN.
PORTO
BENG.
NAMIBE

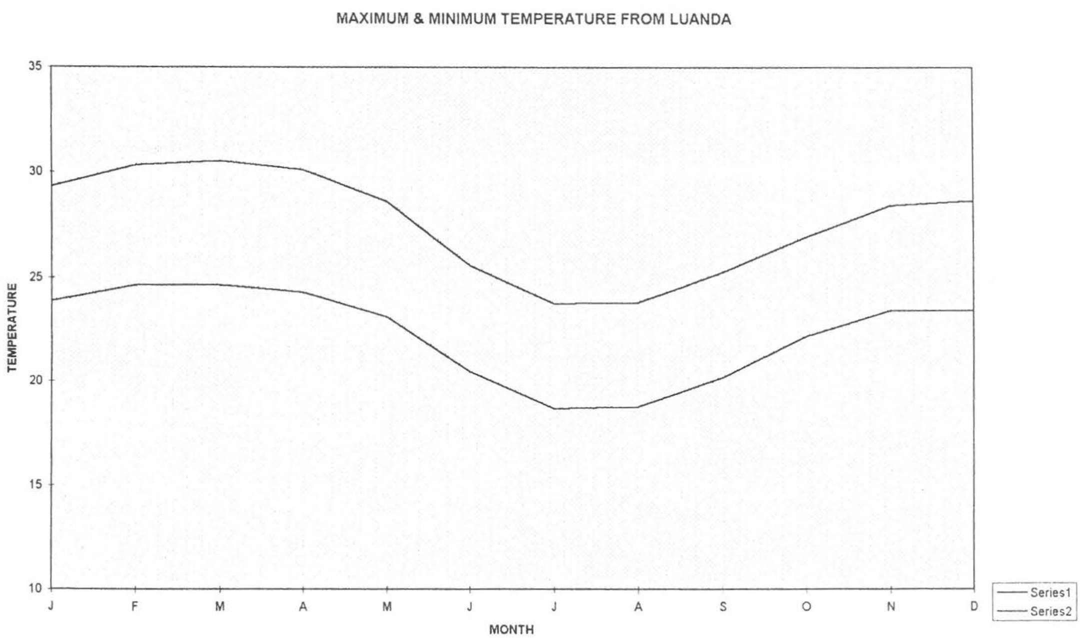
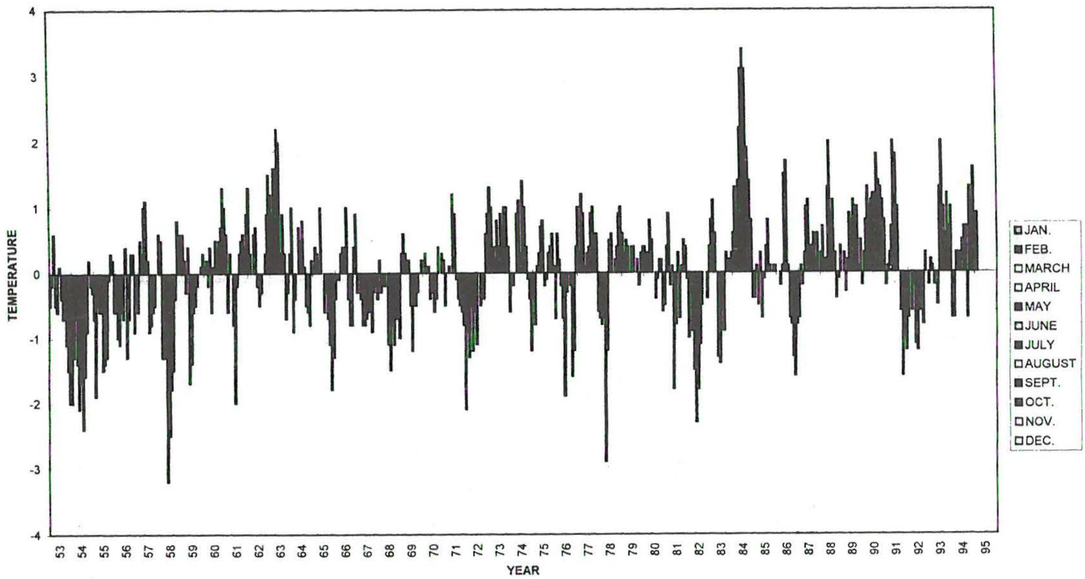

MAXIMUM & MINIMUM TEMPERATURE FROM LUANDA
35
30
25
20
15
10
TEMPERATURE
J
F
M
A
M
J
J
A
S
O
N
D
MONTH
Series1
Series2

Fig 2A and 2B

MAXIMUM TEMPERATURE ANOMALIES FROM LUANDA



Minimum Temperature anomalies from Luanda

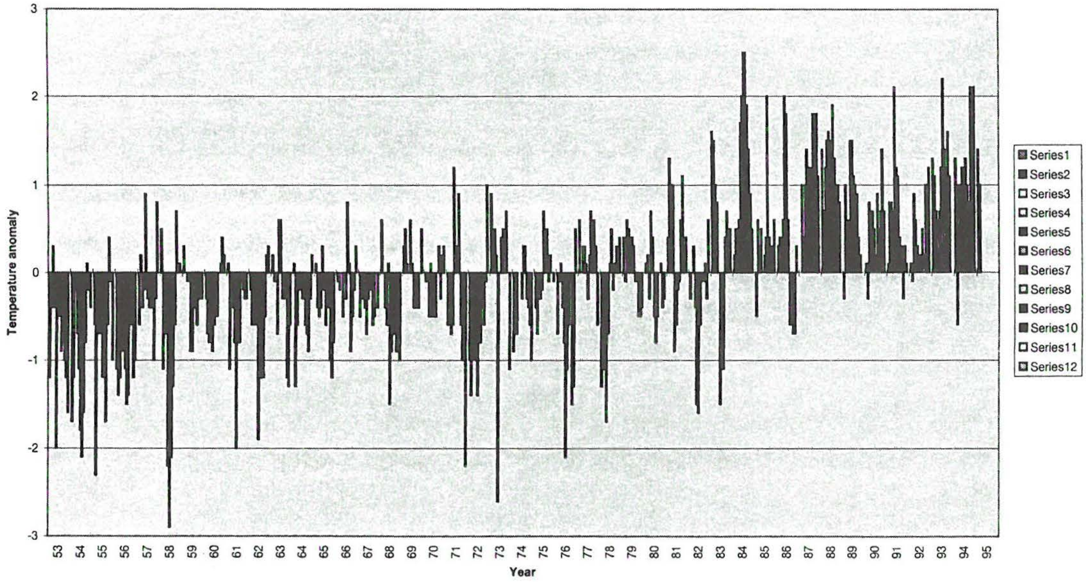
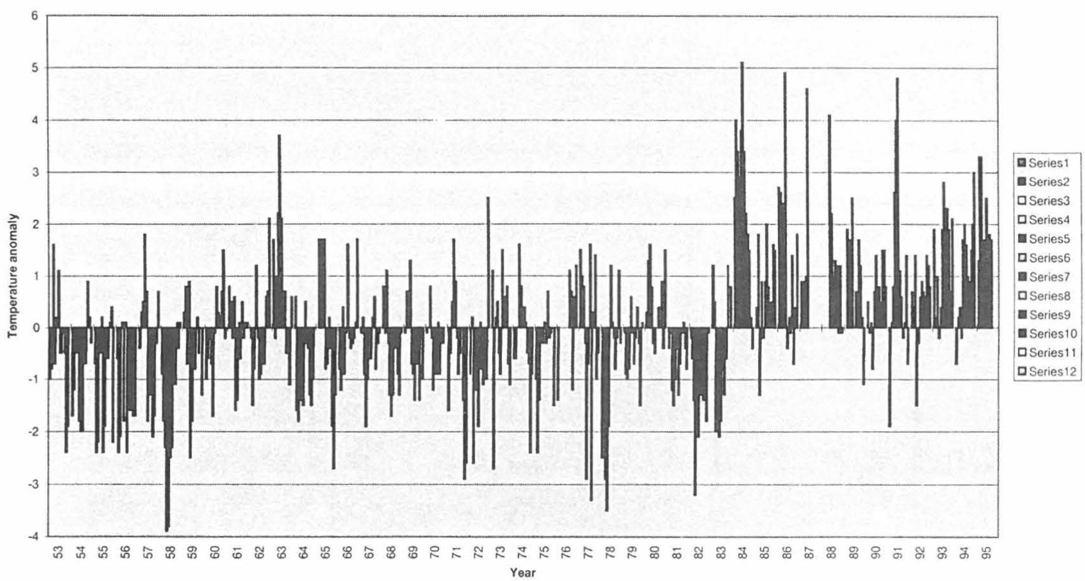


Fig 3A and 3B



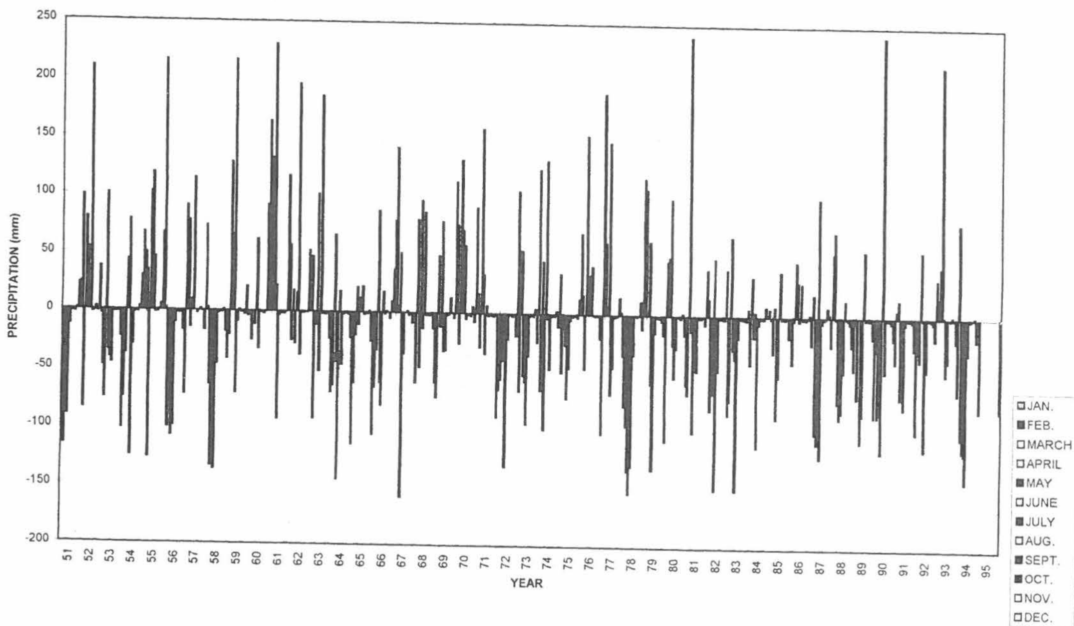


Fig. 4 and Fig. 5

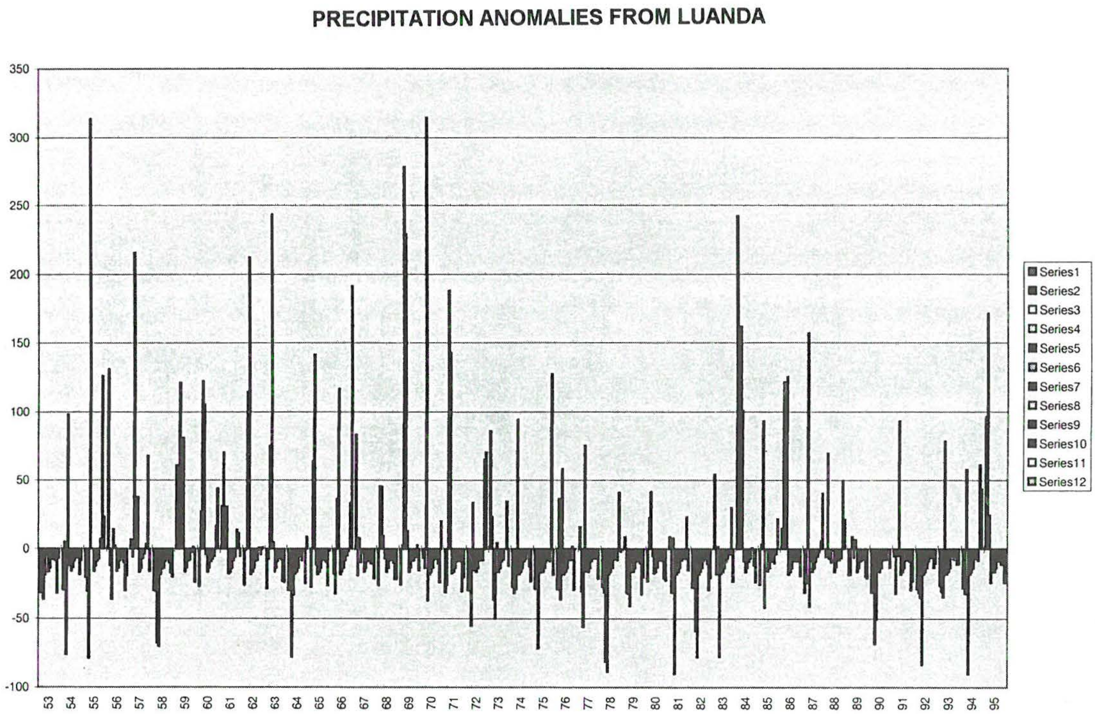

PRECIPITATION ANOMALIES FROM LUANDA
350
300
250
200
150
100
50
0
-50
-100
53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95
Series1
Series2
Series3
Series4
Series5
Series6
Series7
Series8
Series9
Series10
Series11
Series12

Fig.6

NANSEN COURSE IN ENVIRONMENTAL PHYSICS
Swakopmund, Namibia, 14 Nov - 15 Dec 1995

HYDROLOGICAL AND METEOROLOGICAL EFFECTS OF THE BENGUELA NIÑO

By

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Abstract

An analysis of the precipitation and atmospheric temperatures along the coastal belt and over the central plateau of Namibia and of the sea surface temperatures (SST) of the Swakopmund Mole was done to correlate the hydrological and meteorological effects of the Benguela Niño during the suspected 1984 and 1995 phenomena.

INTRODUCTION

Namibia, in south-western Africa, is bounded on the north by Angola and Zambia, on the east by Botswana and South Africa, on the south by South Africa, and on the west by the South Atlantic Ocean.

Namibia can be divided into three physical regions: a low-lying coastal belt, a central plateau, and the Kalahari Desert. The coastal belt consists of the Namib Desert. It extends along the entire Atlantic coast and ranges from 100 to 160 km in width. On the east, the central plateau rises abruptly at the Great Escarpment. The plateau averages about 1100 m in elevation, but rises in several mountainous areas to elevations greater than 1800 m. Along the eastern border is the Kalahari Desert. Due to the vast differences in altitude between the coastal belt and the central plateau, precipitation differs greatly.

The climate is generally hot and dry. The average annual precipitation in the Namib Desert along the coast is 51 mm. Inland, annual precipitation increases from 152 mm in the south to 559 mm in the north. Most rain falls in summer (October to March). The average annual temperature on the coast is 16.7° C (fluctuating between 10° C and 35° C); inland it is 21.1° C (fluctuating between 5° C and 35° C). Years in which the figures fall into these perimeters are considered as normal hydrological and meteorological years.

The cool Benguela Current offshore moderates the temperatures and reduces the precipitation of the coastal region. However, when warm and brackish upper ocean layers are present instead, the phenomenon is referred to as the ***Benguela Niño*** (Shannon et al. 1986, Gammelsrød et. al. 1995) a counterpart of the more frequent Pacific El Niño (Wuetrich, 1995) The South Atlantic Niño is suspected to be a once per decade occurrence, that is related to the relaxation of the zonal windstress in the equatorial west Atlantic and the advection of warm, saline tropical and equatorial water from the west and north-west (Shannon et al, 1986, Gammelsrød et. al 1995). This is due to the slackening of equator-ward wind-stress that leads to reduced upwelling and therefore a warming of near shore surface waters. The last and probably most thoroughly recorded Nino's were in February-March '84 and in March '95. It has been speculated that during these periods, the hydrological cycle has intensified over the coastal belt and decreased over the central part of the country. The idea behind this theory is, that the evaporation of water requires heat energy, where higher sea surface temperatures (SST) encourage more evaporation, hence an increase in precipitation.

The objective of this project is to find a correlation between the Benguela Nino and Namibia's precipitation and temperatures during such indicated periods. In order to asses the changes and their nature, one needs a basis of what is normal. For this purpose, there is only an extremely short period of data available. The data chosen for this project, ranging from 1981 to 1995 should outline the suspected '84 and '95 Nino's events.

In order to forecast such a Nino event, one needs an understanding of the phenomenon. What triggers such an event, what are the direct consequences and when will it make its presence felt again? The aspiration behind such questions lies in the knowledge, that accurate forecasts can aid in the planing towards more severe Niño events. In a desert country like Namibia, this knowledge can help farmers decide on what crops to plant and give authorities time to plan for oncoming droughts.

DATA AND METHODS

Collection of Data

Three sets of data have been analyzed for this paper: Precipitation data, Sea Surface Temperatures (SST) and Atmospheric Temperatures.

Precipitation data

Throughout Namibia there are a number of precipitation stations, where daily precipitation values are taken. In Namibia, readings are taken daily at $8h^{00}$ in the morning. For the purpose of this project it was considered sufficient to choose a station from the central plateau of Namibia and one from the low-lying coastal belt. Consequently, the stations Windhoek, in the central of the country, and Gobabeb, situated in the coastal belt of the country, were chosen, since these two locations are considered to produce the most reliable figures. Due to the intermittent nature of precipitation in Namibia, precipitation varies over an extend of several kilometers. Therefore, data from the Windhoek Weather station and data from the Windhoek Airport were averaged.

Monthly precipitation data, i.e. total precipitation data for a given month, measured in mm rainfall, were used instead of daily precipitation data.

The data were obtained from the Department of Water Affairs, Division Hydrology. Data range from the hydrological season 1981/82 to 1994/95. Breaks in data, denoted by lost data do occur.

Sea Surface Temperatures (SST)

These data were made available by the Sea Fisheries Institute in Swakopmund. Twice a day, early morning and during lunch, the SST figures are measured manually at the Swakopmund Mole. Since the water in the mole is shallow, the temperatures may be influenced by atmospheric temperatures.

Again, monthly averages of the daily temperatures were used for analysis. The data used ranges from 1981 to 1995. The units are in °C and the data set is incomplete.

Atmospheric Temperatures

Similar to precipitation, there are a number of weather stations spread throughout the country. Again, Windhoek and Gobabeb were considered. Data for these stations were obtained from the Windhoek Weather station. These are in the form of daily maximum and minimum atmospheric temperatures for the period 1991 to 1995. The monthly averages on the maximum and minimum figures were used respectively and the unit is in °C.

INSTRUMENTS

Precipitation Data

Precipitation is measured by a rain gauge. The rain gauge consists of an upright cylinder, open at the top to catch the rain and calibrated either in inches or in millimeters, so that the total depth of the precipitated water may be measured.

Sea Surface Temperatures (SST) and Atmospheric Temperatures

For the observation of temperature many different types of thermometers are employed. For most purposes an ordinary thermometer covering an appropriate range is satisfactory. It is important to place the thermometer in such a way as to minimize the effects of sunshine during the day and of heat loss by radiation at night, thus yielding values of the air temperature representative of the general area. Usually, daily maximum and minimum values are distinguished. Either these values may be obtained by taking the temperatures at 3 hour intervals or using a max-min thermometer, which rises up to a maximum temperature and drops to a minimum temperature respectively on two separate thermometers.

Data Processing

All the data was processed in Microsoft Office - Excel:

Precipitation Data

The precipitation data received from the Hydrology Office was sorted by hydrological seasons. For the purpose of this project, the data had to be reorganized into customary years. Now, the monthly totals of all the January, February etc. months for each station were calculated to produce a so-called 15 yr. mean for the data from 1981 to 1995. A spreadsheet would then look as follows:

Monthly Precipitation Data for Windhoek Airport

Season	Jan	Feb	Mar	...
1981	0.7	1.2	0.0	
1982	15	12	1.4	
...				
15 yr. mean	13.0	32.0	40.0	...

From here on the data was transposed, the consecutive years copied underneath each other and the anomalies were calculated by subtracting the 15yr mean for each respective month from the months mean value:

Monthly Precipitation Data for Windhoek Airport

	monthly rainfall	15 yr. mean	anomaly
01-81	0.7	13.0	0.7 - 13.0 = -12.3
02-81	1.2	32.0	1.2 - 32.0 = -30.8
...	...	...	...

Using this data, a graph of the monthly precipitation for the period 1981 to 1995 and a graph of the anomaly for the same period was plotted respectively for the given station.

This procedure was followed for the data sets of Gobabeb, Windhoek Airport and Windhoek Weather station. The Windhoek Airport and Windhoek Weather station data were then used to derive the Windhoek Mean

The final products are discussed and represented in Section 3 .

Sea Surface Temperatures (SST)

Similarly to the precipitation data, the 15yr mean of the SST figures obtained at the Swakopmund Mole was calculated and the respective anomalies were deduced. The graphs representing monthly mean SST and anomaly were then plotted respectively. These are analyzed in Section 3.

Atmospheric Temperatures

The maximum and minimum temperatures were analyzed separately. Thereof, graphs representing maximum mean temperatures, graphs representing minimum mean temperatures and graphs representing anomalies for maximum and minimum temperatures were plotted respectively. This procedure was followed for Gobabeb and Windhoek separately.

Taking each set of maximum and minimum temperatures, a difference between the maximum and minimum temperatures for each month was calculated. From these, an average value was derived, that was subtracted from each difference to give an anomaly:

Anomaly from the 16.3 mean temperature difference for Windhoek

	max temperature	min temperature	(max-min)	anomaly
01-81	35.7	15.8	19.9	19.9-16.3
02-81	32	17.4	14.6	14.6-16.3
...	...	...	...	
			mean = 16.3	

The graphs and results are analyzed in Section 3.

RESULTS AND DISCUSSION

It is suspected that the Benguela Niño Phenomenon occurred during February-March '84 and during March '95. An indication of this would have been increased sea surface temperatures (SST) along the coastal belt of Namibia, as well as a change in local precipitation patterns resulting in changed mean atmospheric temperatures. The objective of this paper is to find and verify the meteorological and hydrological effects these phenomena had on Namibia. The expectations are, that the hydrological cycle over the central plateau of the country was reduced whereas along the coastal belt, the hydrological cycle intensified. Also, as a result of decreased cloud formations over the central plateau during the periods indicated, the differences between the maximum and minimum temperatures should have increased. Along the coastal belt, the differences in temperatures should have decreased.

In addition, the 92/93 season tends to stand out: It is suspected that the effects of the 1992 Pacific El Niño might be the cause. Wuethrich, B. (1995).

Precipitation Data

Below, the mean precipitation and precipitation anomaly graphs are shown:

In Fig 1, the monthly precipitation and anomaly for the monthly precipitation of Gobabeb are presented. Precipitation figures are given in mm rainfall. From both graphs, it can be clearly seen, that precipitation along the coastal belt of the country is relatively irregular. This is due to intermittent fog formation over this part of the country. Furthermore, it hardly ever rains along the coastal belt of Namibia, which is evident from a 0.9mm monthly mean precipitation figure from 1982 to 1995 for Gobabeb. The total precipitation peaked during the 87/88 and 88/89 seasons with 19.6mm and 15.3mm respectively. By season, the year starting in July and ending in June is implied. The 93,94 and 95 data sets are incomplete, which means, that more precipitation might have occurred during these periods.

In Fig 2, the monthly precipitation and anomaly for the monthly precipitation of the Windhoek Airport (2.a) and Windhoek Weather station (2.b) are presented respectively. At the Windhoek Weather station, total precipitation for a season peaks in the 85/86 and 87/88 seasons, whereas the total precipitation for a season for the Windhoek Airport peaks in the 82/83 and 87/88 seasons. Total seasonal precipitation between the two areas differs between 9mm up to 160 mm per season. The 81,94 and 95 data sets are incomplete. Since for 94 and 95, some of these fall into the rainy season, precipitation might have occurred during these periods.

In Fig 3, the monthly precipitation and anomaly for the monthly precipitation of the Windhoek Area, which is a monthly mean of the precipitation data from the Windhoek Weather station and Airport, are presented. The total seasonal precipitation peaked during the 87/88 and 88/89 seasons. The total seasonal precipitation was at a least during the 81/82 and 94/95 rainy seasons.

Sea Surface Temperatures (SST)

Fig 4 represents the mean SST and anomaly for the mean SST graphs for the Swakopmund Mole. All temperature figures are given in °C. For 1991 and 1992, the data sets are incomplete. The mean SST encountered at the mole, for the period from 1980 to 1995 is about 14.8 °C. Yearly average SST peak in the 83/84, 92/93 and in the 94/95 season. The monthly mean SST's also peak in the 83/84, 92/93 and in the 94/95 season. Considering the anomalies for the mean SST at the Swakopmund Mole, the SST before 1984 are virtually all negative, whereas from the beginning of 1984, SST suddenly increase dramatically. In the analysis by Shannon et al. (1986) of the SST data from the Swakopmund Mole, 1984 was preceded by two cooler that normal SST years.

Atmospheric Temperatures

The temperature data is given in °C. Fig 5 represents the monthly mean atmospheric temperatures and anomaly for the monthly mean atmospheric temperatures for the minimum and maximum figures for Gobabeb (5.a) and Windhoek (5.b) respectively. The minimum mean temperature of Gobabeb is 13.8 °C and the maximum mean temperature of Gobabeb is 30.3 °C. The minimum and maximum mean temperatures for a season peak in the 94/95 season.

In Fig 5.b, the minimum mean temperature and the maximum mean temperature for Windhoek are 13.1 °C and 27.3 °C respectively. The minimum and maximum mean temperatures for a season peak in the 94/95 season. Normally, one would expect atmospheric temperatures in the central plateau of the country to be higher than those along the coastal belt of the country. However, from the precipitation data, is seems, that mean precipitation in this period was comparatively less in Windhoek and more in Gobabeb. Hence, the lack of cloud formations over Windhoek might have resulted in a decrease in temperature, whereas in Gobabeb, more cloud formations might have increased the overall temperatures.

Fig 6.a depicts the differences in maximum and minimum atmospheric temperatures for Gobabeb and the anomalies from the 16.5 °C mean temperature for Gobabeb. The anomalies were obtained by subtracting the 16.5 °C mean temperature in the interval 91 to 95 from the mean difference in monthly atmospheric temperature for each month during that period. Here a trend is difficult to identify due to the intermittent nature of atmospheric temperatures along the coastal belt of the country. In Fig 6.b is the graph for the anomalies from the 14.1 °C mean temperature for Windhoek.

CONCLUSION

In this paper, the objective was to verify suspected hydrological and meteorological effects of the Benguela Niño. It is suspected that the Benguela Nino Phenomenon occurred during February-March '84 and during March '95. An indication of this would have been increased sea surface temperatures (SST) along the coastal belt of Namibia, as well as a change in local precipitation patterns resulting in changed mean atmospheric temperatures. For this purpose precipitation data from the Department of Water Affairs, Division Hydrology, for the Windhoek weather station, for the Windhoek Airport and for Gobabeb, atmospheric temperatures from the Windhoek Weather station, for Windhoek and Gobabeb and SST data from the Sea Fisheries Institute, for the Swakopmund Mole were analyzed.

A straightforward interpretation of the data was intricate as a result of intermittency of precipitation and temperature patterns throughout the country and the short period of data available for analysis. Direct conclusions regarding the effects of the Benguela Nino could not be made.

Future projects should incorporate more SST data off the coast of Namibia and a greater number of stations along the coastal belt and in the central plateau. In order to investigate the hypothesis, that the Benguela Niño is present every ten years, one should incorporate data from the beginning of the century. This would also provide a bigger scope to identify trends and deduce anomalies. It might also be interesting to incorporate possible effects of the Pacific El Niño phenomenon on the inland of the country.

Acknowledgments

I wish to thank the following individuals and departments for their support in providing the datas required for this paper:

The Windhoek Weather station for the Atmospheric Temperature data.
At the Department of Water Affairs, Division Hydrology, Mrs A. Eggers for the Precipitation data.

At the National Marine Information and Research Center, Mr C. Bartholomae for the Swakopmund Mole SST data.

Furthermore, the support by the NANSEN program and the NANCEP leader, Prof. Tor Gammelsrod is greatly appreciated

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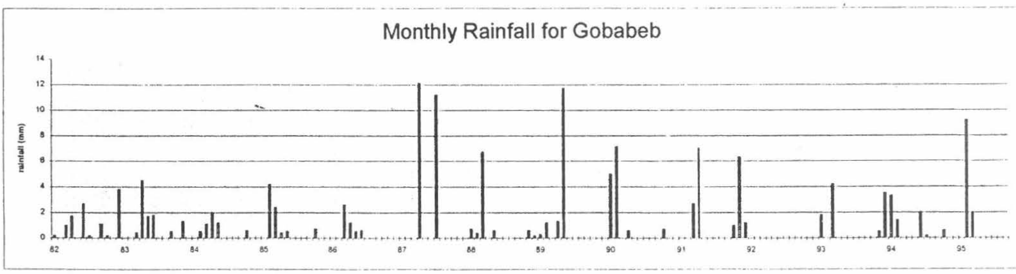
Figure 1. Precipitation Graphs for Gobabeb



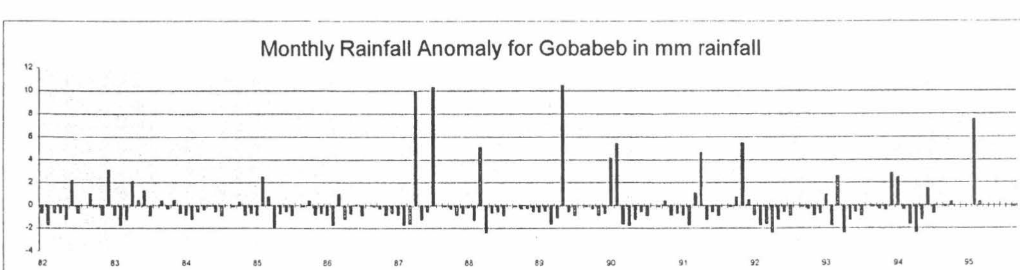
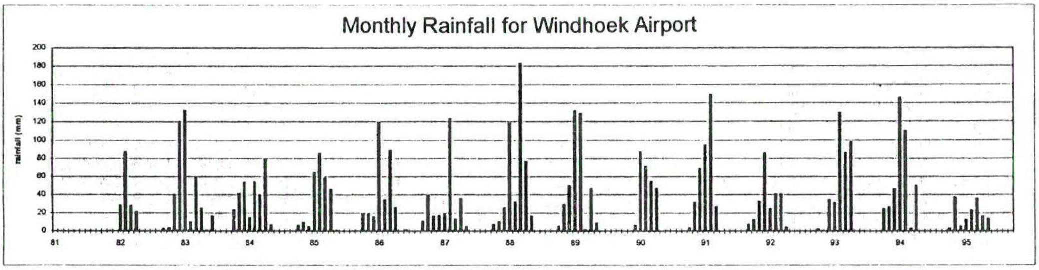


Figure 2a. Precipitation Graphs for Windhoek Airport



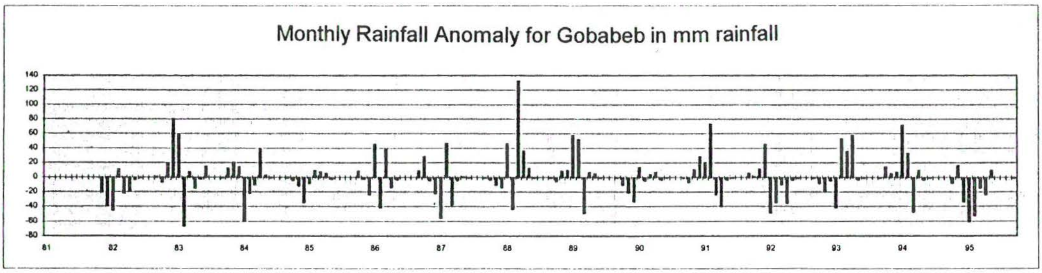
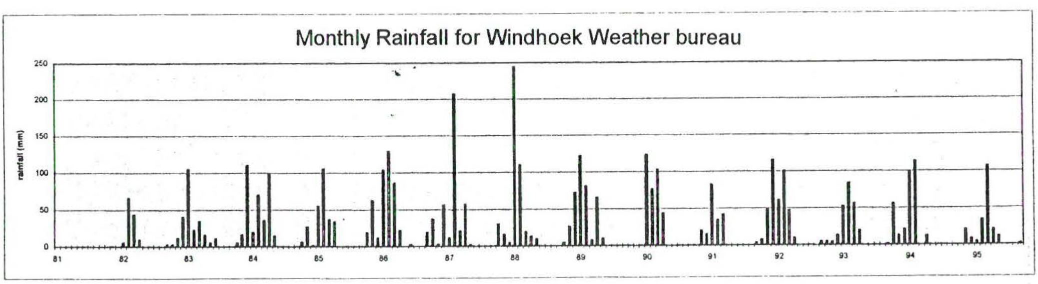


Figure 2b. Precipitation Graphs for Windhoek Weather bureau



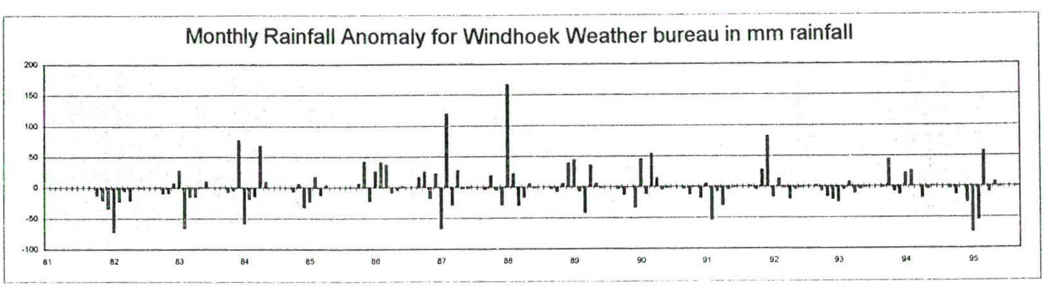


Figure 3. Precipitation Graphs for Windhoek Area

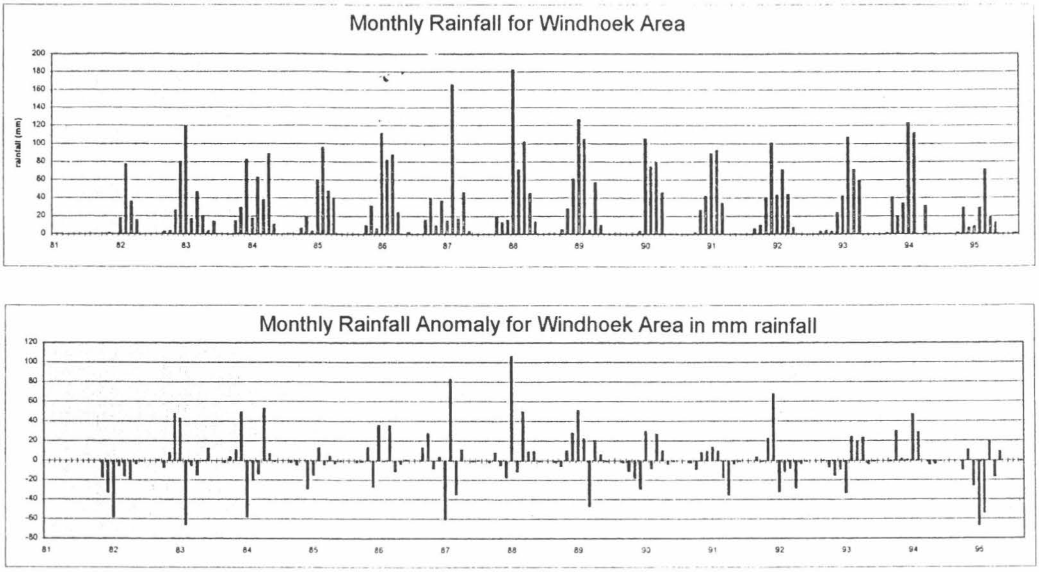


Figure 4: Mean Sea Surface Temperatures for the Swakopmund Mole

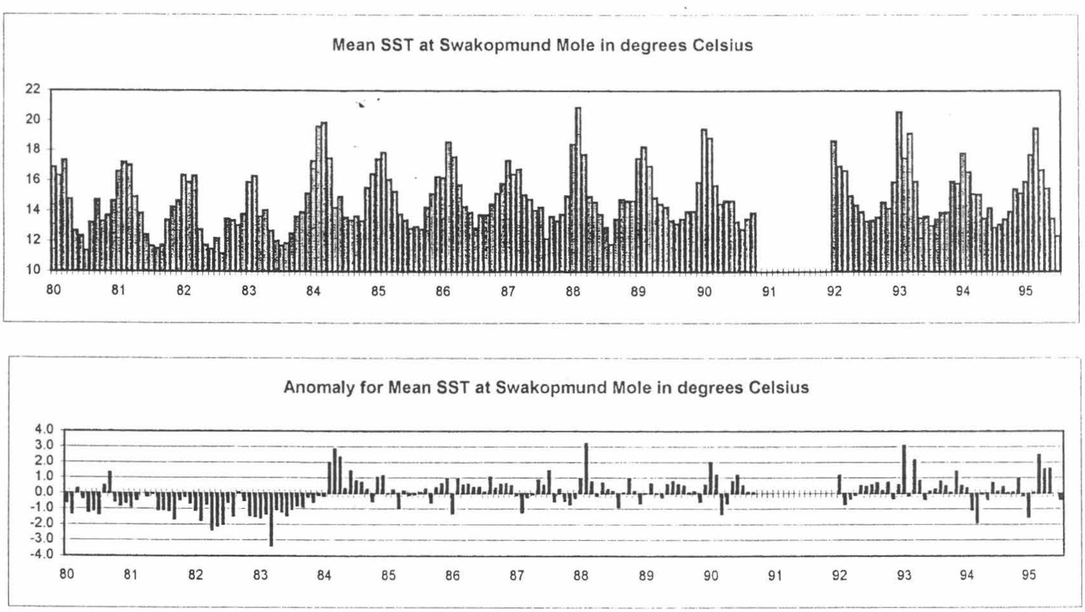


Figure 5.a: Atmospheric Temperatures for Gobabeb

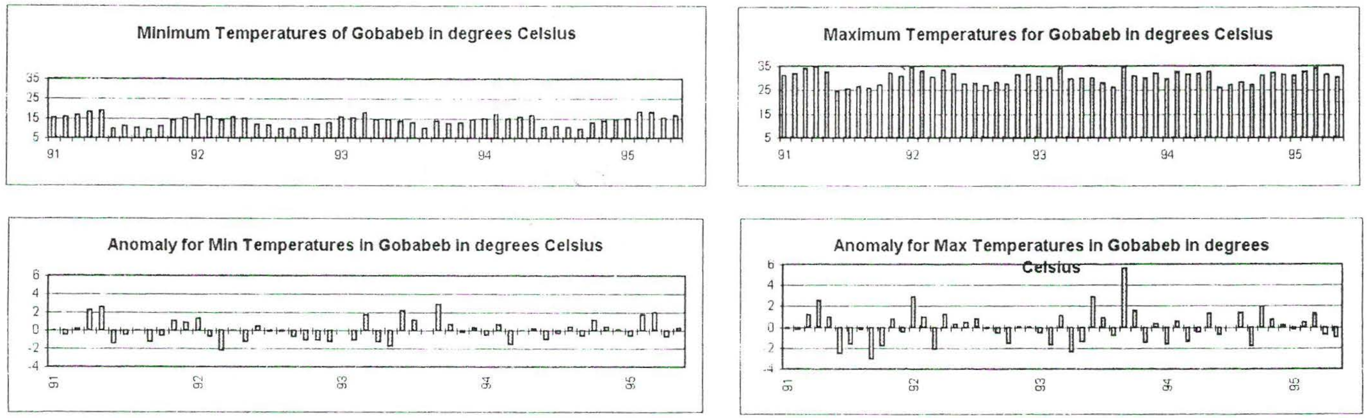


Figure 5.b: Atmospheric Temperatures for Windhoek

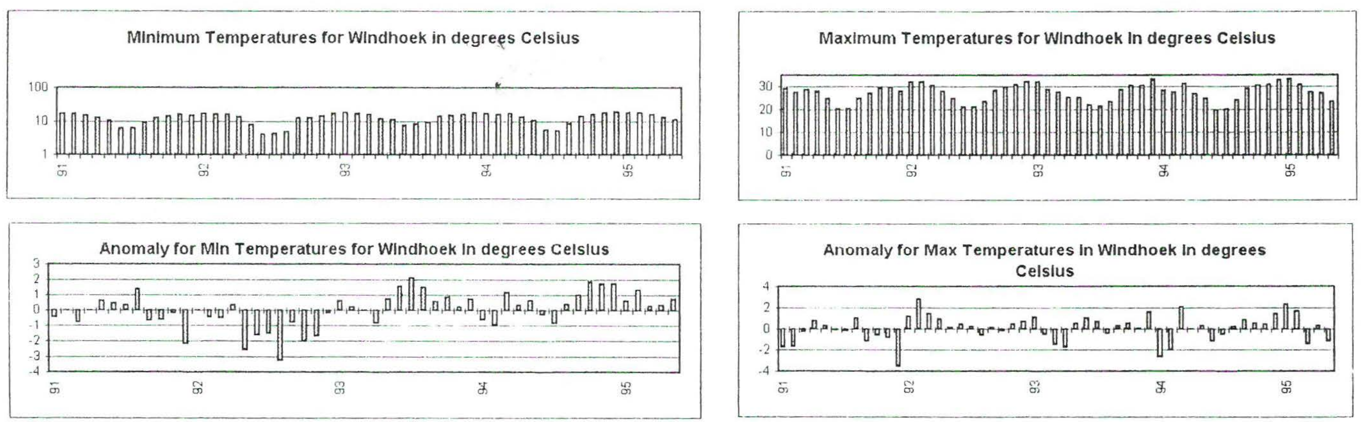
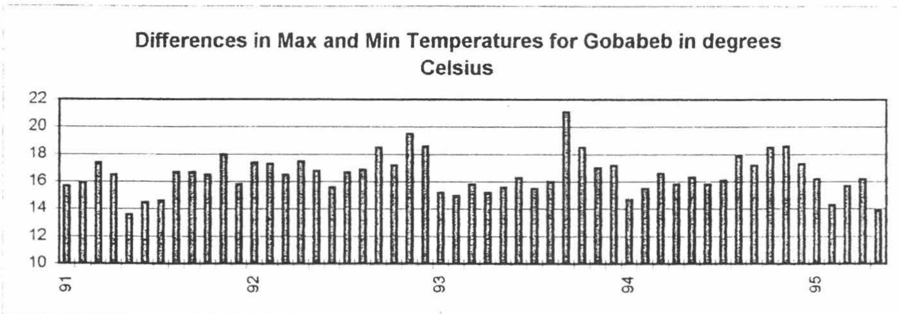


Figure 5.a: Atmospheric Temperatures for Gobabeb

Figure 5.b: Atmospheric Temperatures for Windhoek

Figure 6: Differences between Maximum and Minimum Temperatures

Figure 6a:



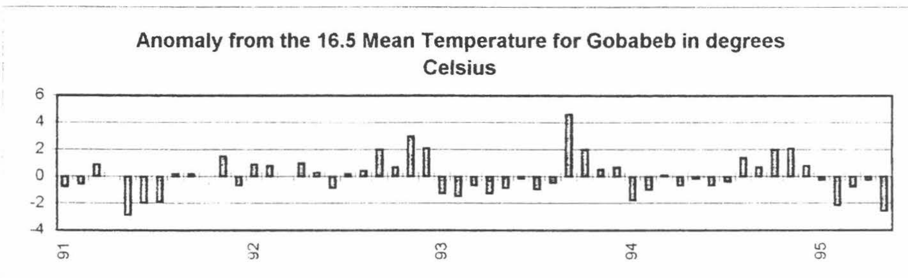
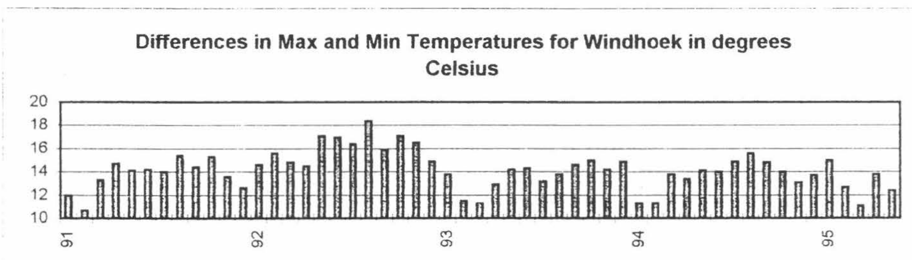
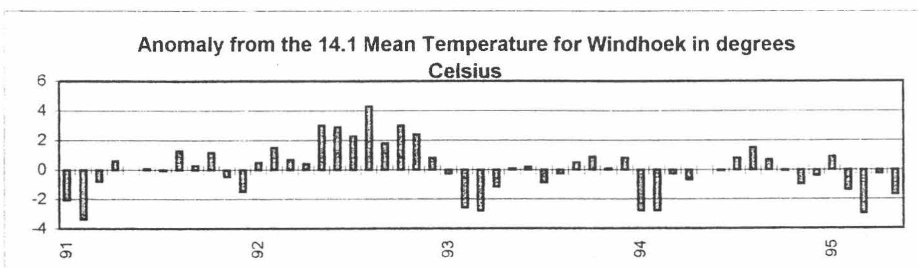


Figure 6.b:





NANSEN COURSE IN ENVIRONMENTAL PHYSICS
Swakopmund, Namibia, 14 Nov - 15 Dec 1995

INERTIAL OSCILLATIONS IN NAMIBIAN WATERS

By

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Abstract

During May 1995 a current meter mooring was deployed for a 18 days period off Walvis Bay on the Namibian coast. The mooring consisted of 3 current metres and a water level recorder. Beside currents and pressure, also temperature and salinity were recorded. The data were analysed for tidal components as well as variations over longer periods. A semi-diurnal signal is clearly revealed in the water level record, which is not seen in the currents. The possibility that the observed periodicity in the currents are due to inertial oscillations are discussed.

INTRODUCTION

The Benguela current is the most significant hydrographic feature along the Namibian coast. Most previous oceanographic studies were in support of biological studies (e.g. Strømme & Hamaukuaya, 1995), or the Benguela current at large (Shannon & Nelson, 1995). The oceanographic parameters studied in this project are the temperature and salinity that characterise the water masses; as well as the current velocities, as they influence productivity in the ocean and the distribution of the species.

In this paper we will look at the current data as measured during an 18-day period in May 1995 outside Walvis Bay at a depth of 170 m. The data were collected with the R/V "Dr. Fridtjof Nansen" (Strømme & Hamaukuaya, 1995). Observations levels were 10 m, 70 m and 140 m, as well as the bottom at 170 m depth where pressure was recorded. The sampling interval was 10 minutes, and the data are presented as originally recorded, as well as filtered values. The currents are presented both as components and progressive vector diagrams. The tidal ellipses for the most important components are also shown.

DATA, INSTRUMENTS AND METHODS

The data used for this study were collected offshore about 60 km from Walvis Bay coast at 23°S, i.e. at one location at three different depths; 10 m, 70 m and 140 m. Data was as well obtained from the sea bottom at the depth of 170 m.

The current measurements were obtained with the help of three Aanderaa RCM-7 current metres also WLR8. the water level recorder; at 10-minute intervals. The instruments were deployed in the water on May 09, 1995 at the coordinates 23°01'S 13°34'E and recovered on May 27, 1995.

The following parameters were recorded: current speed and direction, temperature, pressure and conductivity. According to the manual from the Aanderaa instrument the accuracy of the various sensors is as follows: ±1cm/s for current speed; ±5° for direction; ±0.05 °C for temperature; 0.1mΩ/cm for conductivity and ±0.5% for pressure. The instruments were calibrated at the factory prior to the supply of the instruments.

The analysis of the data was done using the program package developed at the Geophysical Institute; University of Bergen; Norway, (Røyset & Bjerke, 1982) and rewritten for PC by P.Andersen (personal communication). The tidal components were calculated using the programs developed by Foreman (1979).

RESULTS

Currents

The comparison between the current speeds at all three depths, before the data were filtered; are shown in fig. 1. The currents are presented as component towards east (U) and North (V). The time is given as Julian day.

As may be observed the current speeds are usually below 30cm/s, and a periodicity is clearly seen at all levels. Also in fig.1 we have shown the bottom pressure, which is a measure for the total pressure, and therefore will be dominated by the sea level. The tides are here clearly seen.

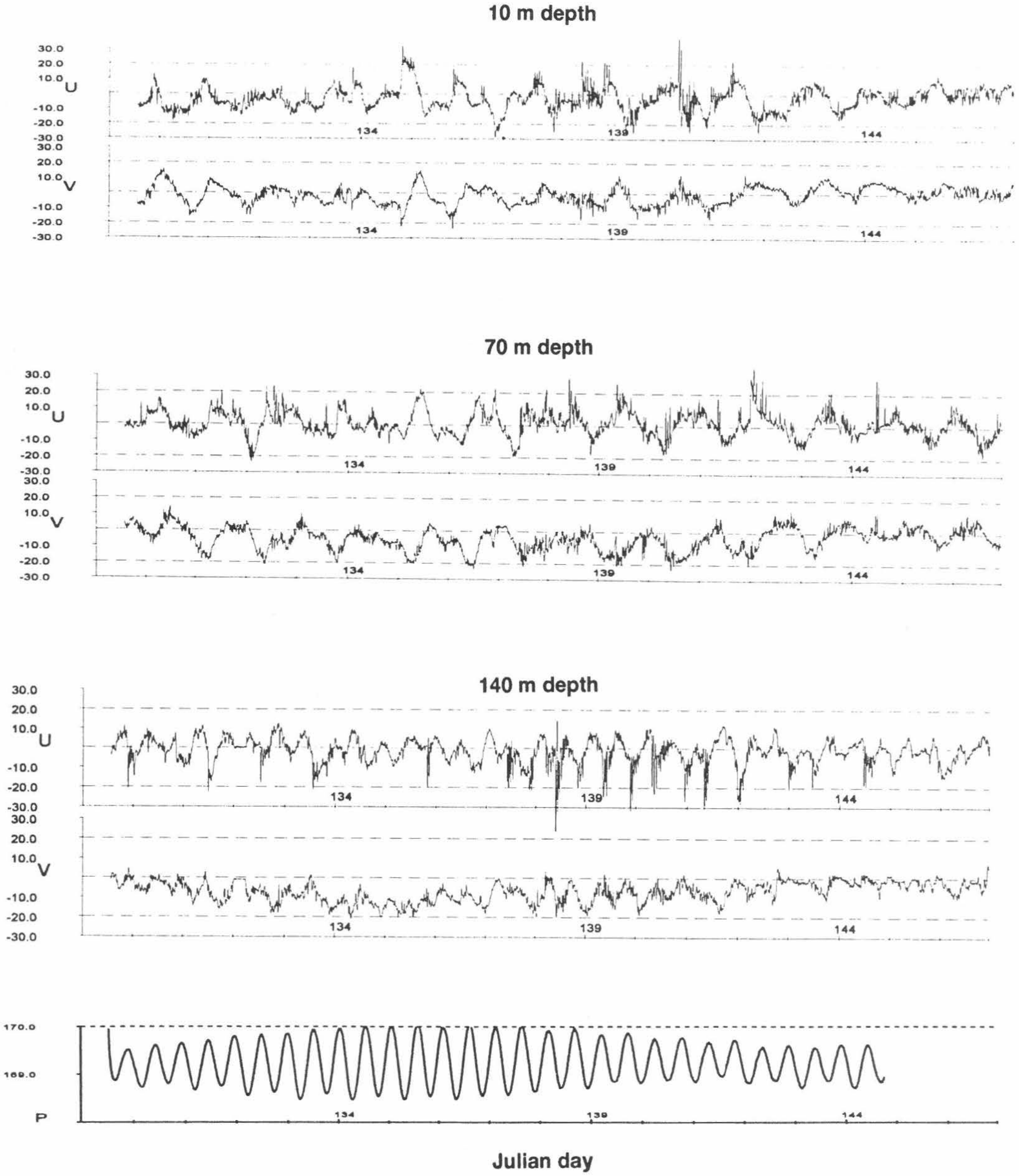


Fig.1 Velocity components (cm/s) towards east (U) and north (V) versus time at 10m, 70m and 140m depth. The lowest panel shows bottom pressure in desibars. Time is given as day of year (Julian day).

To study variations on longer time-scales than the diurnal tides, the data were then filtered with a Butterworth filter with a 1/4 point at 40 hours (Robers & Roberts 1978), the resulting graphs are as seen in fig. 2. The strongest currents were found in the deeper water; where a southward current of about 10cm/s is observed for the most of the observation period.

This is also demonstrated in fig. 3, where the progressive vector diagrams are shown. We note from fig. 3 that at 140 m depth the current is strongest and almost steady towards South, somewhat more variable at 70 m directed SSE. In the surface layer at 10 m the average current is weaker and directed South-West, while the variability seems to be higher.

Pressure, salinity and temperature

The measurements for the pressure, temperature and salinity were also done at the three depths indicated. Temperature was also obtained at the bottom. The graphs of the observations for these parameters are shown in fig. 4. The largest amplitudes found in temperature at 70 m are probably not real but due to some failure in the sensors. There are small temperature and salinity variations at all levels, except at the bottom where the temperature shows an increasing trend.

Tides

The periodic rise and fall of the sea surface, known as tide, are a conspicuous feature of many coastal areas. The tides are mostly a consequence of the simultaneous action of the moon`s, sun's and earth's gravitational forces. The tidal ellipses for these current metres are to be seen in fig. 5. We note that although the semidiurnal dignal seem to be dominating in the bottom pressure record (Fig.1), this does not show up in the current ellipse, where the diurnal components are dominating, see also table I.

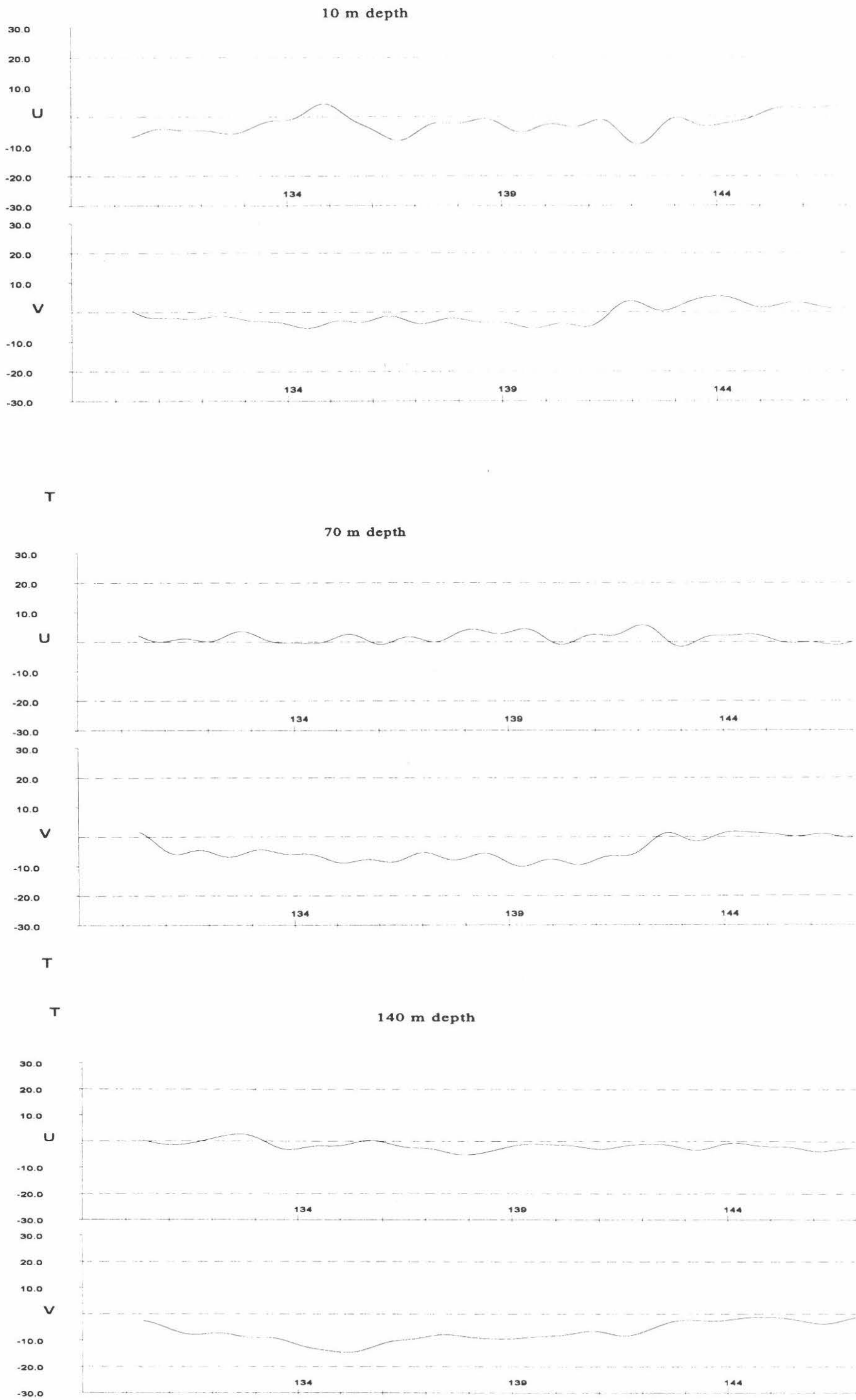


Fig.2 Low pass filter of the velocity components as shown in Fig.1

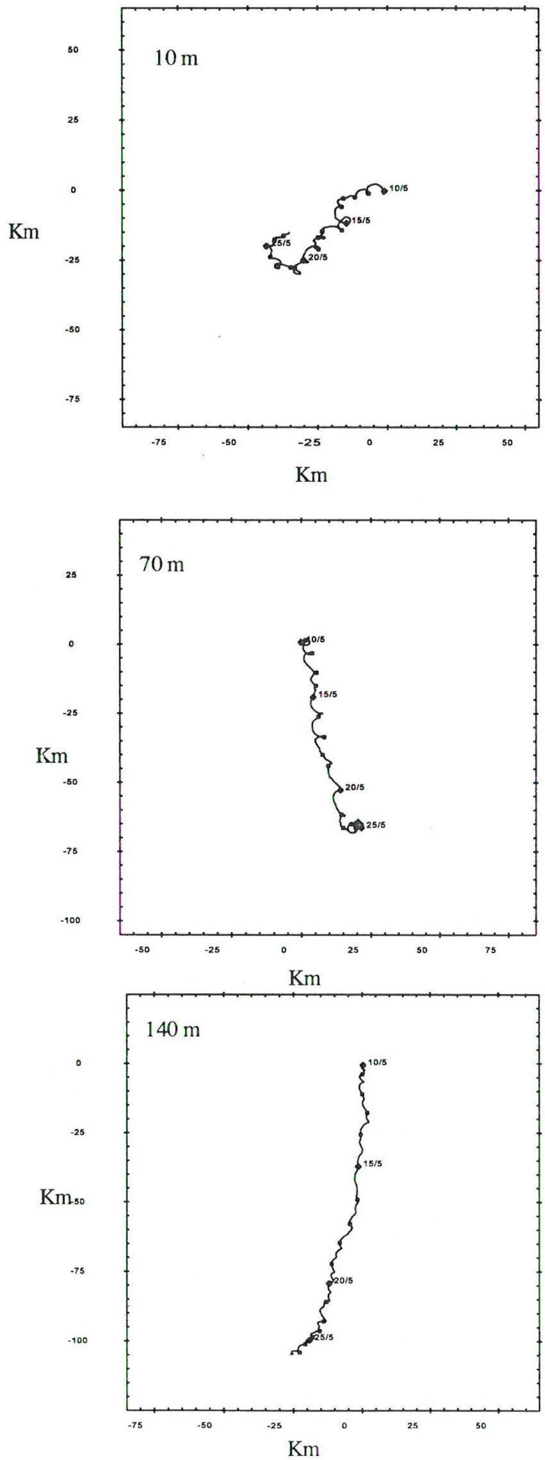


Fig.3 Progressiv vector diagrams for the currents at the 3 levels observed.

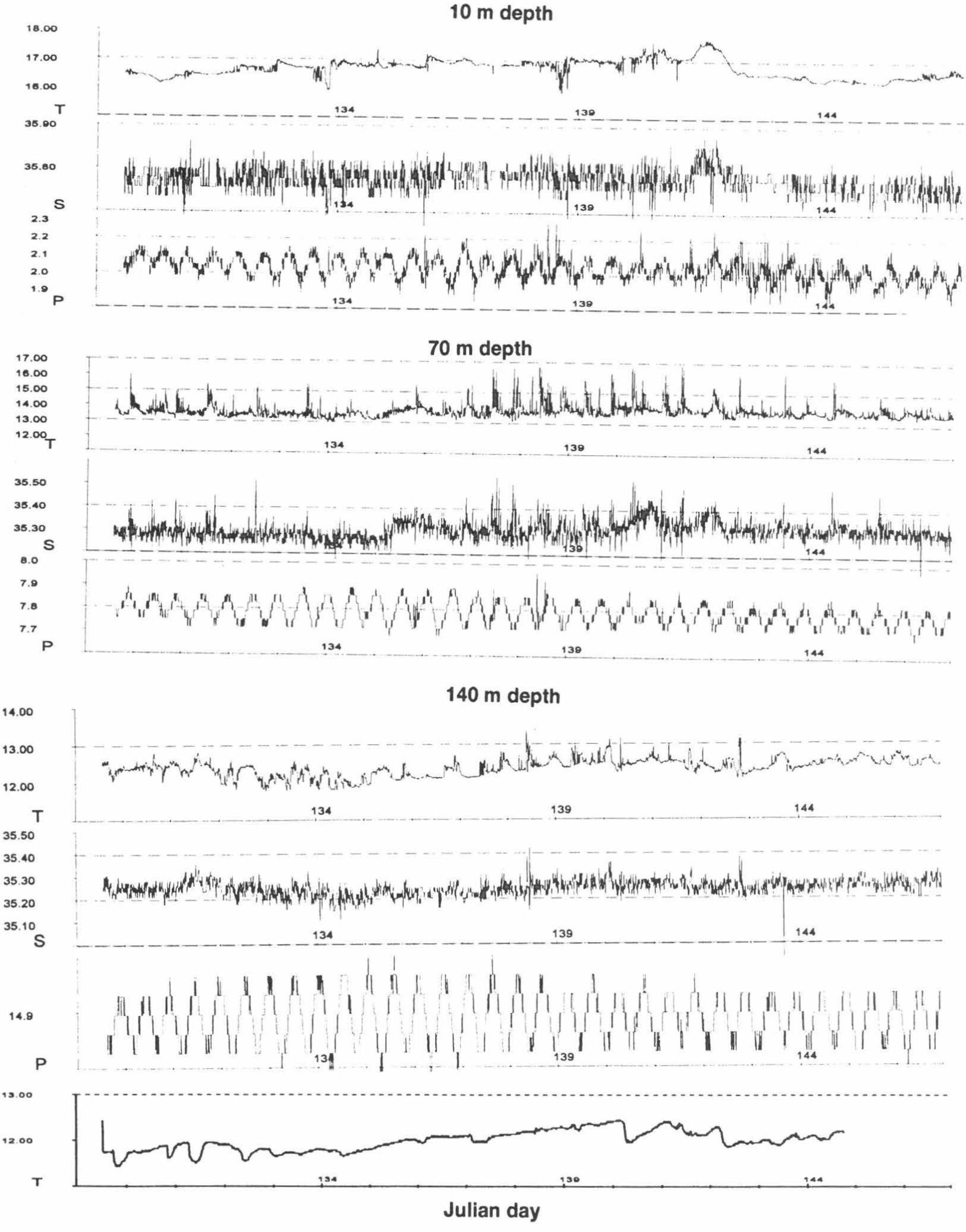
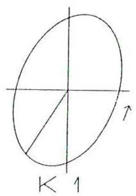
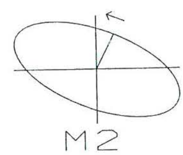


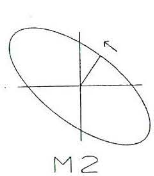
Fig.4 Temperature, salinity and pressure from the 3 current meters versus Julian Day. The lower panel show the temperature observations from the water level recorder at the bottom at 170m depth.



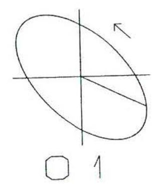
10 m, major axis=2.9cm/s



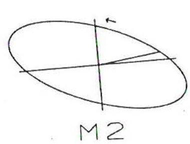
10 m, major axis=2.7cm/s



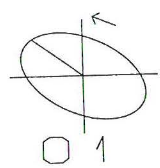
70 m, major axis=3.2cm/s



70 m, major axis=2.1cm/s



140 m, major axis=5.5cm/s



140 m, major axis=1.6cm/s

Fig. 5 Tidal ellipses for the most dominant components at the 3 levels of observation.

Fig 5.

DISCUSSION

The ocean currents are primarily wind driven, but also affected by the rotation of the earth. As a result of wind stress forces the surface current (10 m) was recorded to be weak along the coast, moving south-westerly with a maximum velocity components of about 20 cm/s. According to Ekman analysis the wind driven current speed will decrease as the depth increases and change direction anticlockwise in the southern hemisphere. Knowing this theory one would expect the current to follow the same trend, changing the direction of the current from south-westerly to south as observed in fig 3, but the magnitude has actual increased with the depth. This is probably due to pressure gradient provoking a geostrophic current.

By using the equation

$$v=s/t$$

where s is the displacement and t the period; the mean velocity v was found from the progressive vector diagrams (fig 3). The average velocity at three depths 10 m, 70 m, and 140 m are approximately 5,7 cm/s; 7,7 cm/s;10,5 cm/s respectively.

When looking at fig. 2 for the filtered data, one notice that the current at 10 m have a southerly direction until day 141, then change direction between day 141 and day 142 ; at the same period the surface temperature changes from increasing to decreasing (see fig. 4); indicating advection of cold water from the south.

The tidal patterns described in fig. 5 are dominated by Luni-solar diurnal and Principal lunar diurnal denoted by K1 and O1, having a period of 23.93 hours and 25.82 hours respectively. The water level record data (fig 1) shows a very distinct semi-diurnal period. It is therefore surprising that M2, the constituent that shows semi-diurnal with the period of 12.42 hours; does not show up as a dominant constituent of the tidal ellipses (see fig. 5 and table 1). Looking at the current speeds (fig 1) a periodic oscillation can be seen, (see for instance v-component at 70 m), but it seems to have a much longer period than the semi-diurnal.

Table I.		
10 m	**Major (cm/s)**	**Minor (cm)**
O1	0.716	0.289
K1	0.515	0.194
M2	0.202	-0.167
70 m	**Major (cm/s)**	**Minor (cm)**
O1	1.214	0.333
K1	0.791	0.263
M2	0.287	0.888
140m	**Major (cm/s)**	**Minor (cm)**
O1	0.875	0.238
K1	0.861	0.073
M2	0.445	0.107

By counting the number of maxima (or minima) for this oscillating movement for the whole registration period for the upper two velocities' data, we found that the oscillation period was about 30.9 hours on average.

The inertial period at 23 °S is given by the formula:

T= 0.5 sidereal day/sin ω,

where ω is the latitude and a sidereal day is ≈ 24 hours.

The inertial period was thus found to be 30.7 hours. Comparing the theoretical inertial period and the period observed it can be seen that they do not differ very much. This indicate that the dominant effect here is inertial motion. A better method that can be used to get an accurate answer is the energy spectrum method.

REMARKS AND FUTURE WORKS

As we can see, some trends which were left out unexplained; it was due the fact that the time was not long enough to be able to discover and find all the possible explanation to all the behaviours of the measured parameters. More detailed analysis should include more data points to give an indication if the current motion is indeed inertial and not predominantly tidal. For the next research one can also try to use the correct method of calculating the period.

Acknowledgements

I am very grateful to the "R/V Dr. Fridtjof Nansen" for providing the data as well as Prof. Tor Gammelsrød our coordinator and designer of the program that was used to processes these data as well as for coordinating the course. The Nansen Programme is acknowledged for the interesting course in the environmental physics. I wish to thank Antonio Mubango Hoguane, Detlof von Oertzen and Gunhild Schreiber for their guidance and assistance.

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NANSEN COURSE IN ENVIRONMENTAL PHYSICS
Swakopmund, Namibia, 14 Nov - 15 Dec 1995

TEMPERATURE AND SALINITY VARIABILITY AT THE ENTRANCE OF MAPUTO BAY

By

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Abstract

Temperature, salinity and water level records were obtained at the entrance of Maputo bay over 30 days during 8 April to 13 may 1993. The analysis have revealed that the tides in the bay are semidiurnal. The time series of temperature and salinity show strong influence of both the tides and seasonal variability. The role of the tides as an important exchange mechanism for water masses within the bay and the open ocean is discussed.

INTRODUCTION

Maputo Bay is located on the eastern border of Maputo city in southern Mozambique, Indian ocean at about 26°S, see Figure 1.

This bay holds a marine ecosystem with an important fishery. There are also large possibilities for tourism. The physical processes play an important role in the fishery resource, environmental management, near shore/offshore constructions and tourism. The bay serve also as a recipient of waste for the Maputo city. It is therefore essential to know the residence time and the current regime to be able to determine its capacity as a recipient.

In this report we have analysed the temperature and salinity variability at the entrance of Maputo bay, over a month. The variability are believed to be influenced by the tides. The exchange of the water between the Bay and the open ocean seems to have both semidiurnal and bi-weekly periods.

We hope, in the future to be able to estimate the water, salt and heat budget of Maputo bay, which in turn will give a clue of the residence time.

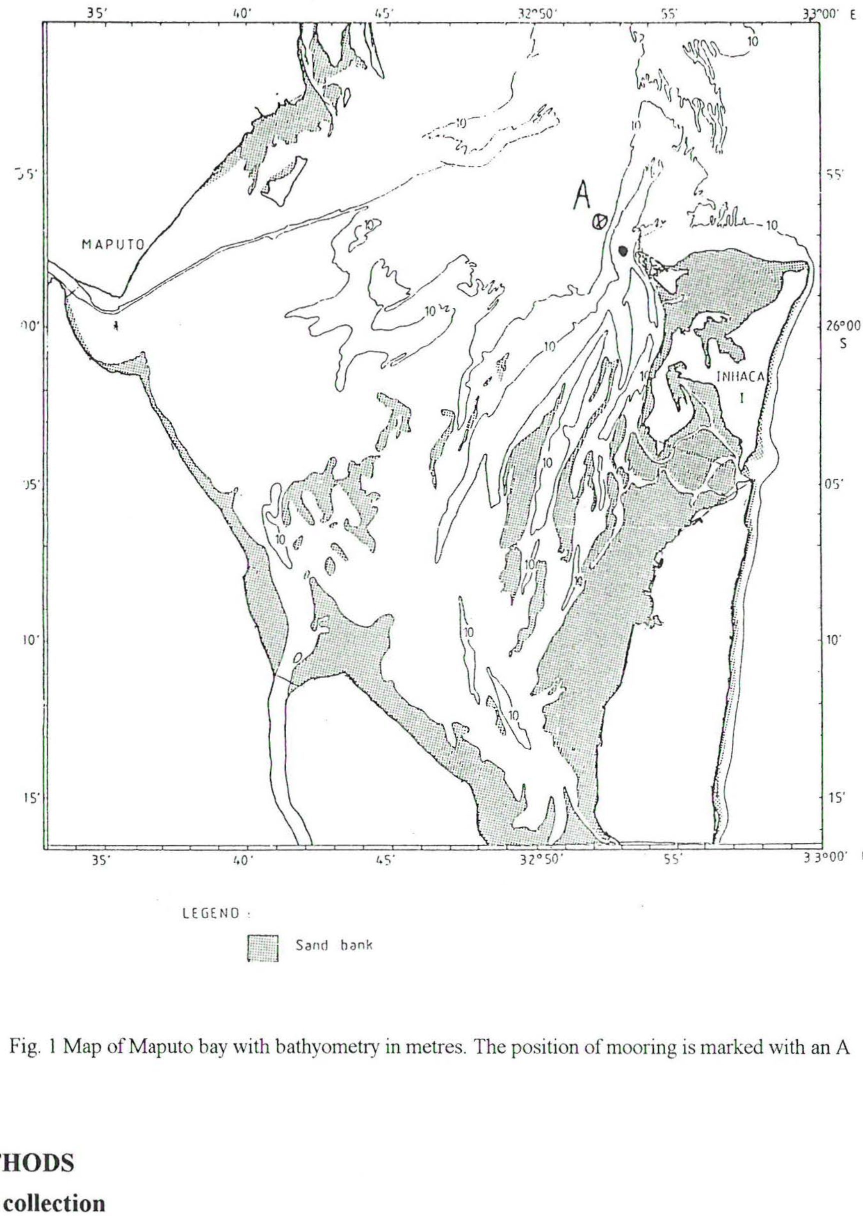

Fig. 1 Map of Maputo bay with bathyometry in metres. The position of mooring is marked with an A

METHODS

Data collection

The data set used here were acquired by the Mozambican Fisheries Research Institute, IIP. The current meter AANDERAA , RCM 7 and water level records WLR, were moored at the entrance of Maputo bay, at position 25°56 south and 32°52 east (Fig.1). This geographical position was determined using GPS navigation system.

The mooring lasted for about 30 days and records were made from 8 April to 13 May 1993. Data were recorded in an internal memory every 10 minutes.

The current meter was equipped with a temperature and conductivity sensor, thus salinity could be computed.

Data processing

The WLR data were used to plot the time series of sea surface elevation.

The current meter data were used to plot the time series of temperature and salinity. The temperature and salinity data were filtered over 50 hours in order to study the variability for longer period than the diurnal tidal cycle.

The programs for the analysis were written in Quickbasic.

RESULTS

Water level

The semi-diurnal signal is dominating the water level record, see Figure 2. Amplitudes of sea surface elevation range from almost 3m during spring tides to a little more than 0.5m during neap tides.

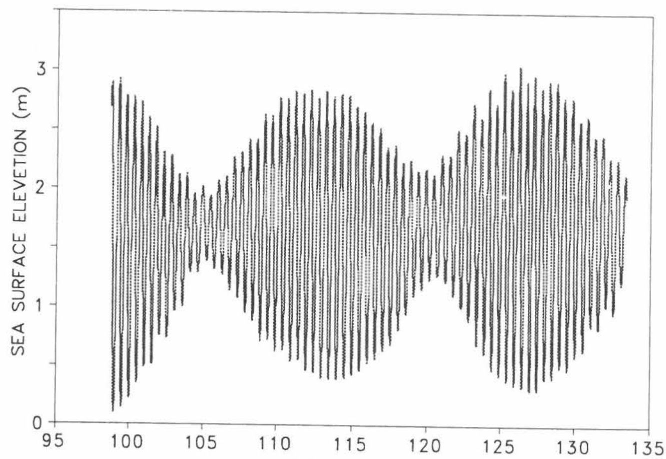

Fig. 2 Time series of sea surface elevation in mooring, at the entrance of Maputo bay from 8 April to 13 May

Temperature

The filtered temperature series are shown in Figure 3. The values ranges from 24.3 °C to 26.5 °C. The temperature shows a general decreasing trend. Superposed on this there seems to be oscillations with a period of about 14 days.

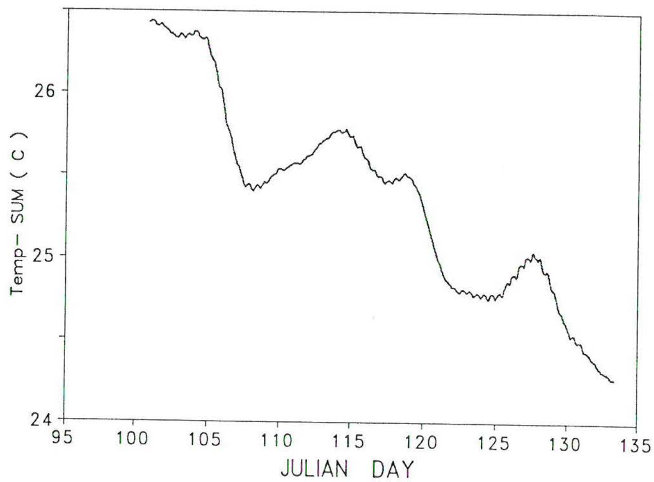

Fig. 3 Time series of temperature in mooring, at the entrance of Maputo bay during 8 April to 13 May

Salinity

The salinity is almost constant during the first 20 days, with some small oscillations, and then decrease fast during the last 10 days, see Figure 4. The values ranges from 35.3 psu to 33.2 psu.

The rapid decrease of the salinity in the end of the record is probably an artifact, due to biological contamination in the conductivity cell, which usually occur in tropical waters when exposed for more than a couple of weeks .

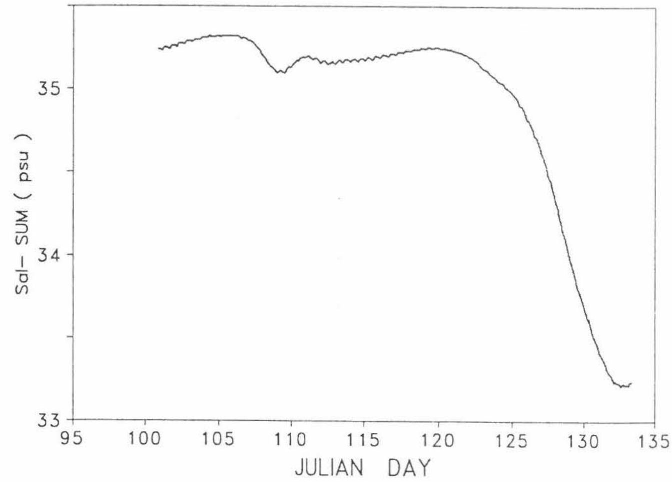

Fig. 4 Time series of salinity in mooring, at the entrance of Maputo bay from 8 April to 13 May

DISCUSSION

The semidiurnal variations of the water level (Figure 2) is due to the tidal component M2, (Saide 1996).

The general cooling trend (Figure 3) is obviously due to the seasonal effect, which at this time of the year is the transition towards winter.

A comparison between the water level record (Figure 2) and the temperature record (figure 3) shows that the cooling seems to be strong during neap tides, but a warming takes place during spring tides. This may be due to the exchange of the water mass with the open ocean. The temperature of the open ocean water is believed to be higher during this period of the year, because the semi-enclosed, shallow Bay is more exposed to the cooling from the atmosphere. The temperature of the atmosphere is usually cooler than the water during this time of the year. This cooling may be due to sensible heat exchange or latent heat exchange (due to evaporation)

.Another possible explanation of the intermittent warmings at spring tides, may be the increased vertical mixing. If the water above or below the current meter is warmer, a warming is expected when the mixing increases during spring currents. Vertical temperature profiles are needed to resolve this problem.

In the future we hope to use the current measurements to develop heat, salt and mass budgets for the Maputo Bay. This will be an important contribution for the estimation of the capacity of the Maputo Bay as a recipient of waste from the City.

Acknowledgements

This work has been carried out with support of NANCEP. I am very grateful to Professor Tor Gammelsrod who organized the Nancep, for his advises and cooperation. Helpful advise was received from Antonio Mubango Hoguane who provided invaluable assistance on computer programs. Also I am grateful to Detlov von Oetrzen and Gunhild Schreiber and finally to National Institute of Meteorology, Mozambique (INAM) who provided the computer machine.

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TIDAL CURRENTS IN MAPUTO BAY

By

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Abstract

Tides and tidal currents are described using 2 Aanderaa current metres deployed for 35 days at 2 different sites at the entrance of Maputo bay. The tidal currents in the bay appear predominantly semidiurnal. The flow is mainly in the southwestward direction into the bay and in the northeastward direction out from the bay. The maximum spring tidal current speed obtained was 120 cm/s. The tidal ellipses plots indicate that the tidal currents are strongly influenced by moon, the major contribution is given by the semidiurnal M2 tidal component which has a major axis of about 53 cm/s.

INTRODUCTION

On the eastern border of Maputo city, in south Mozambique, Maputo Bay is a marine system with important fisheries. The Bay has also large potential for tourism. It is also a recipient of most of sewages coming from the city and its surrounding areas. However, the capacity of the bay by all those activities taking place, can be limited, which constitute a threatening for many of aquatic or marine living species in the bay.

The physical environment of the bay needs to be known in considerable details to understand the fisheries and it is of obvious importance for exploitation for various behaviour. River runoff is discharged in various places into the bay.

The main objective of this paper is to describe the dynamical regime at the entrance of Maputo bay. In order to fulfil this we are supposed to determine the tidal regime, the tidal ellipses and the perpendicular and parallel current components along the main axis of the bay. This is also of interest for navigation purposes, as Maputo is one of the most important commercial harbours in Mozambique.

METHODS

Data collection

The data used in this study were acquired by Institute of Fishery Research in Maputo. Two Aanderaa current meters (designed A on the south and B on the north, see Fig. 1) were moored on 8th April, at different positions, 25° 56' 50" south and 32° 52' 40" east for A and 25 °53' 50"S and 32°48' 40"E respectively, at about 21 and 17 metres bottom depth. The positions are to find in the deepest part at the entrance of the bay, near the Baixo Ribeiro and Portuguese Island. During 35 days the current meters have recorded measurements every 10 minutes. The geographical positions were determined using GPS navigation system.

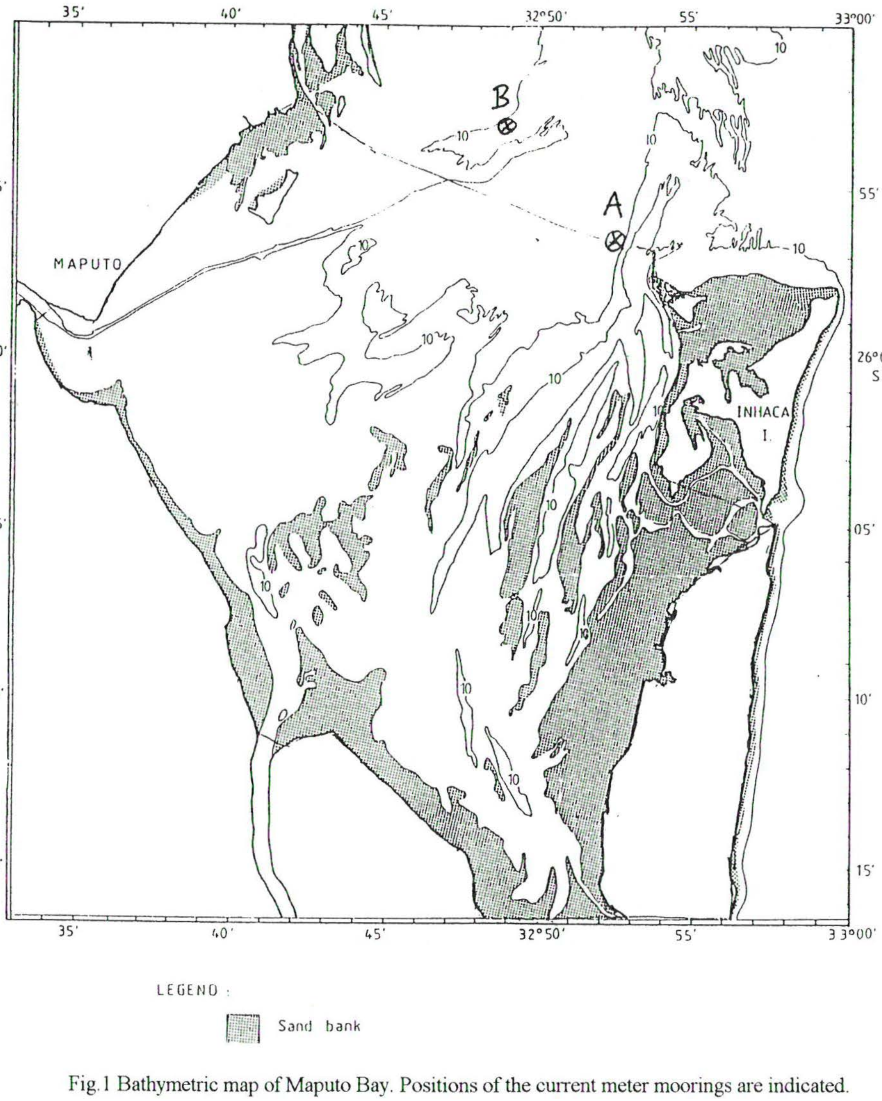


Fig. 1 Bathymetric map of Maputo Bay. Positions of the current meter moorings are indicated.

The accuracy of the various sensors of current meters used in this study is given as 1 cm/s for current speed; 5 degree for direction; 0.05 Celsius for temperature 0.1 mm/cm for conductivity and 0.5% for pressure;

Data analysis

The current metre data were used to compute the time series of current speed F, velocity components U and V, temperature T and salinity S. Further more the results were used to compute the current ellipses.

For the computations of the time series of current speed, east- and northward current components, temperature and salinity, a program package developed by the Geophysical Institute, University of Bergen, and rewritten for PC's by P. Andersen (personal communication) was used.

For a better understanding of the presentations we combine the stick and progressive vector in order to find the main current direction. With the current ellipse analyses hope to find the principal constituents and the driving forces for the currents in the bay. The plotted patterns are compared between the two current meters.
The tidal analysis were performed using programs developed by Foreman (1978).

RESULTS

Time series

The time series for the various parameters from the two current metres are showed in the Fig.2a for position Baixo Robeiro (position B on Fig.1) and in Fig 2b for the position close to Ilha dos Portugueses (position A on Fig.1).

The current speed from both current meters shows a periodical variation. The northern current meter indicates the maximum current speed of about 120 cm/s with the u and v components ranging between -90 and 80 cm/s and between -80 and 60 cm/s respectively. The maximum current speed reached by the southern current meter is around 100 cm/s and the components range approximately from -70 to 70 cm/s for the eastward component and from -65 to 70 cm/s for northward component. In both figures we can observe two distinct periods of small and large amplitude for the velocity components.

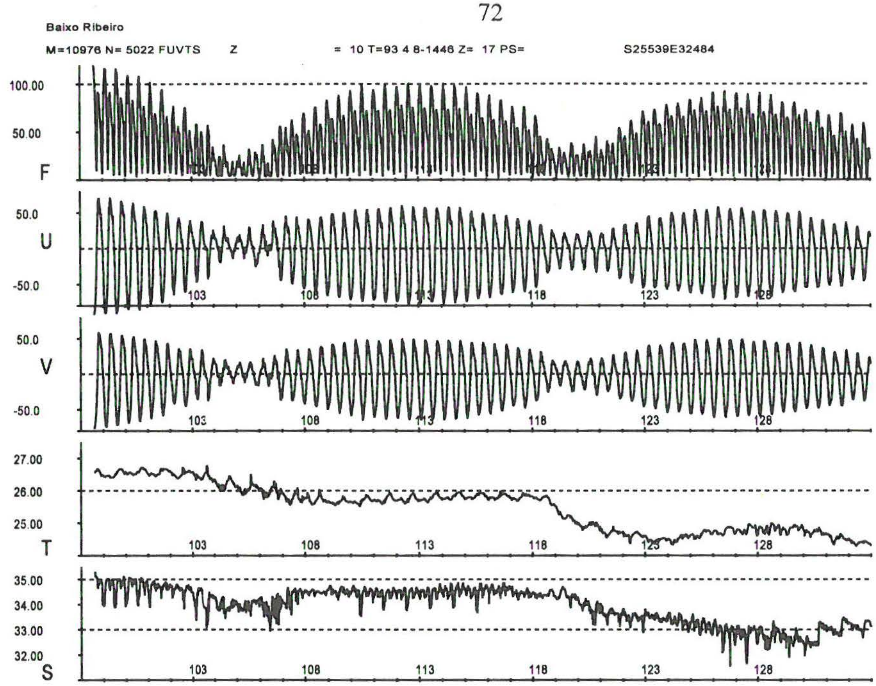


Fig. 2a

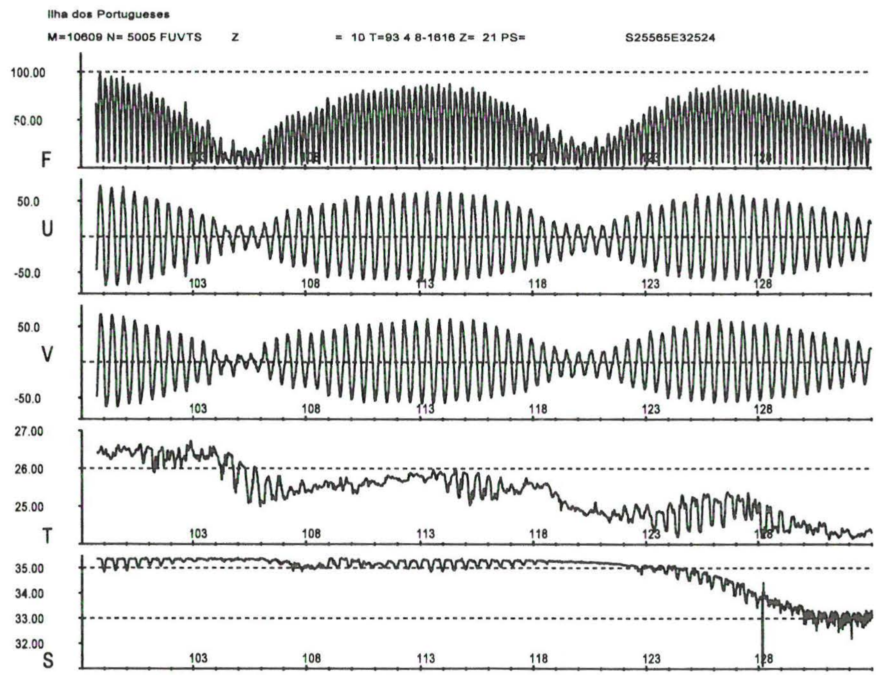


Fig. 2b

Fig.2 Time series of current speed F, eastward velocity component U, northward velocity component V, Temperature T, and salinity S for a) Balxo Ribeiro, (position B in Fig.1), and b) Ilha dos Portugueses, (position A in Fig.1). Time is given as day of the year (Julian day).

The temperature pattern indicates in general that the sea water temperature is decreasing during the whole period with small oscillations, from 26.5°C to 24.5°C for both current meters. The decrease in temperature is relatively stronger during the neap tide.

The salinity remains almost constant along the period of observations for the two current metres with a small decrease of about 2, from 35 in the end of the observation period.

Tidal currents

The observed tidal currents show two peaks and two troughs during the day, which means that the tides are semidiurnal. The progressive vector diagrams (Figs.3) and the stick plots (Figs.4) indicate for both current meters that the flow at the entrance of the bay is oriented NE-SW about 45 degree, ie, southwestward currents flow into the bay while the opposite northeastward currents flow out from the bay.

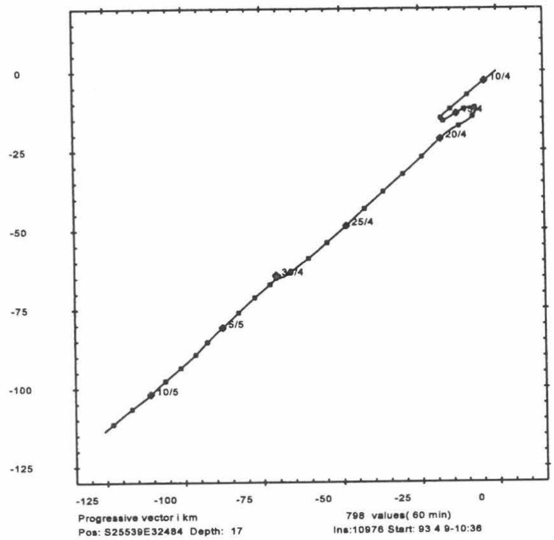


Fig. 3a

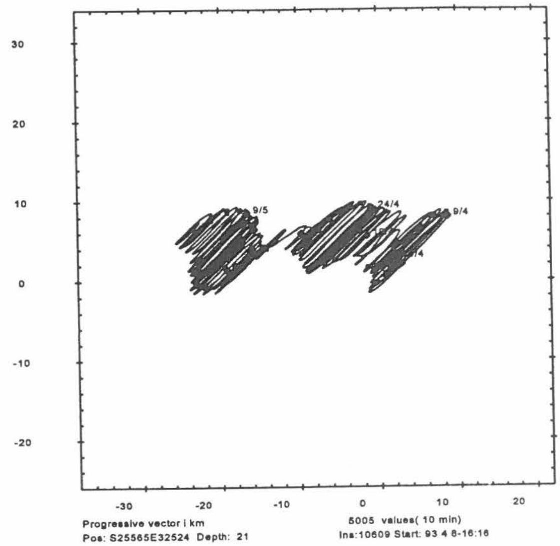


Fig. 3b

Fig. 3 Progressive vector diagrams for a) Balxo Ribeiro (position B in Fig.1) and b) Ilha dos Portugueses, (position A in Fig.1). The axis are given in km and there is one tic on the curve for each day.

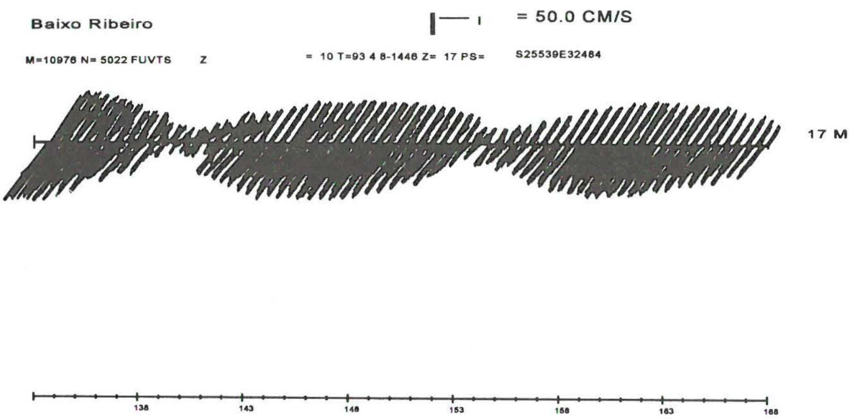


Fig. 4a

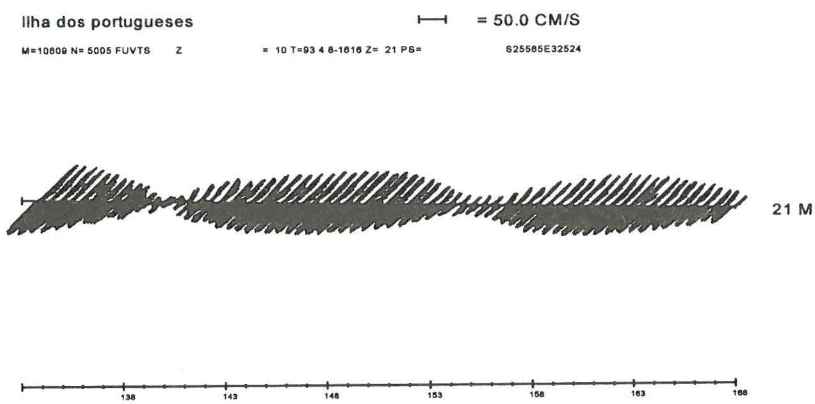
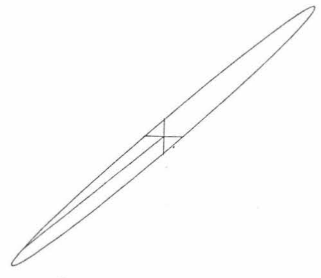


Fig. 4b

Fig. 4 Current stick diagrams for a) Balxo Ribeiro (position B in Fig.1) and b) Ilha dos Portugueses, (position A in Fig.1). Time is given in Julian days.

Tidal ellipse

The current ellipses was plotted using the current components have shown that the major axis of M2 and S2 seem to contribute considerably to the current system in Maputo bay (see Table 1). The major axis of M2 has a value of 53.3 cm/s for southern current meter. The correspondent ellipse the current vector rotate anticlockwise (see Fig.5).



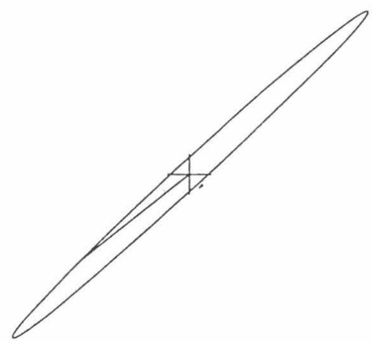


Fig.5 Current ellipses for the tidal components M2 and S2 near Ilha dos Portugueses (position B in Fig.1)

Tab.1 Major axis of M2, S2, K1 and O1 for southern current meter

Constituents	M2 (cm/s)	S2 (cm/s)	K1 (cm/s)	O1 (cm/s)
Southern Current meter	53.3	32.2	1.0	0.8

DISCUSSION AND CONCLUSION

Currents

The flood currents flow toward the bay in southwestward direction, they have negative U and V components. The opposite ebb currents flowing out from the bay. The alternate low and high peaks of current speed (in the ebb and flood respectively) is an evidence of asymmetry of tidal currents, the flood currents being stronger then the ebb currents. The existing distinct periods of strong tidal currents and weak tidal currents is explained by moon-earth interaction.

There is evidence of low salinity around the time of low water see Fig.6. The current speed increases from the time of low water up to a maximum value and then decreases till the time of high water, whereafter it changes the direction and start rising again.

The tidal ellipses show that the main current flows at the entrance of Maputo bay is in south-west and north-east direction.

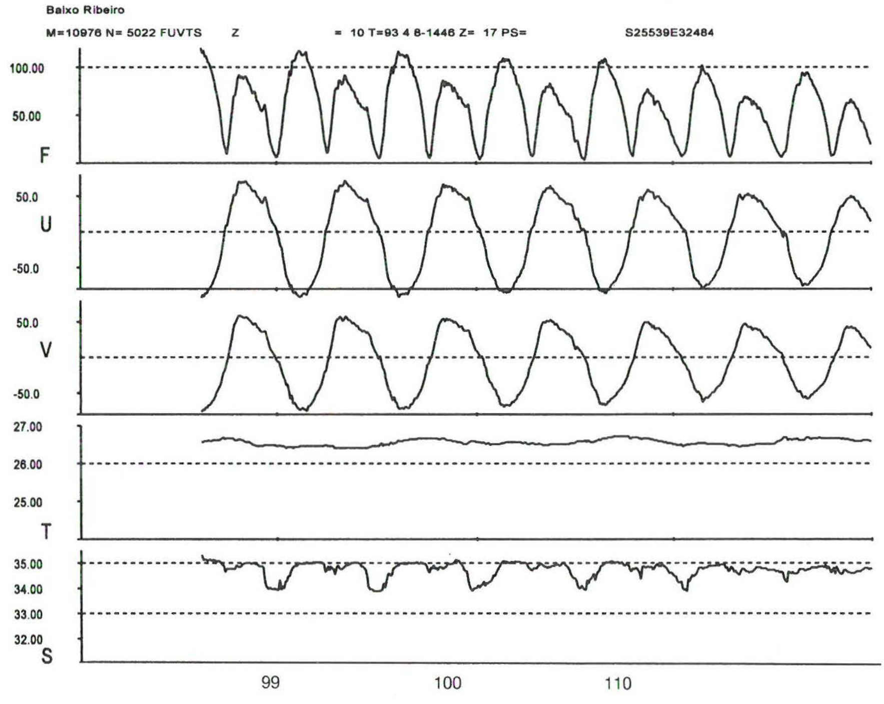


Fig. 6 Same as Fig 2a, but for the first 4 days only.

Salinity and temperature

The salinity decrease in 0.5 psu in the period of low water is an indicator that the river runoff has a small effect in salinity variation in the bay. However, the causes of pronounced variations in the last days of measurements is still unknown.

The pronounced temperature variations after a neap tide might be explained from water exchange between the ocean and the bay. Taking into consideration that the period of measurements was approaching the cold season a decrease of the temperature is expected.

Acknowledgement

This work has been carried out with support of NANCEP and Institute of Fishery Research, Maputo. Helpful advise in preparing the manuscript was received from Tor Gammelsroed, and Antonio Mubango Hoguane who provided invaluable assistance on accessing the data and by their computation of time series. Finally, I am grateful to Detlov von Oertzen and Gunhild Schreiber.

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NANSEN COURSE IN ENVIRONMENTAL PHYSICS
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OCEANOGRAPHIC CONDITIONS NEAR P[ta] das PALMEIRINHAS, SEPTEMBER 1994

By

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ANGOLA

Abstract

In this report we show results of the current measurements taken over a period of 24 hours near Ponta das Palmeirinhas, central Angola. In addition we show the hydrographic condition in the area in the form of vertical sections of temperature, salinity and oxygen taken immediately after the recovery of the current metres. The current was found to be mainly westwards, i.e. off-shore, and the vertical sections indicate that a weak upwelling was occurring in the area on September 10-12, 1994, when the measurements were taken.

INTRODUCTION

Angola is situated on the west coast of southern Africa, and has a coast-line of more than 1600 km. The climate changes from tropical rain forest in the north to desert type in the south. The major part of the territory has a sub-tropical climate, but the in the southern part the coastal zone is influenced by the cold Benguela Current, Khalin and Costa (1981).

The data presented here was obtained by R/V "Dr. Fridtjof Nansen" in September, 1994. The study area, Ponta das Palmeirinhas, is situated just south of Luanda. The data consists of about 24 hours of current measurements. Caution should be taken in drawing conclusion from this time series, as the period is very short, and may or may not be representative for the general conditions in the area. Current measurements are of importance in many respects, it may contribute to the understanding to the drift of fish eggs and larvae, to dispersion of pollutants and so on. Of particular importance is the concern of coastal erosion, which may have important economical consequences.

We also show that the vertical distribution of temperature, salinity and oxygen in the area taken just after the current metre rig was recovered.

DATA

The data used in this ıeport was obtained by the R/V " Dr. Fridtjof Nansen" on one of its routine cruises in Angolan waters. The current metres were launched on September 10, 1994 at 15:30 UTC, and recovered 24 hours later. The position of the current metre mooring was S9^{0}05', E12^{0}51', see Fig.1. The mooring consisted of 2 current metres fixed at the surface (2m depth) and at 45m depth. The bottom depth at the mooring site was 60m.

The CTD section was taken between S9^{0}08', E12^{0}33' and S9^{0}75', E12^{0}82' , corresponding to the CTD stations 667 to 674, see Fig.1

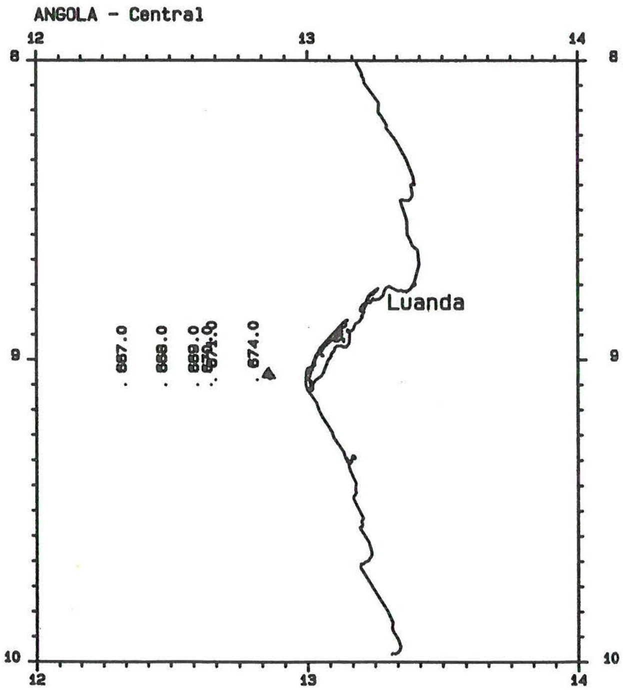

Figure 1. Map of central Angolan coast with the CTD stations used in this study. The position of the current metre mooring is indicated by ▲ .

INSTRUMENTS

The current metres applied was the AANDERAA RCM7. According to the instruments specifications the accuracy of the various sensors are as follows:

Parameter	Precision
Conductivity	± 0,1 mmho/m
Direction	± $0,5^0$
Speed	± 1 cm/s
Pressure	± 0,5 %
Temperature	± $0,05^0$C

The CTD utilized was a Seabird 911 plus system. The oxygen values were standardized against water samples analysed by the Winkler method onboard, and when obvious erroneous calibration points were rejected, 118 data pairs gave a standard deviation 0.142.

The salinity values were compared with water samples analysed by a ship-born Guildline Portasal salinometer. A standard deviation of 0.0085 was obtained.

METHODS

The current metres were set to make a registration every 10 minutes. The data were transferred from the DSU memory to an ASCII file using the DSU reader program supplied by the AANDERAA INSTRUMENTS.

The current metre data were then analysed by using a program package developed at the Geophysical Institute, University of Bergen.

The CTD data were converted where checked, filtered and converted to 1db averages ASCII files using the programs provided by the Seabird Instruments. The vertical sections were drawn using a program package also developed at the Geophysical Institute, University of Bergen. (Røyset and Bjerke, 1982). Both program packages provided by the University of Bergen were implemented for PC's by Petter Andersen (personal communication).

RESULTS

Current metre moorings

The results of the 24 hour monitoring of the various parameters are shown in Fig.2. The parameters shown are speed (F), velocity component towards east (U), velocity component towards north (V), temperature (T), salinity (S), and pressure (P) for the two current metres at 2m depth and 45m depth.

The current speed is somewhat stronger at 45m than at 2m depth. Also note that the current component towards north at 2m is very weak, and that the component toward east is negative, meaning that the current is towards west. This is more readily seen in the progressive vector diagrams (Fig.3), which clearly demonstrate that the current in the surface layer is due west, while at 45m it is towards south-west.

The temperature at 45m varies between 16 °C and 17 °C, (see Fig.2) while at 2m it is between 20 °C and 21 °C. The salinity at the two levels are plotted in the same range, but the salinity at 45m is somewhat higher and varies less than in the surface layer.

Vertical sections of temperature, salinity and oxygen

In Fig.4 we show the vertical distribution of temperature, salinity and oxygen as observed with the CTD. For station positions, see Fig.1 We note that the temperature decreases rapidly with depth at about 25m, where the thermocline is found. The temperature decreases monotonically with depth, in contrast to the salinity, which show a sub-surface maximum at about 20m depth. The oxygen concentration decreases rapidly with depth and reach the value 2ml/l at about 30m depth.

We also note that there is a for an upward tilt of the isolines towards the coast in the innermost 20km or so. This indicates that an upwelling may take place.

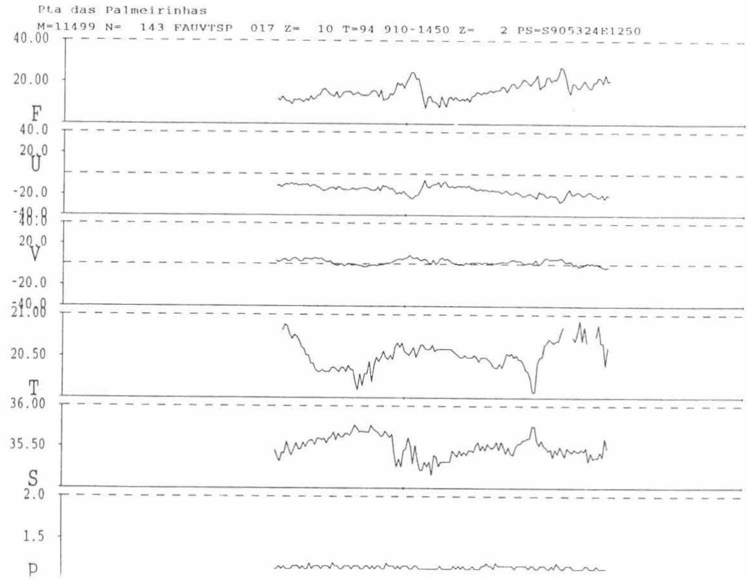

Fig 2a

2m

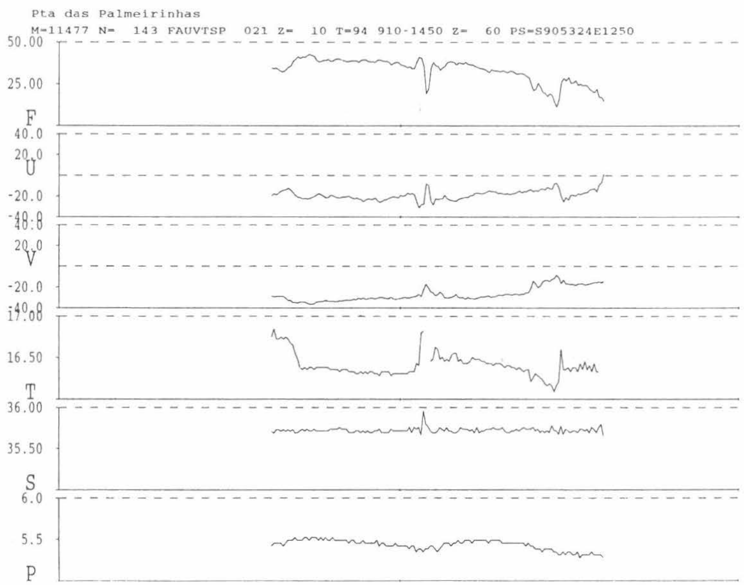

Fig 2b

45 m

Date 11/9 1996 Time 00

Figure 2. Plot versus time of of the parameters speed (F), velocity component towards east (U),velocity component towards west (V), temperature (T), salinity (S) and pressure (P) for the current meter at a)2m depth and b) 45m depth.

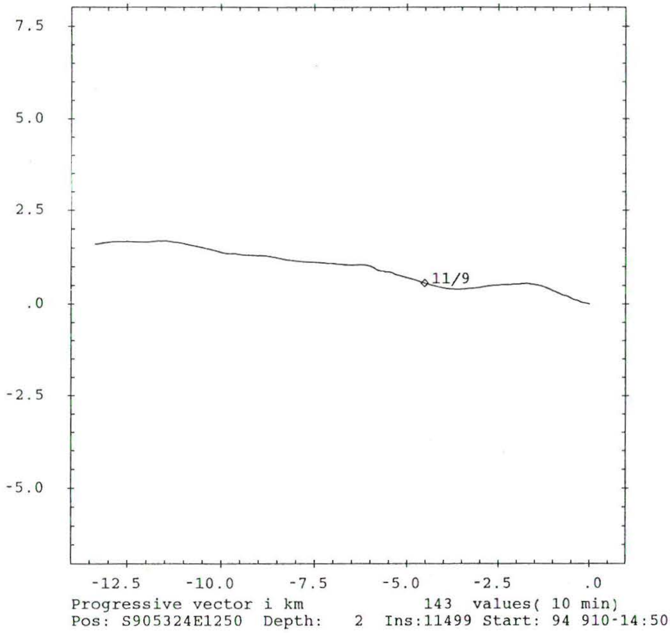

Fig 3a

2m

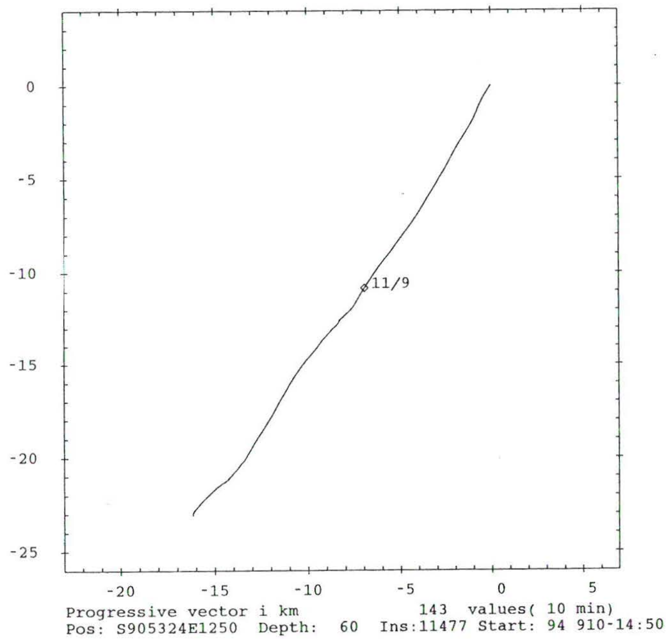

Fig 3b

45m

Figure 3. Progressiv vector diagram at a) 2m and b) 45m depth.

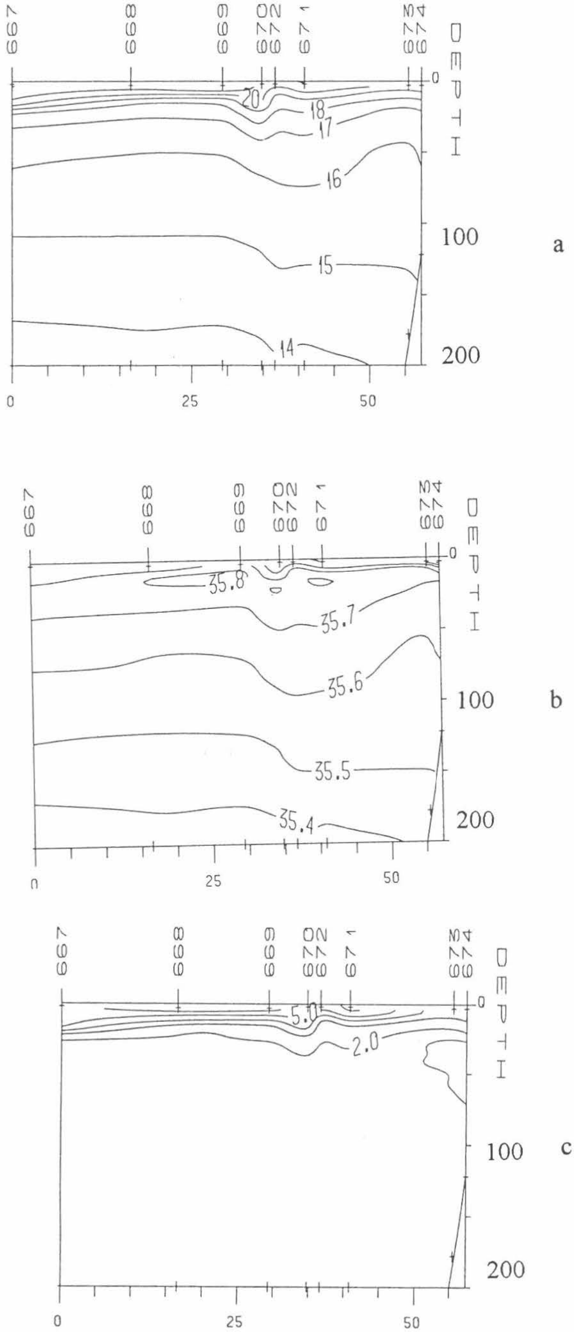

Figure 4. Vertical sections of a) Temperature, b) Salinity and c) Oxygen

DISCUSSION

The results of the temperature observations from the current metre mooring (Fig.2) and the CTD (Fig. 4) compares well, as both indicate a temperature between 20°C and 21°C at the surface layer, and between 16°C and 17°C at 45m depth. Also the salinity measurements compare well with a slightly higher salinity at 45m compared with 2m depth

The upward tilt of the isolines towards the coast indicate that an upwelling may take place. The winds in the region are predominantly from south-west, which will provoke an off - shore Ekman transport. This is consistent with the results of the current measurements, which both at 2m and 45m depth reveal an off-shore current component.

Acknowledgements

I am very much greatful to the NANSEN program, and especially to the advisers Tor Gammelsrød, Mubango Hoguane, Detlof Von Oertzen, Gunhild Schreiber and all those who contributed to make this project possible.

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(From Portugues by Tor Gammelsrød)

APPENDIX

Exercises

PREFACE

The exercises were distributed to the participants a couple of days before they were discussed in the groups. This gave the fellows the possibility to test themselves, to discuss the problems within informal groups, and also ask for individual support from the tutors in the problem-solving process.

The groups were organised according to language, i.e. we had one Portuguese-speaking and one English speaking group. This was of particular value for the Portuguese speaking fellows, as both the lectures and text books were in English, this was the only forum where they could develop the Portuguese vocabulary in environmental physics.

During the group work the general philosophy was to discuss the problems in some detail, instead of rushing towards an answer. Realising that it is the process of obtaining an answer, the discussion, which is important in the teaching process, the tutors allowed for, and stimulated arguments, objections and alternative solutions from the fellows. Also, after finally arriving at a hopefully "correct answer", we tried to stimulate discussions on what do we learn from this, what does it mean, is the model a good description of nature, and so on. Therefore, the time spent on each exercise could vary a great deal, depending on if the exercise worked in the sense that it created discussions. We found it wise, on several occasions, to break up the group discussion to give the students a break, and the possibility to continue individually on the problem. Then we typically reassembled the group to continue the next day or so.

The group work was also essential as a feedback to the lecturers, as they could adjust the teaching according to the performance by the students.

Exercise 1. Continuity equation.

An example of application of the continuity equation on the form

$$\nabla \cdot \mathbf{v} = 0$$

is given in Chapter 4.3 in Pond & Pickard's text book. Calculate through this example and discuss the results.

Exercise 2. T-S diagrams. Stability

a) Table I shows temperature and salinity observations from a hydrographical station. Plot the vertical profiles of temperature and salinity.

b) Fig. 1 shows a T-S diagram where the isopycnal $\sigma_t = 24$ is marked. Based on the values shown on the figure you may also draw the lines $\sigma_t = 25$, $\sigma_t = 26$, $\sigma_t = 27$ and $\sigma_t = 28$.

c) Plot the values from Table I on the T-S diagram, and draw a straight line through the points.

d) Use the T-S diagram to estimate the apprixímate density at the different depths, and draw the vertical density profile.

e) Discuss the stability of the water column, for example find the level where the stratification is most stable.

f) If a water mass m_1 with temperature T_1 and salinity S_1 is mixed with a water mass m_2 with temperature T_2 and salinity S_2, it can be shown that the temperature and salinity of the mixture may be calculated according to the formulas:

$$T = (m_1 T_1 + m_2 T_2)/(m_1 + m_2)$$

and

$$S = (m_1 S_1 + m_2 S_2)/(m_1 + m_2)$$

A water mass with temperature 12.3°C and salinity 32.0 psu mixes with another water mass with temperature 7.0°C and salinity 30.5. Compute the T and S values of the mixtures if they mix in the ratio 1/2, 1/1 and 2/1. Plot the "parent" water-masses and the values for the different mixtures on the T-S diagram. Comment the results. Discuss particlarely the density of the mixture as compared to the density of the "parent" water masses.

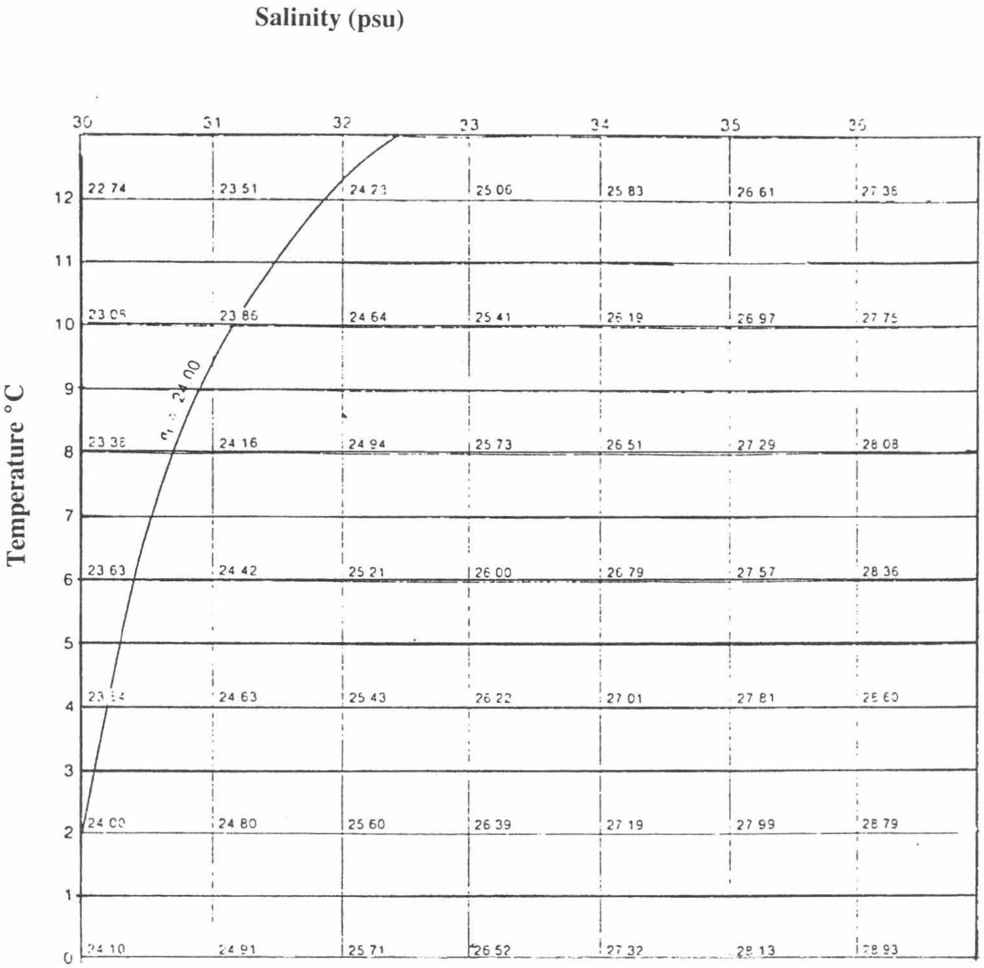

Figure 1.

Depth (meters)	Temperature (°C)	Salinity (‰)
0	12	33.7
10	12	33.7
20	12	33.8
50	10	33.9
100	8	33.7
200	7	34.1
300	6	34.2
400	5	34.2

Table I

EXERCISE 3. STATIC STABILITY

a) Explain the terms stable, indifferent and unstable stratification. What processes in the atmosphere or the ocean may influence the stability?

b) Derive the following expression for the stabilty E:

$$E = -\frac{1}{\rho}\left[\frac{\partial \rho}{\partial S}\frac{\partial S}{\partial z} + \frac{\partial \rho}{\partial T}\left(\frac{\partial T}{\partial z} + \Gamma\right)\right]$$

Here ρ=density, S=salinity, T=temperature, z the vertical coordinate (upwards=positive), and Γ= the adiabatic temperature gradient.

c) Show that the equation of motion of a particle which is displaced a distance δz in the vertical is:

$$\frac{d^2}{dt^2}(\delta z) + g\,E\,\delta z = 0$$

d)

Assume the solution

$$\delta z = A\sin(\omega t)$$

where A is an amplitude and ω is the frequency. Find an expression for this frequency, and show that it is equal to the Brunt-Väisäla frequency N defined by

$$N^2 = gE$$

e) What terms are neglected if we approximate the stability by the expression:

$$E = -\frac{1}{\rho}\frac{\partial \sigma_t}{\partial z}$$

where

$$\sigma_t = \rho_{t,s,o} - 10^3$$

$\rho_{t,s,o}$ = densty for atmospheric pressure (given in kg/m^3). Let us use this approximate expression for E to solve the problems below.

f) In the previous exercise you have found the distribution of σ_t with depth for a hydrographic station. Find the oscillation periods for the most stable and least stable layers. You may approximate the gravity by $g=10\ m/s^2$.

EXERCISE 4.

HYDROSTATIC PRESSURE. THE EQUATION OF MOTION.
As an approximation for the density stratification in the ocean we some times use a two layer model, i.e. we assume the ocean consists of two layers with constant density, seperated by a thin layer where the density changes abruptly between the two values as shown on the figure 4.1.

a) Use the hydrostatic equation to find an expression for the pressure in the upper and in the lower layer, when the atmospheric pressure is p_o, the thickness of the upper layer is h, and the densities in the two layers are ρ_1 and ρ_2.

b) A free-falling sonde is equipped with a pressure sensor which releases a load at a given pressure such that the sonde may return back to the surface. Which pressure must be chosen if one want the sonde to turn at 1) 100m depth, 2) 1000m depth. We assume that h=100m, ρ_1=1025kg/m^3 , ρ_2=1027kg/m^3 and p_0=10^{5}Pa. Use g=9.81m/s^2.

c) We assume that there is no motion in the ocean, and that an equation of motion for the sonde may be written as:

$$\frac{d\vec{v}}{dt} = -2\vec{\Omega}x\vec{v} + \frac{\rho_d - \rho}{\rho_d}\vec{g} + \vec{F}$$

where ρ_d is the density of the sonde (with eventual load). Using this equation, discuss the movement of the sonde. (Decompose the equation and try to see which terms contribute to the acceleration. Don't try to solve the equation.) What is the horizontal displacement of the sonde?

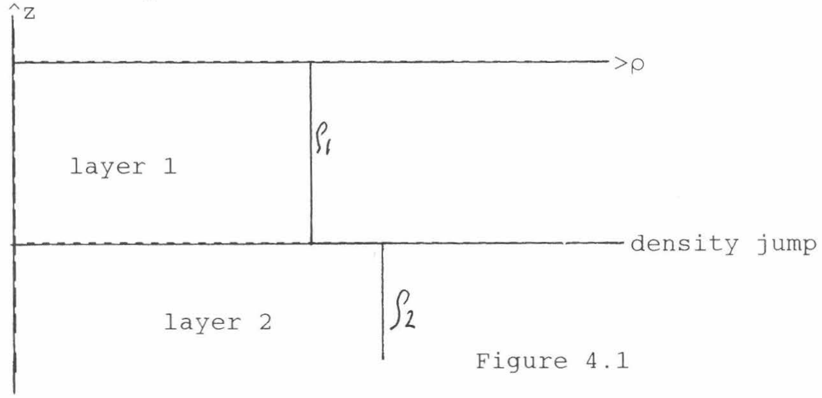

Figure 4.1

EXERCISE 5.

The equation of motion is often written as:

$$(I) \qquad \frac{d\vec{v}}{dt} = -\frac{1}{\rho}\nabla p - f\vec{k}x\vec{v} + \vec{g} + A_H\left(\frac{\partial^2\vec{v}}{\partial x^2} + \frac{\partial^2\vec{v}}{\partial y^2}\right) + A_z\frac{\partial^2\vec{v}}{\partial z^2}$$

a) Explain briefly the origin of the various terms in equation (I)

b) What is the difference between the Lagrangian and the Eulerian description of a flow?

c) In Fig. 1 we show a progressive vector diagram. The curve may be considered as the position of a water particle as a function of time. Tics are marked every 6th hour.

Estimate from the figure the mean velocity for the period 21.-27. september.

d) These measurements were obtained in the Mediterrenian Sea at ca. 43°N. You may therefore choose a horizontal scale L=500 km and a vertical scale H=2,5 km. Choose the time-scale to T= 10 days $\approx 10^6$ s, $A_H=10^5$ m^2/s, $A_z=0.1$ m^2/s, the gravity g=10 m/s^2 and the Coriolis parameter $f=10^{-4}s^{-1}$. Scale equation (I) and show that the mean current may to a good approximation may be described by the equation

$$(II) \qquad 0 = -\frac{1}{\rho}\nabla p - f\vec{k}x\vec{v} + \vec{g}$$

e) What do we call this version of the equation of motion?

f) Estimate the Rossby-number and the Ekman-number for the mean motion.

g) In the period 9.-13. october the mean current was weaker. The progressive vector diagram for this period is shown in Fig.2. The water seems to be moving around in orbits which we assume are circles.

Estimate the orbital velocity and the time-scale for this phenomenon from Fig. 2.

h) Use the values given in paragraph d) and the time and velocity scales found under g) to make a new scaling of the equation of motion, and show that the equation of motion for the horizontal $\vec{v}_H$ now reads:

$$(III) \qquad \frac{d\vec{v}_H}{dt} = -\frac{1}{\rho} \nabla_H p - f\vec{k}x\vec{v}_H$$

i) Describe this velocity as the sum of a statioanry part $\vec{v}_g$ given by equation (II) and a time-dependent part $\vec{v}_i$. Subtract the balance equation for $\vec{v}_g$ from equation (III), and show that the equation for $\vec{v}_i$ becomes:

$$(IV) \qquad \frac{d\vec{v}_i}{dt} = - f\vec{k}x\vec{v}_i$$

j) What is the kind of motion described by equation (IV) called?

k) Show that $\vec{v}_i^{\,2}$ is constant.

l) Solve equation (IV) and find an expression for $\vec{v}_i$.

m) Estimate the theoretical period for this phenomenon.

n) Estimate the radius of the theoretical circle if $|\vec{v}_i| = 0.1\text{m/s}$.

PROGRESSIVE VECTOR DIAGRAM OF CURRENT IN 60 M. DEPTH

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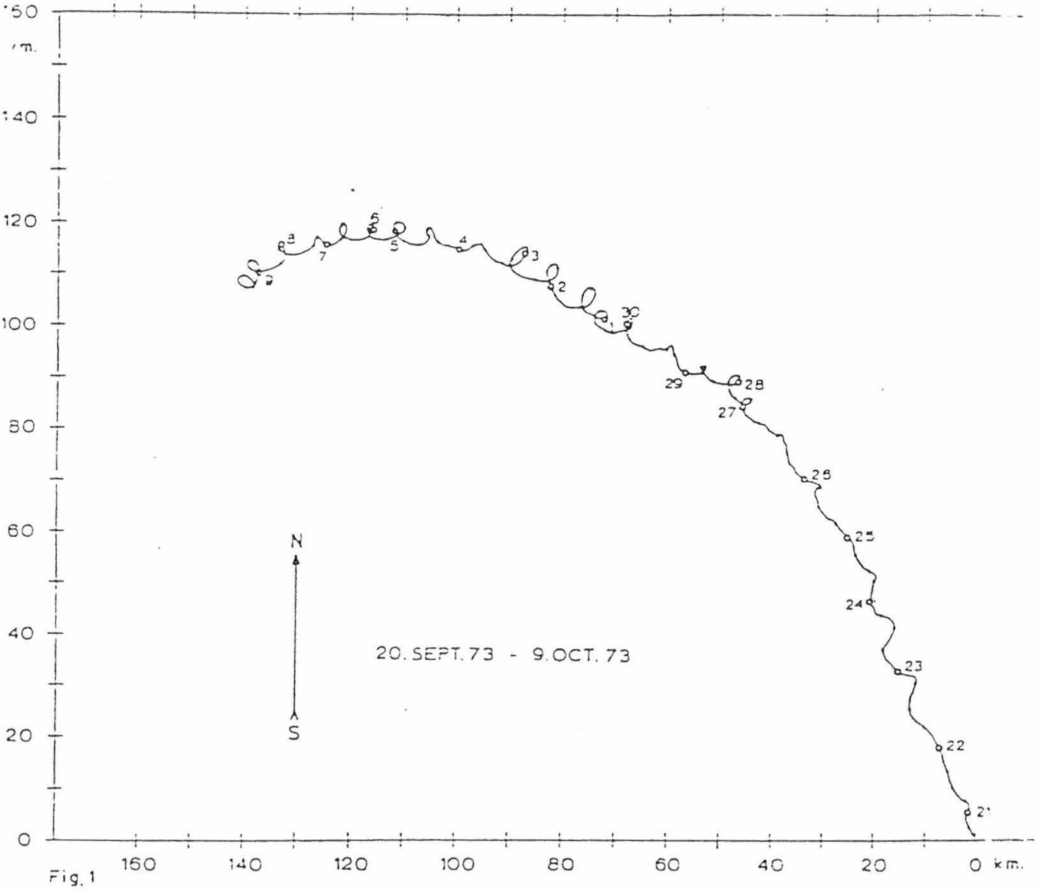

Fig. 1

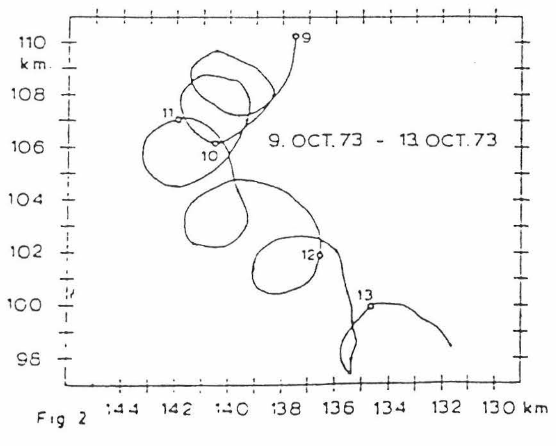

Fig 2

EXERCISE 6

Let us consider a two layer model for a coastal current, where the density in the two layers ρ_1 ρ_2 are constants. We assume that the pressure at the surface (z=s) is zero; p(s)=0. The interface is given by z=-d see Figure I.

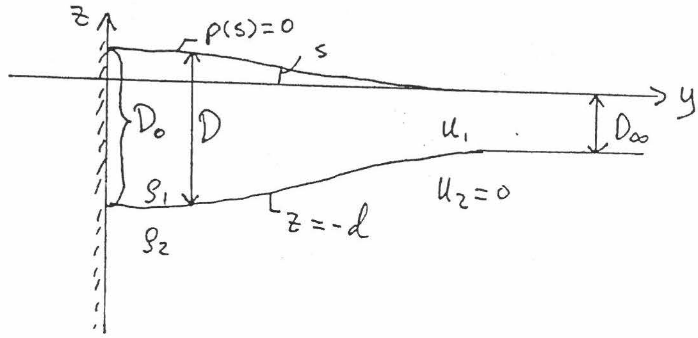

Figure 1.

a) Show that the thickness of the upper layer D=s+d.

b) Show that the hydrostatic pressure in the upper layer is given by

$$p_1 = g\rho_1 (s-z)$$

and in the lower layer by

$$p_2 = g\rho_1(s+d) - g\rho_2 (d+z)$$

c) We assume that the current parallel to the coast (u_1) in the upper layer is in geostrophic balance. Show that u_1 is given by the tilt of the surface:

$$u_1 = -gf^{-1} (ds/dy)$$

d) We assume that the velocity in the lower layer is zero ($u_2 = 0$)

Show that we then have the following relation between the surface and the thickness of the upper layer:

$$\frac{dD}{dy} = \frac{\rho_2}{(\rho_2-\rho_1)}\frac{ds}{dy}$$

e) Calculate the ratio between the slope of the surface and and the rate of increase in the upper layer given that ρ_1= 1024kg/m^3 and ρ_2= 1026kg/m^3. How much does the surface slope contribute to the thickness of the upper layer?

f) Show that the velocity may be expressed as a function of the thickness of the upper layer as:

$$u_1 = -\frac{g}{f}\frac{\rho_2-\rho_1}{\rho_2}\frac{dD}{dy}$$

g) Show that the total volume transport in the upper layer is given by the formula:

$$Q = \int_o^{\infty}\left(\int_{z=-d}^{s} u_1 dz\right)dy$$

h) Substitute the solution for u_1 from question f) and show that the transport Q may be written as:

$$Q = -\frac{g'}{2f}(D_{\infty}^2 - D_o^2)$$

where g'is the reduced gravity g' = $(\rho_2 - \rho_1)/\rho_2$, D_o is the thickness of the upper layer close to the shore (y=0), and D_{∞} is the constant thickness of the upper layer far from the coast (y→∞).

i) Calculate the total geostrophic volume transport in the upper layer when D_o = 100m and D_{∞} = 20m. The Coriolis parameter may be chosen as f=10^{-4}s^{-1} and g=10m/s^2.

EXERCISE 7

In a geostrophic model for a coastal current we choose the y-axis along the coast, the surface elevation is given by $z=\eta$, and the bottom described by $z=-H(x)$, see Figure 7.1. The density is increasing outwards from the coast, such that the density surfaces are tilting. We assume that the tilting of the surfaces are constant everywhere, and also that the distance between them are constant, such that the demsity gradient $\nabla\rho(x,z)$ =constant.

Let us neglect the variations parallel to the coast; $(\partial/\partial y = 0)$

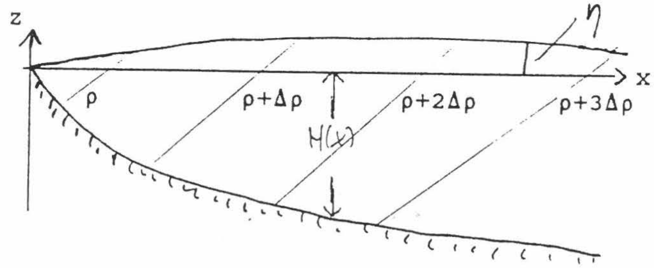

Figure 7.1

a) Write up the eqations of motion for this current and show that there is no velocity perpendicular to the coast (u=0).

b) Show that the following relation between the horizontal density gradient and the vertical velocity gradient is valid:

$$\frac{\partial \rho v}{\partial z} = -\frac{g}{f}\frac{\partial \rho}{\partial x}$$

c) We assume that the velocity at the bottom is zero (v(x,-H)=0). Show that then the velocity at an arbtrary depth z is given by:

$$v=-\frac{g}{f\rho}\frac{\partial\rho}{\partial x}(z+H)$$

d) Show that the mass-trnsport T(x) between the coast and a distance x from the coast is given by

$$T(x)=-\frac{g}{2f}\frac{\partial\rho}{\partial x}\int_{o}^{x}D^{2}dx$$

where D is the total water depth.

e) Show that the relative vorticity ζ at level z=0 is

$$\zeta=-\frac{g}{f\rho^{2}}\frac{\partial\rho}{\partial x}(\rho\frac{dH}{dx}-H\frac{\partial\rho}{\partial x})$$

Discuss this result. Which of the two terms gives the largest contribution to the vorticity?

f) Scetch the velocity profiles in the (x,y) plane, the (y,z) plane and the (x,z) plane.