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**Seasonal and Inter-Annual Variability of SST and
chlorophyll-a off Angola.**

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Abstract

The aim of this dissertation is to use satellite-derived images for the study of spatial and temporal variations in SST and in concentration of surface chlorophyll-a of the main oceanographic features off Angola.

SST time-series over the years 1987 to 2002 were derived from Meteosat 5-day SST composites with a spatial resolution of about 5-6 km in Angolan waters and a thermal resolution of 0.5°C. Chlorophyll-a data were from a 5-day composite of SeaWiFS GAC (4.5 km 'Global Area Coverage') images. Such images were available in a format comparable with the Meteosat SST composite images and covered the period 1998 to 2004.

For data processing, two powerful suites of software were largely used in this research approach either to read and extract data from binary satellite images or to visualize such images:

- IDL (Interactive Data Language) is a complete computing environment for the interactive analysis and visualization of data. It was largely used in this work as a strong tool for reading and extracting Meteosat-SST and the concentration of SeaWiFS chlorophyll-a data.
- Envi 4.0 (Environment for Visualizing Image) is a powerful tool used to process satellite remote sensing data. It was less used in this work except for visualizing Meteosat-SST and AVHRR-SST images.

The examination of oceanographic conditions off Angola consisted of the following parts:

1. Investigation of seasonal and inter-annual variation of SST and surface chlorophyll-a concentration and in order to do so, the western region was divided into homogeneous sub-regions:

Subdivision was achieved by first examining alongshore and cross-shelf variation of SST and chlorophyll in order to gain some insight into the degree of spatial variation and hence the number of sub-regions. Thereafter sub-division was performed using an unsupervised multivariable clustering procedure with eight input variables (the average monthly SST and chlorophyll-a of March, April (summer) and July, August (winter)).

Three sub-regions were accurately defined with cluster procedure:

The northern sub-region (5.02°S-8.7°S) with 370 km wide from the coast and 70 km offshore between 6.7°S and 8.7°S.

The coastal sub-region (6.7°S-17.2°S) with 103 km wide from the coast between 8.7°S-17.2°S; 300 km and 103 km wide from 70 km offshore respectively from 6.7°S to 7.1°S and from 7.1°S to 8.7°S.

The offshore sub-region (7.1°S-17.2°S) with 197 km (173 km offshore) wide from 7.14°S to 8.71°S and with 267 km (103 km offshore) wide from 8.7°S to 17.2°S.

2. **Investigation of upwelling:** A simple upwelling index off Angola was computed from the difference between nearshore and offshore SST on each scanline. Three upwelling cells were clearly identified: Cabinda (5.01-5.5°S), Ambriz (7-8°S) and Cunene (16.5-17.5°S). Cunene is seasonal and the only wind driven upwelling cell while Cabinda and Ambriz are permanent and are believed to be driven by Kelvin waves. The index suggests weak upwelling in the northern cells in comparison with the strong upwelling in the Cunene cell.
3. **Investigation of the Angola-Benguela front:** Mean-SST and mean-Chlorophyll-a were computed at each scanline in a 60 km wide swath between 10°S and 19°S in order to detect the seasonal and inter-annual position of the Angola-Benguela front (ABF). Temperature at the ABF showed clearly the seasonal variability along the coast with higher temperatures (20-24°C) in summer (January-April) and lower temperatures (16-20°C) in winter (May-September). The ABF was found to be located between 15.7-18°S with a mid-position at 16°S. Its position varied seasonally, being furthest south in summer and furthest north in winter. When the frontal position was determined, using the same methodology but chlorophyll-a data instead of SST, a different result was obtained. Although the latitudinal limit were the same, the front was furthest north in summer and furthest south in winter.
4. **Investigation of the influx of fresh water from the Congo River:** The large volume of fresh water discharged by the Congo River into the northern Angolan coastal region could have a significant affect on the marine environment in that area. To demonstrate the affected region, cluster procedure was used in order to define the extension of the plume. Fresh water outflow from the river not only affects the salinity but also stimulate primary production. The results showed that the plume couldn't be detected with SST but only with chlorophyll-a. It extends from the mouth up to about 300 km away and flow southward down to 7°S (Ambriz) just north of Luanda (8°S). The width of southward flow is around 70 km offshore. No spatial correlation between chlorophyll and low salinity plume was found; instead salinity allowed defining the extension of the plume.
5. **Benguela warm and cold events were identified with the SST anomalies made in different sub-regions off Angola: 1987-1989, 1994-1995, and 1999-2000 (warm events) and 1996-1997 and 2001-2002 (cold events).**
In depth analysis was made with Benguela 94/95 and the impacts of Niños or Ninas over the Angola-Benguela front, coastal upwelling and Congo River plume were described and highlighted.

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Mohrholz et al., 2001). The structure has also been identified in mathematical models (Evensen, 1998 and Veitch, 2004)

All these equatorial and the Angola currents affect the Angola ecosystem in terms of the temperature, salinity and the oxygen content including its biodiversity, which makes it different of the southern part of Angola influenced by the Benguela current.

The southern Angolan region (14-17.3°S) is affected by the northern part of the Benguela current flowing from the Cape of Good Hope up to 15°S where it deflects westward converging with the southwards Angola warm current. This converging zone (15-18°S) between the Angola and Benguela Current is called “the Angola-Benguela Front” (Shannon et al, 1987). This thermal oceanographic feature, as the Angola Dome, has been the subject of much research, using both remotely sensed data as well as hydrographic data (Dias, 1983a, 1983b; Kostianoy, 1996b; Meeuwis and Lutjeharms, 1990; Shannon et al., 1987; Gammelsrød et al., 1997; Lass et al., 2000; Mohrholz et al., 2001; Hardman-Mountford et al., 2003 and Veitch et al., 2006).

The Inter-Tropical Convergence Zone (ITCZ), also called the “the Meteorological Equator” is situated to the north of the equator (4°N) in July (winter of the southern hemisphere) and in south of the equator (≈4°S) in January (summer of the southern hemisphere). The equatorward southeast and the northeast trade winds converge near the geographic equator (low pressure zone). The seasonal variability of the ITCZ might affect the variability of the Angola-Benguela front (Boyd et al., 1987). It is also believed to affect the variability of the Angola Dome since it is above the thermocline when the ITCZ is in its most southerly position (January-April) and is underneath the thermocline or disappears at 20 m depth in June-September when the ITCZ is in further north (Voituriez, 1981).

It was observed that in the Angola ecosystem seasonal upwelling takes place during July and September mainly off Cabinda (5°S) and off Luanda (9°S) (Hardman-Mountford, et al., 2003). This upwelling occurring in the northern part of Angola is not wind-driven Ekman transport but is related to equatorial upwelling in the eastern Atlantic and can be explained by remote forcing from the western equatorial Atlantic (Hardman-Mountford et al., 2003; Moore et al., 1978).

On the other hand, in southern Angola, strong wind-driven coastal upwelling takes place inducing biological productivity (Shannon, 1985; Lutjeharms and Meeuwis, 1987; Hardman-Mountford et al., 2003). The equatorward trade winds are very strong inducing Ekman transport throughout the year.

So-called Benguela Niños have stricken the Angola Coast several times. It was reported to have occurred in 1934, 1963, 1974, 1984 and 1995 (Shannon et al., 1986; Gammelsrød et al., 1998). In his study of atmospheric temperatures and precipitation, Filipe (1995) confirmed those occurrences. They showed clear temperature anomalies of 2°C (in 1964, 1974 and 1995), 4°C (in 1984) and monthly precipitation anomalies of 300 mm (1964), 250 mm (1984) and 160 mm (1995) above the average.

During the 1995 Benguela Niños, the sea temperature was 8°C higher at 30 m depth, salinity was 5 lower at 5 m depth and the thermocline depth was 25 m deeper along the Angolan coast relatively to 1994 which was considered as a normal year (Gammelsrød et al., 1998). Heavy rainfalls were recorded at coastal cities of Angola. The main rivers (Congo, Cuanza) flooded and fresh water outflow into the ocean reduced the salinity down to 28 in the upper layer (Gammelsrød et al., 1998), minimum values never reached during normal years. During the same period of time, the estimated biomass for three commercially

important pelagic fish species (sardinella, Cunene horse mackerel and sardines) declined. The first two species recovered in 1996 but the stock of sardines remained depressed (Luyeye, 1995).

Knowledge of oceanographic conditions off Angola and presented in the preceding paragraphs, has mostly been acquired from conventional hydrographic data. Only a relatively small number of studies made use of data obtained from satellite remote sensing and then mostly SST data used in conjunction with hydrographic data (i.e. Shannon et al., 1987; Veitch et al., 2006, Hardman-Mountford et al., 2003)

This dissertation aims to describe spatial and temporal variations in the Angola marine environment and will for this purpose use monthly SST and surface chlorophyll-a data obtained from satellite images.

Broadly speaking the dissertation consists of a general description of seasons and inter-annual variations of SST and chlorophyll-a off Angola as well as focused description of the most prominent oceanographic phenomena i.e. coastal upwelling, the Angola-Benguela front and the Congo River plume. (The other prominent feature, the Angola Dome has no known surface expression in SST and chlorophyll-a).

The following is a set of key questions to be addressed and the steps to be taken to do so:

1. In order *for the spatial and temporal variations of the area of interest to be studied*, the area must be partitioned into regimes (zones) of more-or-less uniform oceanographic properties. *How many such regimes should be considered? What are their boundaries?*

For this a period will be chosen for which all two data parameters (SST and chlorophyll) are available. Data from this period will be used to compute monthly averages, i.e. averaged images. These averaged images will then be used in a two-parameter unsupervised spatial classification scheme which is available as part of IDL to achieve partitioning. This result will be augmented by examining plots of the two parameters, taken from sample lines in both longshore and offshore direction, for obvious discontinuities. The classification is expected to yield irregular shaped regions, not ideally suitable for a description of the spatio-temporal variation of the oceanographic parameters. The regions obtained from the classification will therefore only be used as a guide to partition the area of interest into sub-regions with linear boundaries.

A pre-requisite for applying the classification, is that the three types of images are of exactly the same format (i.e. that they are geographically registered). ENVI will be used to perform this image-to-image registration of the averaged images.

2. *Seasonal and inter-annual variation.* IDL software will be used to generate time series of SST and surface chlorophyll-a concentration for each of the sub-areas. The temporal variation will be described on hand of plots of these time series. Cross correlations will be computed between the two parameters (where there is a temporal overlap of the series) to investigate possible cause and effect relationships.

3. **Upwelling.** If the initial examination of the images indicates upwelling activity then *upwelling indices* will be computed from SST data. The SST-based upwelling estimate will be based on the SST at the coast and an offshore location. If applicable, seasonal and inter-annual variations in upwelling activity will be described as for SST and chlorophyll-a.

4. **Can the Angola-Benguela front and Congo River outflow be detected with the SST- and/or chlorophyll images?** To address this question one year's archive of images (both SST and chlorophyll-a) will be visually examined. Although it is already known that the Angola-Benguela front can be detected, useful insight will be gained regarding the behaviour, characteristics and variation of the front. The exercise will also help to gain a qualitative impression of spatial and inter-seasonal variation of the SST and chlorophyll-a fields and to identify any other prominent oceanographic features in the area of interest.

5. **Variation in the position of the Angola-Benguela frontal zone.** The structure of the frontal zone is complex so that objective determination of the position becomes a difficult matter. The approach will be to reduce spatial variability by first computing monthly averages of SST and chlorophyll-a from the monthly composites and then to further smooth the resulting images with a low-pass filter. The position of the front will then be determined for each month from north-south SST and chlorophyll-a gradients in swaths parallel to the coast.

6. **The Congo River outflow.** If initial examination of the images (Step 1) indicates that the outflow plume can be detected in the SST and/or chlorophyll-a images then a strategy will be devised to estimate the size of the plume. The results such a scheme will be validated by compared with ships' measurements of salinity and measured river discharge rates. The southward extend of the plume into the Angolan marine environment is also a matter of interest. It is expected that an adoption of the strategy used to determine the plume size could be employed to determine the southern extent of the plume. Temporal variation of plume size and southward extent will be described.

Chapter II: Overview of the main oceanographic features off Angola

2.1 Bathymetry

The Angola coastline has a length of around 1650 km and lies between 5.02°S and 17.3°S. The Neretic Zone off Angola just covers one third of the EEZ (Exclusive Economic Zone), which is around 370 km wide. Off Angola, the EEZ is made up of the Neretic Zone covering the littoral (0-30 m depth), the continental shelf (50-200 m depth), the Oceanic zone covering the continental rise (500-2000 m depth) and the Abyssal (2000-4000 m depth).

The width of the Continental Shelf varies in width between 11 and 33 km. Its depth varies on average between 50 and 200 m. In the region of Cabinda (5°S) to Luanda (8.6°S), it is wide (≈ 33 km wide and 180 m depth) near the mouth of the river Congo (6.2°S). This is due probably to the sediment deposited by the river (Fig.II 1).

From Luanda (8.6°S) to Benguela (12.6°S), the width of the shelf is almost constant (≈ 22 km wide) and its depth varies generally between 50 and 100 m depth. From Benguela to Namibe (16.5°S), the shelf is very narrow or almost absent (≈ 6 km wide) and very deep (≈ 200 m depth). In some areas, it is replaced by the continental rise reaching about 1000 m depth.

Southwards from Tombwa to the Cunene River (17.3°S), it widens to 11 and 18 km and a depth is less than 120 m (Fig.II 1).

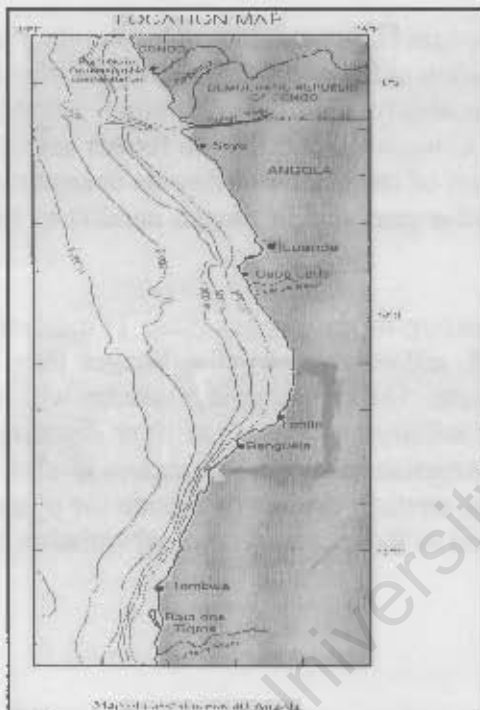


Fig.II-1 Bathymetric map of Angola

2.2 Angola Ecosystem

2.2.1 Equatorial Current System

The Equatorial Current System consists of the surface South Equatorial Current (SEC) and three subsurface currents, the Equatorial Undercurrent (EUC), the South Equatorial Undercurrent (SEUC) and the South Equatorial Counter Current (SECC).

2.2.1.1. South Equatorial Current (SEC)

According to Peterson & Stramma (1991), this current is characterized by high temperature ($>25^{\circ}\text{C}$), high salinity (36.5), high oxygen concentration (5 ml l^{-1}) and a velocity of about 10 cm s^{-1} . The South Equatorial Current (SEC) is broad, westward flowing current that extends from surface to a nominal depth of 100 m.



Fig.II-2 Map of the Atlantic Ocean off Southern Africa and Gulf of Guinea.

2.2.1.2 South Equatorial Undercurrent (SEUC)

The SEUC was observed under the thermocline. This subsurface current flows eastward and deflects against the African coast from 3 to 8°S . It can be observed down to 150 and 200 m and it is around 100 km wide. Its velocity is around 40 cm s^{-1} and it springs from the same region as the SEC.

This current springs from the South Atlantic off Brazil and flows eastwards parallel to the Equator across the Atlantic to the African Coast where it bifurcates into the north and south Equatorial Undercurrents (Fig.II 2).

2.2.1.3 Equatorial Undercurrent (EUC)

Peterson and stramma (1991) defines this current as a narrow jet having a half-width of about 1.5° of latitude. It is generally found under the thermocline at the depth of about 100 m or less and its velocity can reach 100 cm s^{-1} . This velocity weakens as it flows eastwards down to 30 cm s^{-1} at the African coast. Wacogne and Piton (1990) have observed the same current between $1-6^{\circ}\text{S}$ at the African coast and it is believed to feed the Angola current further south.

This current like other equatorial currents springs from the South Atlantic of the North of Brazil current. It features high salinity (36.5).

The EUC and SEUC are both equatorial subsurface currents, they differ in the latitude, the velocity and the depth in which they flow. The EUC is observed just near the equator ($0-6^{\circ}$), has high velocity ($30-100\text{ cm s}^{-1}$) and has a maximum depth of 100 m. However the SEUC has low speed (10 cm s^{-1}) and it is observed between $5-10^{\circ}\text{S}$ at 200 m or more.

2.2.1.4 South Equatorial Countercurrent (SECC)

The South Equatorial Undercurrent (SEUC) and the Equatorial Undercurrent (EUC) flow to the north of 5°S but the SECC flows between 5-10°S at a depth of 150 m to 275 m but between 10-14°S, it reaches the surface (Peters and Stramma, 1991). Reid (1964) observed this current between 5-12.5°S with an eastward velocity of 9 cm s⁻¹ at 200-250 m depth. The SECC splits into two branches: the Angola current flowing southwards and the northwards branch taking up the waters of the Congo River plume and continues northwards in westerly direction as the SEC (Bennekomp & Berger, 1984).

2.2.2 Angola Current

The Angola current covers the shelf and the continental rise of the Angolan coast (Moroshkin et al., 1970). Wacogne & Piton (1990) and Bubunov (1972) found that the Angolan Current is supplied by the EUC and the SEUC springing from the Equator. These authors found that the southward flow in the region of the Angola current appears to be significantly deeper than the equatorial currents. Its average velocity is around 50 cm s⁻¹ between 9-16°S and can be observed down to 250-300 m.

It features high temperature (>24°C) and salinity (>35.0) modulated by weak, seasonal equatorial upwelling. The oxygen content is always around 5 ml l⁻¹ at the surface layer. Biological productivity in the current is low. Gammelsrød et al., (1997) made current measurements at Cabo de Santa Maria (14°S, 12.2°E) and found a poleward current with a speed of 50 cm s⁻¹ at 25 m depth and 30 cm s⁻¹ at 125 m depth.

The Angola current flows polewards down to 14°S-16°S where it converges with cool upwelled water in the Benguela current, creating a front called the Angola-Benguela front (Figs. II 3 & II 4).

According to Gammelsrød et al. (1997), the Angola current is in near-geostrophic balance. Geostrophic equilibrium exists when the Coriolis force is in opposite direction to the pressure gradient. Mathematically speaking, the geostrophic motion is expressed by two equations defining the equilibrium of forces at the axis of X (E-W) and axis of Y (N-S). In the X-direction, the equation would be:

$$F_v = [1/\rho] * [dP/dx]$$

Where F_v is the Coriolis force along the X-axis in equilibrium with the component of pressure gradient dP .

In the Y-direction, the equation would be:

$$F_u = [1/\rho] * [dP/dy]$$

The Y-component of the pressure gradient is in equilibrium with the Coriolis force. The same force will tend to deviate it away from the coast. However at 16°S, the Angola current is moved away from the coast and diverges with the Benguela current giving birth to the "Angola-Benguela front".

2.2.3 Angola Dome

Between 1902 and 1963, about 200 surveys were conducted in the southeastern Atlantic by several research vessels including the survey by the R/V "Equalant I" during the southern hemisphere summer (January-April, 1964). With these data, Mazeika (1967) was the first to identify the Angola Dome at (10°S, 9°E) at 20 m depth. In February 1971 Voituriez (1981) identified the same thermal feature at (11°S, 9.5°E) and characterized it by the lower temperature (19°C) at the centre of the dome compared to the surrounding waters (24°C) and by the higher concentration of oxygen (4 ml l⁻¹) at 20 m. At 200 m, the oxygen content is still high (1.8 ml l⁻¹).

In two consecutive years (1996, 1997), Gammelsrod et al. (1997), Filipe (1997), Filipe, (1998) successfully surveyed this dome-like thermal structure (Figs.II 3 & Fig.II 4) with the Norwegian R/V "Dr Fridtjof Nansen" as well as Mohrholz et al. (1999) with the German R/V "Poseidon" during the southern hemisphere summer (February-April). In all these surveys, the dome was located between latitudes 9-12°S and longitudes between 9-10°E. It was identified as a thermal feature at 20 m depth with ΔT (temperature difference) between the center of the dome and the surrounding waters varying between 3°C to 7°C which is a sign of an open ocean upwelling.

The oxygen content was higher and the salinity lower in the center than in the surrounding waters. The thermal dome is a cyclonic eddy due to the uplifting of the thermocline (Voituriez, 1981).

This cyclonic eddy termed Angola Dome has its counterparts in the northern hemisphere, the

Guinea Dome which is centered at 12°N, 22°W and it is well developed at 50m depth (Rossignol & Meyreuis, 1964; Mazeika, 1967) and the Costa Rica Dome centred around (10°N, 90°E) (Cromwell, 1958; Wirtki, 1964) in the Pacific.

Peterson & Stramma (1991) noted that there is no Angola dome present in the thermocline in those months (May-September) when the surface geostrophic flow is no longer eastward in the Gulf of Guinea.

The Angola Dome is regarded as a subthermocline structure and is permanent, as it is associated with the undercurrents, which are themselves permanent. The uplifting of the dome above the thermocline is subject to the seasonal variations. It occurs during the summer of the southern hemisphere (January-April) when the trade winds weaken, letting the surface waters flow eastwards.



Fig.II-3 Map based on the NOAA-16 AVHRR composite SST image of 11 March 2004 showing the Atlantic Ocean off Angola.

The Guinea Dome appears above the thermocline in July-September when the ITCZ is in its most northerly position (4°N). The Guinea Dome is then situated just to the south of ITCZ in the zone of low pressures and weak variable winds. The Angola dome is also located in a region of weak and variable winds associated with the western boundaries of the South East Trade Winds (Voituriez & Herbland, 1982). As a subsurface oceanographic feature, the Angola dome cannot be detected with SST, but it might be possible with altimetry.

2.3 Benguela Ecosystem (South of Angola)

2.3.1 Benguela current

According to some scientists like Defant (1961), Reid (1989) and Stramma & Peterson (1989), the Benguela current is an equatorward flow from the Cape of Good Hope that skirts the African coast to around 15-17°S. It is composed of water from the South Atlantic Current, the large Subtropical Southern Gyre and from the Agulhas warm water as well as Subantarctic Surface waters.

The current (Fig.II 2 & Fig.II 3) itself features cold water of low salinity due to the intense upwelling in the south of the ecosystem in summer and in the north in winter. The upwelling rate is not uniform along the Coast. It is associated to the wind regime, coastal topography, the width and depth of the shelf (Shannon, 1998; Nelson, 1992). Upwelling is intense where the winds are strong and the shelf is narrow and deep (Nelson, 1992). The region is biologically highly productive.

According to Peterson & Stramma (1991) the Benguela upwelling system is strongly influenced by the semi-permanent high-pressure system over subtropical South-Atlantic, the South Atlantic Anticyclone (SAA), and the continental heat low that develops over southern Africa during the summer months. The winds in the region blow from a south to southeasterly direction. This in turn drives offshore Ekman transport that results in the upwelling of cold, nutrient rich water onto the continental shelf

Gammelsrød et al., (1997) made current measurements at Rocky Point (18°S, 12.1°E) in the northern Benguela and found equatorward current with a speed of 50 cm s⁻¹ at 25 m depth but only 10-20 cm s⁻¹ at 125 m depth. And noted that this was very fast comparing with the geostrophic velocity of 5 cm s⁻¹ computed for Rocky Point.

In his review of the Benguela system, Shillington (1998) classifies the coastal Benguela Current into four categories in terms of velocity: 10-15 cm s⁻¹, 40 cm s⁻¹, 5-8 cm s⁻¹ and 70 cm s⁻¹. Nelson and Hutchings (1983) found the mean velocity to be between 23 and 35 cm s⁻¹ and Shannon (1985), reported to be about 15 cm s⁻¹. But a map of surface currents presented in Shannon (1985) shows current velocities of 15-25 cm s⁻¹ off South Africa (reaching 50 cm s⁻¹ at Cape Columbine), 10-25 cm s⁻¹ off Namibia and 30-50 cm s⁻¹ off Cunene (Angola). According to Shillington (1998) the highest velocity observed in the Benguela is the equatorward shelf-edge front jet off Cape Peninsula (70 cm s⁻¹). Altogether, it would therefore see that the velocity measured by Gammelsrød et al., (1997) was unusually high for that latitude.

2.3.2 Angola-Benguela Front (ABF)

Hart and Curie (1960), Moroshkin et al., (1970), Bubunov (1972), Dias (1983a,b), Shannon et al., (1987) and Meeuwis & Lutjeharms (1990) pioneered the study of the Angola-Benguela front and found it to be a permanent oceanographic feature varying between 15-18°S (Fig.II 4). They found that this front extends down to 200 m depth with salinity data but it is intense down to 50 m with the temperature distribution. It is aligned perpendicular to the coast, with a seaward extension between 200 and 600 km. Its average width is approximately 200 km (Meeuwis and Lutjeharms, 1990). The same feature can be observed in the distribution of salinity showing the existence of the front between 15 and 18°S (Shannon et al., 1987).



Fig.II-4 Map based on the Meteosat monthly composite SST image of April 1994 showing oceanographic features off the southern Atlantic.

Possibly the northerly of the two is the convergence of the Angola and Benguela currents and the southerly one being associated with the upwelling cell situated at Cape Frio at about 17-18°S.

2.3.3 Distribution of the chlorophyll-a along the Angola Coast

Chlorophyll-a is a green pigment found in plants. It absorbs sunlight and converts it into sugar during photosynthesis. Chlorophyll-a is an indicator of phytoplankton abundance and biomass in coastal ocean (http://www.gov.au/oracle/ozestuaries/Indicators/In_chlorophyll_a_f.html). It absorbs most strongly in the blue and red but poorly in the green portions of the electromagnetic spectrum. Besides chlorophyll-a, phytoplankton contains

other pigments structurally similar but chemically different (Chlorophyll-b, chlorophyll-c1, chlorophyll-c2 and chlorophyll-d). These chlorophyll pigments are all associated with the photosystems but have different electromagnetic spectra (Brian, 1997). Photosynthesis and pigments are discussed in details in Brian (1997) and in <http://en.wikipedia.org/wiki/Chlorophyll>.

Robinson (1985) and Robinson (2004) discuss thoroughly how chlorophyll concentration is measured by satellite sensors (Nimbus-7 CZCS and Orbview-2 SeaWiFS respectively) and how these measurements allow estimating primary productivity in a water column. In this regard, Carr (2002) undertook an interesting study where she explains how primary production can be deduced from the chlorophyll-a and the diffuse attenuation coefficient. She also discussed the influence of environmental parameters such as temperature, or primary production as well as the effect of variations in euphotic layer depth and mixed layer depth or estimation of primary production. Besides, chlorophyll off Angola (15-17°S) is estimated to be between 2-3 mg m⁻³ and the computed primary production between 2000 and 3000 mg Cm⁻² d⁻¹.

It is well known that Phytoplankton abundance is associated with coastal upwelling and river plumes or estuaries that provide nutrient necessary for growth. Off Angola Plankton distribution in the northern region linked to the Congo River plume, where the chlorophyll-a concentration varies between 7-8 mg m⁻³ and to the upwelling cell of the Cunene where it varies between 3-5 mg m⁻³ (Hardman-Mountford et al., 2003) Mann (1992) discusses the critical depth where phytoplankton still produces photosynthetic surplus for growth, impact of upwelling intensity (strong and weak windstress) in the stratification and mixing of the euphotic layer and the impact of river run-offs in the production of algae blooms (Case of Congo river)

Boltovskoy et al., (1999) made an in depth study of the distribution of chlorophyll-a, primary production and zooplankton biomass in the South Atlantic and observed:

- fairly high phytoplankton biomass and production at the surface between 5-7°S; low in the region 9-13°S (0.25-0.50 mg m⁻³ plankton biomass and 21 mg Cm⁻² h⁻¹ production);
- High in the region 13-16°S (0.3-0.8 mg m⁻³ plankton biomass and 5021 mg Cm⁻² h⁻¹ production);
- To the south of 16°S (0.2-0.8 mg m⁻³ plankton biomass and less than 13 mg Cm⁻² h⁻¹ production), nutrient rich layer is at about 100 m, too deep to fuel high productivity.

The same authors discuss how the Congo River flow affects the phytoplankton biomass. In the region of the ABF, John et al., (2004) found the chlorophyll-a concentration of less than 3 mg m⁻³ while to the south of 16°S, the concentration ranged between 3-10 mg m⁻³.

In their review on phytoplankton studies off Angola, Rangel et al., (*unpublished*) found a higher biomass of microalgal organisms in the upwelling region (13-17.3°S) and near the Angola Dome in April 1999, while in August 2001 the highest abundance occurred in centre-south (10-17.3°S). They also reported maximum density in the depth ranging from 15 to 50m, irrespective of the season.

Hardman-Mountford et al. (2003) reported chlorophyll-a concentration less than 1 mg m⁻³ for months January–May and October–December for the entire Angolan coast except at the Congo River where the concentration was at the level 7-8 mg m⁻³. During winter months

(June-September) the average between 5°S and 12°S was higher than in summer at 5 mg m⁻³ but remained constant in Congo River mouth (6°S).

2.3.4 Benguela Niños

The so-called Benguela Niño is a regional phenomenon that affects the coastal ocean between Angola and Namibia. It is equivalent to the Pacific El Niño but is less intense and less frequent (Shannon et al., 1986). In the past, Benguela Niños tended to occur one year after the Pacific Niños, leading to the belief that teleconnection exists between them. However Shannon et al. (1986) stated that the 1963 and 1984 events in the northern Benguela were clearly out of phase with major Pacific events. The effects of Benguela Niños are similar to those of the Pacific although in a small scale and not as disastrous. Shannon (1985) discussed warming and high salinities observed in Namibia in 1963.

The same situation was observed in 1984 (Shannon et al., 1986; Boyd et al., 1987) and it was reported that an intrusion of warm saline water from Angola into Namibia, weakened coastal upwelling and resulted in flooding rivers in northern and central Namibia.

Shannon and Nelson (1996) observed that the Benguela Niño occurs approximately once per decade, with major events in 1934, 1963, 1974, 1984 and 1995. Some of these major events were reported by Shannon (1985), Shannon et al., (1986), Boyd et al., (1987), Mann (1992) and Gammelsrød et al., (1998). These authors discussed the Benguela Niño off Namibia and very little was said about Angola:

- 1934 was characterised by an increase of temperature for about 2-3°C above the long time average. Heavy rainfalls were recorded causing flooding in the Namibia Desert.
- In 1950, the 27°C isotherm was recorded about 600 km south of its normal position and flooding occurred again in central Namibia.
- In 1963 positive temperature (2-3°C) and salinity (0.1-0.2) anomalies were observed in the upper layer off Namibia.
- 1984 warm event is discussed in depth by Shannon et al. (1986).

The 1995's Benguela-Niño was observed during a survey undertaken by the R/V "Dr. Fridtjof Nansen" in March-April 1995. Gammelrød et al., (1998) found an increase of temperature of about 8°C at 30 m depth while at 5 m depth, no warming was observed compared with measurements made in March 1994. Unlike temperature, salinity decreased at 5m depth at the rate of 5 relatively to 1994. Gammelrød et al. (1998) also found a deepening of the thermocline at Ponta das Palmeirinhas (9°S) from 15 m (normal) to 40 m depth. While low salinity was observed off Angola, it was higher off Namibia throughout the warming period.

During the 1995' event the estimated biomass of the three commercially important pelagic fish species (sardinella, Cunene horse mackerel and sardines) declined sharply. The first two species recovered by 1996 but the stock of sardines remained depressed (Luyeye, 1995).

The event was also associated with heavy rainfalls at the coast as well as in the interior of Angola. The main rivers (Congo and Cuanza) flooded and the outflow of fresh water into the ocean reduced the salinity down to 28 in the upper layer, minimum value never reached during normal years (Gammelrød et al., 1998).

Most of these warm events featured an increase of temperature of about 2-3°C and a decrease (increase) of salinity off Angola (off Namibia) respectively. Heavy rainfalls were recorded, increase of sea level observed, upwelling intensity weakened, ITCZ shifted southwards and biological productivity affected either in Namibia or in Angola. As to the coastal upwelling, winds were favourable in 1963 and in 1984, but biological effectiveness of the upwelling was greatly reduced by the cap of warm saline water spreading south from Angola (Mann, 1992).

2.3.5 Coastal Upwelling

It is well known that upwelling is a fundamental factor to primary productivity and the primary driving mechanism in coastal upwelling is Ekman divergence, which acts in response to longshore wind (Nelson, 1992).

Upwelling is never uniform in the longshore direction of the coast; it is affected by coastal morphology, the width and depth of continental shelf and submarine topography, such as capes or canyons as well as the wind stress (Shannon, 1998; Nelson, 1992). Upwelling is intense where the winds are strong and the shelf narrow and deep.

According to Nelson (1992), upwelling induced by wind events that last a few days is more productive than continuous upwelling. One disadvantage of continuous wind is that Ekman layer can deepen to a point below the euphotic zone. At that level, respiration of developing plankton continues, but because light levels are low, carbon is not fixed and there is no growth. Nutrients are consumed unprofitably and a part of the stock will not reach maturity. Ekman flux depends only on windstress and latitude.

The Benguela current region is one of the world's major coastal upwelling systems. It is characterized by the pulsed input of cold, nutrient-rich water into the euphotic zone at specific sites along the west coast of Southern Africa between 15-35°S (Lutjeharms and Meeuwis, 1987), latitude 15°S is the approximate northern boundary of the highly upwelling favourable wind field in the Benguela (Shannon, 1985; Picaut, 1983; Nelson & Hutchings, 1983).

Hardman-Mountford et al. (2003) used the nearshore-to-offshore SST gradient as an upwelling index and found that for months January-April, upwelling along the Angola coast restricted to the section off Namibe (16-17°S) where the SST gradient was (-2°C) all year round. The windstress at those latitudes reaches a maximum in April and October (Shannon, 1985).

During the dry season (May to September), upwelling of similar intensity was observed between 8-12°S (Luanda-Lobito). Obviously this could not be wind-driven upwelling because the pseudo-wind stress observed in that location was less than $10 \text{ m}^2 \text{ s}^{-2}$ and insufficient to drive Ekman transport. Berrit (1976) also found that north of 15°S the winds do not favour Ekman upwelling and that the strong upwelling signal in the temperature data had other causes. According to Hardman-Mountford et al., (2003) upwelling is caused by remote forcing from the Western Equatorial Atlantic. This remote forcing is explained by Moore et al., (1978) who attribute part of the upwelling to an internal Kelvin wave generated by increased easterly winds off northern Brazil.

2.4 The Inter-Tropical Convergence Zone (ITCZ)

The ITCZ (Intertropical Convergence Zone), also called the “meteorological equator” is the convergence zone between the northeast trade winds blowing from the tropics of Cancer towards the geographical equator and the southeast trade winds blowing from the tropics of Capricorn towards the equator. The ITCZ is situated at approximately 4°N but varies seasonally. It moves further north, when the southeast trade winds are strong (June-September/ winter of southern hemisphere) and close to the equator when they are weak (January-April/summer of southern hemisphere).

According to Evenson (1998), the southeast trade winds blow across the equator leading to an Ekman drift to the left (southwestwards) south of the Equator, a drift into the wind direction on the equator where the Coriolis force is zero and an Ekman drift to the right north of the equator. This generates the well-known equatorial divergence just south of the equator. Thus there is no significant Ekman transport in the region between the two trade wind zones.

2.5 Influx of the Congo River flow

The Angolan marine environment is influenced by the inflow of several rivers, the largest being the Congo River with a maximum discharge of about $90,000 \text{ m}^3 \text{ s}^{-1}$ and a minimum of $23,000 \text{ m}^3 \text{ s}^{-1}$ (Peters, 1978). This reduces the normal surface salinity from about 35 to as low as 27.6 at the mouth of the river (5°S) and 30.3 at Ambriz (7°S) and is also thought to enhance biological production in the vicinity of the mouth. Compared with

the Congo, the influences of other rivers, like the Cuanza, Ambriz and Cunene, are relatively small.

According to Probst and Tardy (1987), the Congo River has an annual discharge of about $1.45 \times 10^{12} \text{ m}^3 \text{ year}^{-1}$ and it is considered as the second largest river in the world after the Amazon (Brazil). The seasonality index (SI), which is the ratio between the high and low flows, is 1.7. The index is very low for the Congo when compared to that of other rivers like Niger (13) and Orange (8) and is due to the regularity of rainfall.

The annual total rainfall in the equatorial region of the Congo exceeds $1400 \text{ mm year}^{-1}$.

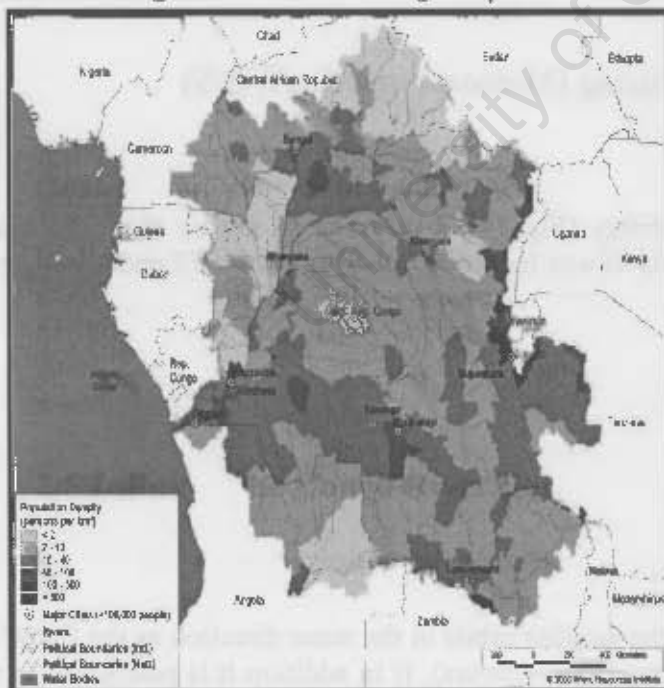


Fig. II-5 The Congo River basin (after the World Resources Institute, 2003).

The catchments area of the Congo River (Fig.II 5) is situated in Lubumbashi/ Katanga (southeast of Congo) region (5-10°S, 25-30°E) with a tropical climate similar to the northern Angola.

It then flows northward through Kisangani (1°N, 25°E) to Mbandaka (0°S, 18.5°E). Between Mbandaka and Kisangani (Fig.II 5), the river flows through the dense equatorial rain forest, where the flow varies between 5,050 m³ s⁻¹ and 19,800 m³ s⁻¹. These cities have an equatorial climate i.e. the rainy season lasts all year. Downstream at Kinshasa (5.3°S, 15.5°E), the flow reaches 90,000 m³ s⁻¹, almost four times that observed at Kinsangani.

This is due to several tributaries (Kassai, Kuango, etc...) feeding the river between Mbandaka and Kinshasa (Fig.II 5). From there it flows to and out into the Atlantic Ocean, maintaining almost the same flow rate (www.oasisfoundation.org/oasis/okapi/congoriver). According to Eisma and Van Bennekom (1978), the flow of the Congo River has two highs and two lows. The maxima occur in December (60,000 m³ s⁻¹) and in April-May (41,000 m³ s⁻¹) respectively. The minima occur in July-August (29,000 m³ s⁻¹) and in March (32,000 m³ s⁻¹) respectively.

In general the outflow of the river is directed towards the northwest, turning westwards near the edge of the continental shelf. Another part of the flow is directed southwards and this plume is observed down to 11°S (Berrit, 1966).

According to Eisma & Van Bennekom, (1978) the horizontal salinity distribution observed in 1976 showed a variation on the surface from 15 to 23 just at the mouth, and varies between 23-34 in the offshore direction (11-9°W off Cabinda and Pointe Noire 4-6°S). During the Benguela Niño-95, the salinity values dropped down to 28 all along the plume at 5 m depth and the brackish water was observed in the south of Luanda (Gammelsrød et al., 1998).

2.6 Brief overview of Remote Sensing (Meteosat and SeaWIFS)

2.6.1 METEOSAT

Meteosat is a geostationary satellite (Fig.II-6) series maintained by the European Space Agency (ESA). Meteosat-1 (Fig.II-7) was launched in November, 1977 and six others since then (Robinson, 2004):

- Meteosat-1 (1977-1979)
- Meteosat-2 (1981-1989)
- Meteosat-3 (1988-1995)
- Meteosat-4 (1988-1995)
- Meteosat-5 (1991-2003)
- Meteosat-6 (1993-2003)
- Meteosat-7 (1997-2003)

A geosynchronous orbit is achieved if the satellite orbits in the same direction as the Earth's rotation with a period of one sidereal day (23.934 hours). If in addition it is positioned in a circular orbit above the equator then it appears to be stationary relative to an observer on the Earth and therefore always views the same area of the Earth's surface. The satellite is then said to be in a geostationary orbit and in order to maintain this orbit, it must be at an altitude of 35785 km above the Equator (Robinson, 2004).

A geostationary satellite (Fig.II 6) is thus in principle, capable of continuous observation of a single point on the earth's surface but, because of its position, it is incapable of observation at high latitudes. Meteosat, for example can not "see" beyond 60°N and 60°S.

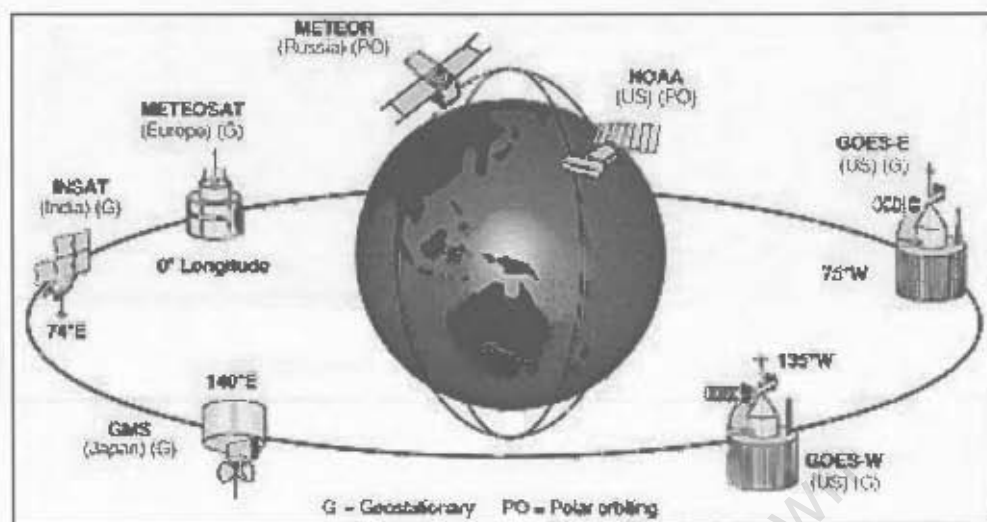


Fig.II-6 Geostationary and orbital satellites (after Lillesand et al., 2004)

Meteosat carries a sensor called VISSR (Visible and Infrared Spin Scan Radiometer), designed to monitor cloud, measure cloud and earth surface temperatures and estimate the water vapour content of the atmosphere. It has three spectral bands: 10.5-12.5 μm (thermal infrared), 5.7-7.1 μm (water vapour) and 450-1000 nm (visible) (Fig.II 8)

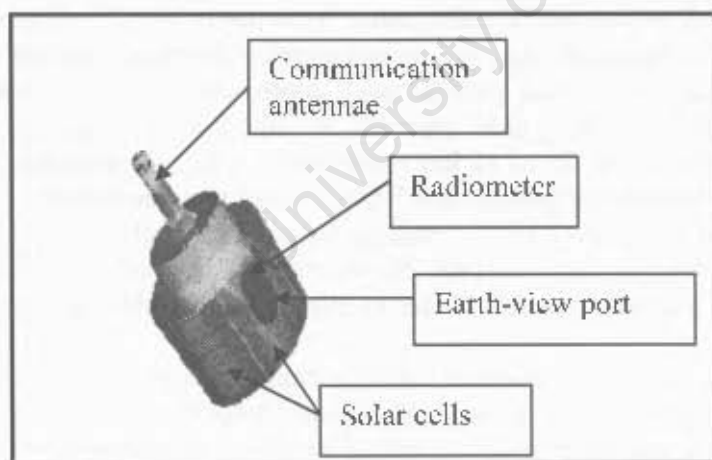


Fig.II-7 Meteosat (after Robinson, 2004)

The sensor generates two thermal Infrared images per hour consisting of 2500 scan lines and 2500 pixels each. The visible channel has two detectors, thus sampling twice as fast to produce a 5000 x 5000 pixel images.

Because the sensor has only one IR band, split window or multiband atmospheric corrections such as employed to correct NOAA/AVHRR (Advanced Very High Resolution Radiometer) SSTs cannot be used. Such corrections are therefore normally achieved through comparison with ships observations (Demarcq and Citeau, 1995).

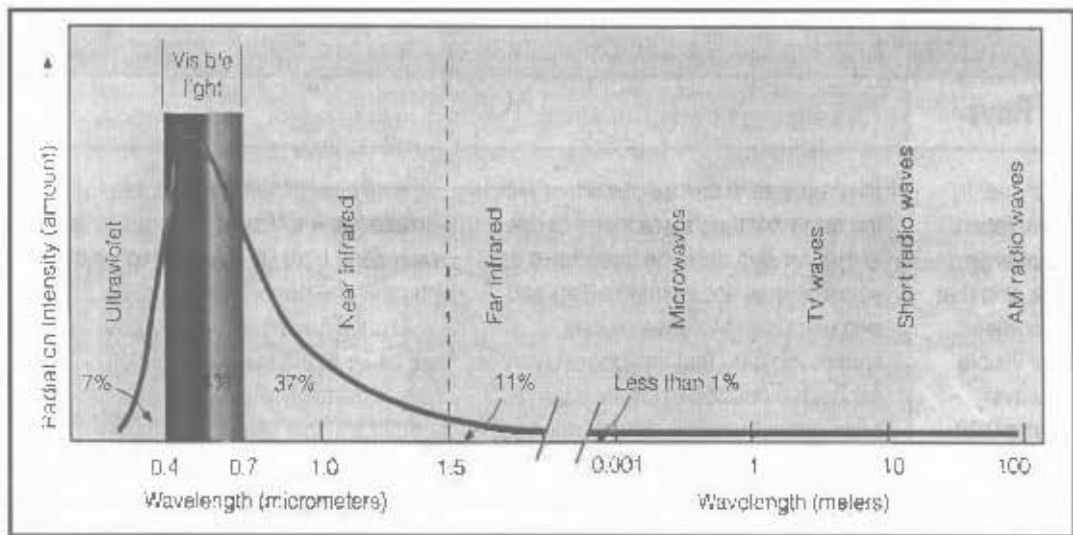


Fig.II-8 Electromagnetic spectra (Lillesand et al., 2004)

2.6.1.1 Meteosat composite SST data sets

The basic Meteosat SST data products are delivered in the form of an image data set in satellite coordinates, the rows corresponding to scanlines and the columns to the pixels. The pixel size is based approximately on the sensor spatial resolution that is around 5-6 km. Such data are not convenient for oceanographic applications because

- They are not gridded in geographical coordinates
- The volume of data, 48 images per day, is usually unnecessarily large.

For this reason, as well as to draw out useful information from partly cloudy images, SST images are often condensed into composite data sets, which average the measurements within larger space-time sampling bins. The spatial grid for such composite products is normally defined in coordinates of latitude and longitude, typically 5', 10', 0.5°, 0.1° in size of the cells which corresponds to about 9, 19, 55 or 11 km respectively. The east-west size in km varies with latitude. Typical timescale integrations are 5 day, 1 week and one month.

Composite SST images are produced by averaging, for each grid cell, the SSTs from cloud-free pixels within the binning time interval. Sometimes, instead of averaging, the maximum SST from the time interval is used in order to eliminate possible bias caused by cloud contamination.

The SST images used in this study were 5-day and monthly composites provided by IRD in France. The images cover the geographical area (5-40°S) and (5-40°E) and consist of 650 scanlines and 650 pixels each and produced according to the procedure described by Demareq and Citeau, (1995). The SST resolution is 0.5 and the spatial resolution, 5.91 km in central Angola.

Besides the chlorophyll, there are other substances such as:

- Suspended particulates (sediments)
- Dissolved organic compounds (detritus of dead organisms)
- Yellow substances (decayed vegetation)

which contribute to the light scattering and absorbing properties of sea water. A portion of the sunlight incident on the sea is reflected at the surface and a portion is refracted to penetrate the ocean. Light reflected at the surface carries no information on the water constituents, but the spectrum of the portion which penetrates is modified by the in-water constituents so that the light scattered back out of the ocean towards the satellite sensor carries information on the optical properties of these constituents. The depth to which the light penetrates depends on the concentrations of suspended and dissolved material but typically varies between 20 and 50 m. The absorption properties of water is such that only light within the visible part of the solar spectrum can penetrate to a significant depth, hence ocean colour remote sensing, which operates within this spectral band, is the only form of remote sensing which provides information on the bulk water properties.

Data are processed from the measurement of radiance entering the sensor in each channel until obtaining the digital counts. Patt et al., (2003) made in depth study, more detailed and updated analysis of SeaWiFS data processing steps consisting of on-orbit calibration between the radiance measured by the sensor against MOBY (Moored Optical Buoy off Hawaii) data, atmospheric correction, calibration and validation, against in situ measurements, masks and flags and level-2 and level-3 SeaWiFS products. The same processing steps are also discussed in Robinson (2004).

In this study 5-day composite images of chlorophyll-a concentration were used. They were produced from SeaWiFS GAC ('Global Area Coverage') format data by IRD (France) according to the procedure described by Demarcq et al., (2003). These images cover the same geographical area as the Meteosat SST images (5-40°S; 5-40°E) and consist of 825 scanlines with 825 pixels per scanline. The spatial resolution in Angolan waters is about 4.5 km.

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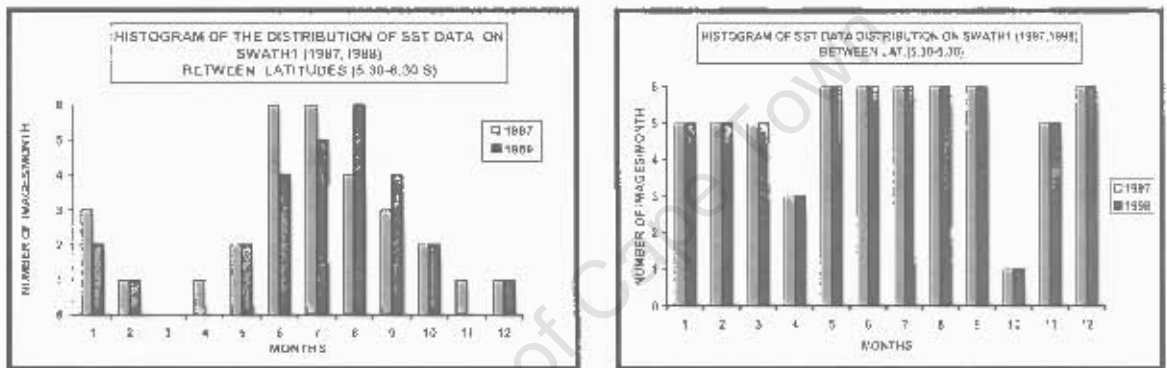
Chapter III Data and Methods

3.1 Data

3.1.1 SST Composite images from Meteosat series (1987-2002)

A time series of 5-day SST composite images (1987-2002) in the form of 650 x 650 byte arrays, covering the region between 5°-40°S and 5°-40°E, with a spatial resolution of about 5-6 km in Angolan waters and a thermal resolution of 0.5°C, were provided by the IRI (France) (Demarcq & Citeau, 1995). These images were used to produce:

- Monthly SST composites (650 x 650) covering the same area and having the same spatial resolution and thermal resolution.
- Monthly SST averages (climatologies) as binary images covering the same region and with the same resolution.



FigIII-1 Histogram of the distribution of Meteosat-SST data on swath1 (1987-1988) and (1993-1994)

The pixel values are digital numbers (DN) ranging between 0 and 255. Those values are converted into degree Celsius as follows:

$$SST=55-(DN/2) \quad (3.1)$$

The x- and y-coordinates of the image are converted into geographical coordinates (latitude and longitude) as follows (Appendix #3):

$$Lat=latn - (yp/2)-(y1 * yp) \quad (3.2)$$

$$Lon=lone + (xp/2) +(x1 * xp) \quad (3.3)$$

Where

$$xp=(lone-lonw)/x \quad (3.4)$$

$$yp=(latn-lats)/y \quad (3.5)$$

x1 & y1 are the given x- and y- coordinates of any pixel
 xp & yp are the size of the pixel in x- and y-directions
 (latn=5 & lats=-40) are the northern and southern latitudes

(lon_e=5 & lon_w=40) and the eastern and western longitudes
 x=650 and y=650 (pixel size of the image)

3.1.2 SeaWiFS GAC images for Chlorophyll-a concentration (1998-2004)

A time series of 5-day surface chlorophyll-a composite images (1998-2004) were provided by the IRD (France) from SeaWiFS GAC ('Global Area Coverage') images (Demarcq et al., 2003). These images are in the form of 825 x 825 byte arrays and cover the region between 5°-40°S and 5°-40°E, with a spatial resolution of about 4.5 km in Angolan waters. They were used to produce:

- Monthly chlorophyll-a composites covering the same area and with the same spatial resolution.
- Chlorophyll-a monthly averages (climatologies) as binary images with the same coverage and spatial resolution.

The digital numbers (DN) in these images are converted into $mg\ m^{-3}$ as follows:

$$Chl = 10^{(0.015 \cdot DN + 2.0)} \quad (3.6)$$

The same conversion formulas (x- and y-coordinates into latitude and longitude) used with Meteosat-SST images (Appendix #3), are also used with SeaWiFS chlorophyll images, except that the pixel sizes are different (x=825 and y=825).

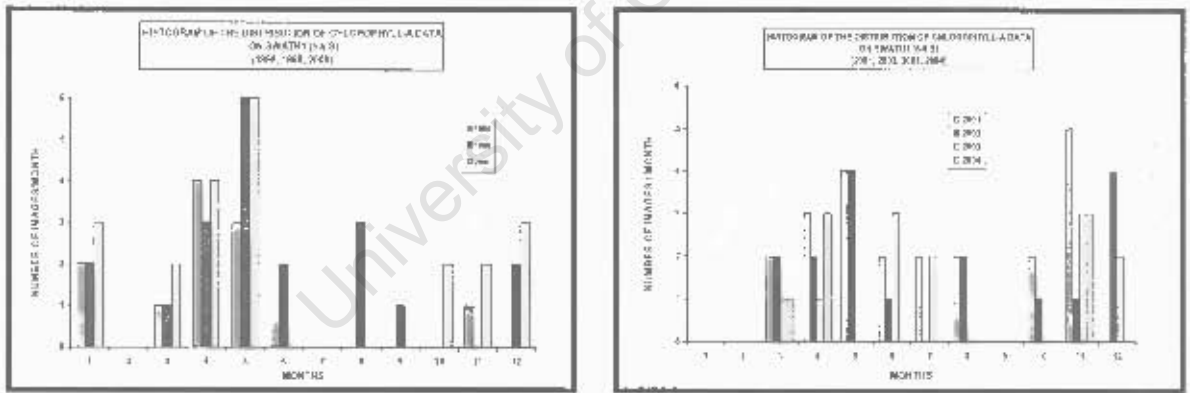


Fig.III-2 Histogram of the distribution of SeaWiFS Chlorophyll data on swath1 (1998-2004)

NB. In the 5-day SeaWiFS images, there are more cloudy pixels than in 5-day Meteosat SST images. This is inevitable consequence of the fact that only one SeaWiFS image per day is available comparing with 48 in the case of Meteosat SST. This was particularly a problem off northern Angola. (Fig.III 1 & Fig.III 2).

3.1.3 CTD data from the R/V “Dr. Fridtjof Nansen”

A set of CTD data from oceanographic surveys (1994-2003) conducted by the Norwegian R/V “Dr. Fridtjof Nansen” off Angola, were obtained from the National Fisheries Research Institute of Angola (INIP).

All CTD data were in ICES format, converted into CSV format, for import to software such as Microsoft Excel or Golden software, “Surfer 8.0”. The temperature is in degree Celsius (°C) and the salinity in standard unit (IAPSO).

CTD temperature and salinity data were used in conjunction with satellite data to study aspects in the Congo River plume and Benguela Niño '95.

3.2 Methods

3.2.1 Display of images using ENVI 4.0

Envi 4.0 (Environment for visualizing image) is a powerful software tool (by Research Systems Inc.) used to process satellite remote sensing images. In this study, it was used mainly to visualize images (Fig.II 3 & Fig.II 4).

This powerful software was also used to display high resolution NOAA-AVHRR-SST, including gridding, geographical coordinates and annotations...(Fig.II 4) but also to convert Meteosat-SST images from their matrix 650 x 650 form into the 825 x 825 of SeaWiFS chlorophyll-a images.

3.2.2 Data extraction and manipulation using IDL.

IDL (Interactive Data Language by Research System Inc.) is a complete computing environment for the interactive analysis and visualization of data. For the purposes of this investigation, almost all data extraction and data manipulation tasks were performed with small programmes written in IDL (Appendix # 1-23).

3.2.3 General principles of low spatial averages

Statistics was largely used in most of the computations made in this particular study.

1. Data extracted from a swath or from a scan-line/latitude are averaged to get a mean-value.
2. The same formula is also used to compute the average of the mean monthly SST/Chl-a in a time-series in order to get a mean-value for all January...December.

The mean-value is computed as follows:

$$SST_{ij} = 1/N \left(\sum_{j=1}^N SST_j \right) \quad (3.7)$$

Where SST_{ij} is the averaged temperature
 SST_j is the temperature in a given time (year)
 i is the month (January - December)
 N = number of samples and j is the year

3. In order to despiked a curve, smoothing is applied by averaging a certain number of pixels. The formula is slightly different from the previous one:

$$SST_i = 1/w \left(\sum_{j=1}^w SST_{i+j-(w+1)/2} \right) \quad (3.8)$$

4. The SST or Chlorophyll-a gradients are computed as follows:

$$\Delta SST_\lambda = SST_i - SST_{i+w-1} \quad (3.9)$$

$$\lambda = (2i+w-1)/2 \quad (3.10)$$

Where

SST_i is the result of the smoothing by averaging “w” computed at i rank (position)

$I = (w-1)/2, \dots, N-(w+1)/2$

SST: the original SST

J: index (j=0 to j=w-1)

N: is the total number of samples

W= number of data values considered (ex: 11 or 25) equivalent δ SST

5. The standard deviation is a measure of the typical difference of a data value from the mean value of all data points (Emery W.J & Thomson R.E, 2003) and it is computed as follows:

$$(\sigma_{ij}) = \left[\frac{1}{(N-1)} \sum_{j=1}^N (SST_j - SST_{ij})^2 \right]^{0.5} \quad (3.11)$$

Where σ_{ij} is the standard deviation

SST_{ij} is the averaged temperature computed at (3.7)

SST_j is the temperature

i is a given month

N (number of samples

J is a given year

6. The anomaly is the difference of a sampled data from the mean value of that particular point. It shows a positive or negative trend and it is largely used in oceanography in order to study the inter-annual variations of a given parameter. It is computed with the following formula:

$$SST(A)_{ij} = (SST_j - SST_{ij}) \quad (3.12)$$

Where SST_{ij} is the averaged temperature
 SST_j is the sampled temperature
 i is a given month

J is a given year
SST(A)_{ij} is the temperature anomaly

7. The principle of normalization, also called standardization is widely used in the computation of the anomalies. This principle returns a normalized value from a distribution characterized by mean and standard deviation. The standard normal variable **SST(A)_{ij}** is normally distributed with a mean of zero (0) and a standard deviation of unity (1).

$$\text{SST (A)}_{ij} = (\text{SST}_j - \text{SST}_{ij}) / \sigma_{ij} \quad (3.13)$$

Where σ_{ij} is the standard deviation at a given time *j*

NB. In all cases, SST is replaced by the concentration of chlorophyll-a whenever dealing with SeaWiFS-chl-a data.

3.2.4 Variation of SST and chlorophyll in the longshore direction (Angola Coast/North-South)

5-day composite images both from Meteosat-SST (1997-2002) and from SeaWiFS-Chlorophyll-a (1998-2004) were used as input. An appropriate IDL program (Appendix # 1, 2) allows reading and extracting data, then computing the mean-SST or the mean-Chlorophyll-a of a given sub-area bounded by the northern and southern latitudes and an offshore distance (swath) for an image. Six images over a month is used to compute the monthly average (Eq 3.7) then another mean over the entire period of study is computed using the same equation.

The northern and southern boundaries correspond to each degree of latitude from 5.5 to 17.3 °S (5.5-6.5, 6.5-7.5, 7.5-8.5, ... 16.5-17.33) and three different offshore distances were used: 10 km, 20 km and 30 km.

Swath1=10 km (An offshore distance from the coastline)

Swath2=20 km (An offshore distance taken from swath1=10 km)

Swath3=40 km (An offshore distance taken from swath2 +swath1=30 km)

In order to study the monthly variation of SST/Chl-a, mean-SST/mean-Chlorophyll-a are plotted in a diagram (latitude versus months) with Surfer 8.0 while the inter-annual variation is plotted in a diagram (SST/Chl-a versus latitude) with Microsoft Excel, using the monthly averaged mean-SST/mean-chl-a as input.

This particular study was undertaken in order to find out discontinuities in the SST and in the Chlorophyll-a. Those changes defined the boundaries of the sub-regions, which exist in Angola in the longshore direction.

3.2.5 Variation of SST and chlorophyll in the offshore direction (off Angola/ East-West)

As the longshore direction, a similar study was undertaken in order to identify the changes observed in the offshore direction. Instead of 5-day composites, averaged monthly composite images (climatologies) were used as input either for SST or for chlorophyll-a with a wide offshore distance (300 km), almost covering all the EEZ (Exclusive Economic Zone).

An IDL program (Appendix #4) was used to read and extract data from each image from January to December at each latitude (5.5, 6, 7, 8, 9, 10... 17.3) from 5.02 to 17.3°S. Thirteen (13) lines corresponding to the latitudes were considered with 54 pixels for SST and 68 pixels for chlorophyll with the same offshore distance (300 km).

Instead of twelve, only four months were selected for this present study: January and March for summer and July and August for winter.

Since SeaWIFS-Chl-a images are cloudy in the northern part of Angola and especially in January for some years (Fig.III 2), averaged composite images (climatologies) were used for this study.

The pixel values converted into SST and chlorophyll-a are plotted in a diagram (SST/Chl-a versus offshore distance) in Microsoft Excel. In order to despiked the curves (SST/Chlorophyll-a), a 5-pixel average smoothing was applied (Eq 3.8).

Then the anomalies were computed at each latitude (Eq 3.13) from the despiked SST or chlorophyll (Eq 3.8) in order to find the trends (positive or negative). At last, a correlation was made from one latitude to another for the selected months and allowed to divide the region in sub-regions.

3.2.6 CLUSTER ANALYSIS

3.2.6.1 Introduction

The main objective of this study was to partition the Atlantic Ocean off Angola into regimes (zones) of more or less uniform oceanographic properties. For that, it was necessary to find the number of sub-regions and their respective geographical boundaries.

A technique used for this particular study was "Cluster Analysis" which is an exploratory data analysis tool aiming at sorting objects into groups in a way that the degree of association between two objects is maximal if they belong to the same group and minimal otherwise (<http://www.statsoft.com/textbook/stcluan.html>).

It can also be described as a multivariate analysis technique that seeks to organize information about variables so that relatively homogeneous groups or "clusters" can be formed. The clusters formed with this family of methods should be internally highly homogeneous (members are similar to one another) and externally highly heterogeneous (members are not like members of other clusters) (<http://socialsearchmethods.net/tutorial/flynn/cluster.htm>).

The classification is based upon a cluster analysis of sample-based distances. Bryan et al. (2003) gives more details in the book entitled "Cluster Analysis". The joining or tree clustering method uses dissimilarities (similarities) or distances between objects when forming clusters. Similarities are a set of rules that serve as criteria for grouping or separating items. The distances (similarities) can be based on a single dimension or multiple dimensions, with each dimension representing a rule or condition for grouping objects.

The most straightforward way of computing distances between objects in multi-dimensional space is to compute Euclidian distances.

If one has a two- or three-dimensional space this measure is the actual geometric distance between objects in the space.

$$D(x,y) = (\sum(x_i-y_i)^2)^{1/2} \quad (3.14)$$

These Euclidian distances are usually computed from raw data, and not from standardized data. The advantage of this method is that the distance between two objects is not affected by the addition of new objects to the analysis, which may be outliers.

Other methods are used to compute the distances, for example:

- Unweighted pair-group average: In this method, the distance between two clusters is calculated as the average distance between all pairs of objects in the two different clusters (Sneath and Sokal, 1973).
- Weighted pair-group averages: this method is identical to the previous except that in the computations; the size of the respective clusters is used as a weight.
- Unweighted pair-group centroid; the centroid of a cluster is the average point in the multidimensional space defined by the dimensions (it is the centre of gravity for the respective cluster). In this method, the distance between two clusters is determined as the difference between centroid (Sneath and Sokal, 1973).
- Weighted pair group centroid median: is similar to the previous one, except that weighting introduced into computations to take into consideration differences in cluster sizes (i.e. the number of objects containing in them).

Sneath & Sokal (1973), Vermunt & Magidson (2000) and Bryan et al., (2001), provide more details in different methods used to compute the distances in order to classify objects into clusters (squared Euclidian distance, City-block distance, Chebychev distance, power distance, single distance (nearest neighbour) and complete linkage (furthest neighbour).

3.2.6.2 Cluster procedure applied in Angolan waters

For purposes of this study, the objective was to classify image pixels in the ocean off Angola. So as to form clusters (groups) with similar SST and chlorophyll-a properties. As input to the cluster procedure, four SST and four chlorophyll-a images were chosen corresponding to January and March (summer) and July and August (winter). These months were chosen for most representatives of seasonal changes.

Two steps of pre-processing were required i.e. (a) the SST images were transformed from their matrix 650 x 650 form to the 825 x 825 form of the chlorophyll-a images and (b) to avoid bias in the cluster procedure to one or other of the eight input parameters, all images were normalized by subtracting the mean and division by the standard deviation of pixels in the research area. The research area was defined as the 370 km wide swath (approximately 200 nm EEZ) between the Angola borders (5.1-17.3°S).

The cluster procedure itself was performed with IDL program "make-cluster.pro" (Appendix #19) based on the two IDL commands: CLUST_WTS (weights of the cluster/center of the clusters) and CLUSTER (classification of the samples).

A weakness of the procedure is that in itself it provides no objective means at deciding on the number of clusters. From Berrit (1958), Fidel (2001) and the Nansen Program division in conjunction with the preliminary analysis of longshore and cross-shelf variation, it was decided that the area should be divided into three sub-regions. Hence the program “make cluster-pro” was viewed to produce 12 clusters and these were reduced using a smoothing feature of the program to reduce the number to three. South of the ABF should be a fourth sub-region, but the cluster procedure did not define that part as a single area with common properties. Instead it was defined as a large number of small sub-regions indicating an immensely very variable region.

3.2.6.3 Delimitation of the boundaries of sub-regions off Angola.

The previous studies did not allow defining accurately the boundaries of the sub-regions off Angola. Different results were obtained in the longshore and offshore directions and those results also differ whether the input was chlorophyll or SST. But the approach was not useless instead it was used as a guide in structuring the results obtained with the cluster procedure described earlier in this chapter.

This approach uses a combination of SST (4 images) and chlorophyll (4 images) and the technique consist in grouping pixels of the same properties. The number of images is unlimited and in this particular research, a test was made up to 24 images (12 SST and 12 chlorophyll-a). Bryan et al., (2003) give a detailed analysis of cluster procedure and this technique is used in numerous fields: biology, medical science, sociology...

In this particular research, the best result was obtained with twelve clusters (12 groups) which were reduced to three clusters (3 groups or sub-areas) by smoothing several times each of the clusters. The results obtained previously in the second approach (variation of SST and chlorophyll in offshore direction) in defining the sub-regions off Angola, were used as a guide in the choice of the number of clusters as well as the last results obtained thereof.

The IDL program outputs three files:

- A header file containing the x and y-coordinates and the one-dimensional indices, which can be read in WordPad.
- A binary file with the entire cluster results including what contains in the header file can be read only with IDL program.
- The cluster image saved in png format (portable network graphic file) showing three clusters corresponding to three sub-regions off Angola (Fig. III 3-4).

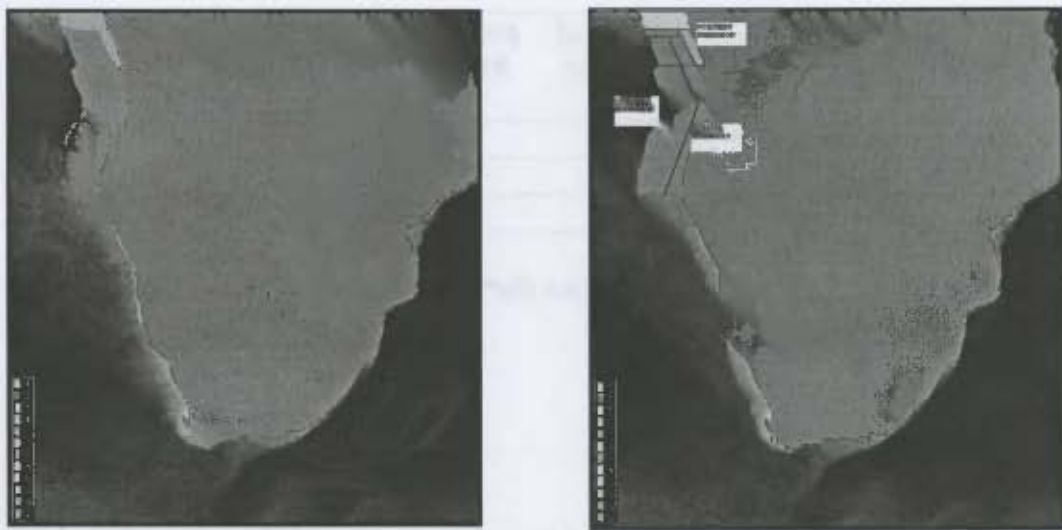


Fig.III-3 The original structure of the three sub-regions as obtained from the "Cluster Procedure"(left) and their corresponding new geographical boundaries (right)

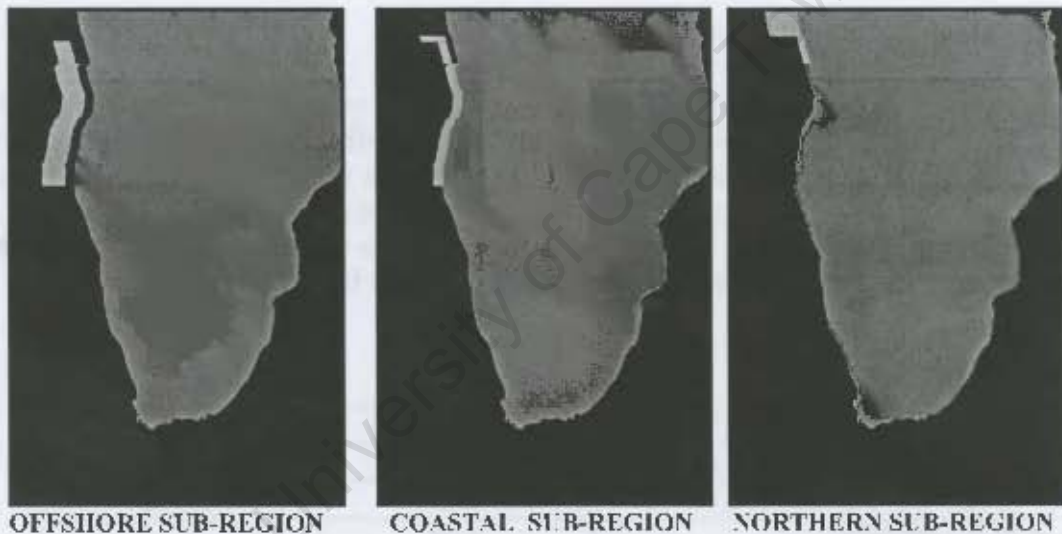


Fig.III-4 Geographical structure (swath) of the three sub-regions with new boundaries.

The cluster image was read and displayed with different colours (RGB) and the results are described in the table below.

Clusters	Colours	Red	%	Green	%	Blue	%
Clus12	Dark pink	252	99	43	17	255	100
Clus11	Dark orange	252	99	107	42	0	0
Clus10	Orange	255	100	194	76	18	7

Then the number of pixels contained in each cluster was computed using different colours then compared with the numbers found in the header file (results from IDL cluster program)

Clusters	Number of pixels from the RGB (colours)	Number of pixels from the header file	Difference
Clus12(offshore sub-region)	14673	14523	150
Clus11 (coastal sub-region)	5562	5412	150
Clus10 (northern sub-region)	3496	3346	150

With RGB, the number of pixels was 150 more than in the cluster file. The RGB includes the colour bar, which contains 150 pixels.

The sub-regions were denominated:

1. The northern sub-region
2. The coastal sub-region
3. The offshore sub-region

The original sub-regions (cluster results) had irregular geometrical shape, which could make geographically difficult their location or their repeatability. For this reason, the original cluster results were used as a guide to draw sub-areas structurally more or less identical.

3.2.6.3.1 Boundaries of the northern region (Fig.III 3)

In all cases, the x and y coordinates of each sub-region were measured with the IDL function RDPIX. The distance between two points (swath width or offshore distance) was computed using another IDL function MAP-2POINTS. The conversion from x- and y-coordinates into longitude and latitude was made with the appropriate conversion formulas (Eq 3.2-3.5).

This sub-region was divided into two sub-areas (I & II) due to the difference of swath widths; which were afterwards merged in a single sub-region (Tables III-1 &2).

Table. III-1 Northern sub-region (I)

X1	Y1	X2	Y2	Distance (km)	Latitude
84	0	167	0	370	5.1°S
95	41	172	41	370	6.8°S
Average of the distance				370	
Swath width (I)				370	
Boundaries				latn =5.1°S	lats =6.8°S

Table. III-2 Northern sub-region (II)

X1	Y1	X2	Y2	Distance (km)	Latitude
150	41	172	41	103.31	6.8°S
173	64	188	64	70.19	7.7°S
190	87	198	87	37.34	8.7°S
Average of the distance				70.28	
Swath width (II)				70.28 ≈70 km	
Boundaries				latn =6.76°S	lats =8.71°S

For the whole northern sub-region

Latitude north: 5.02°S

Latitude south: 8.71°S

The offshore distance: 370 km (200 nautical miles).

From latitude =6.76°S to 8.71°S, the offshore distance was reduced to 70 km.

3.2.6.3.2 Boundaries of the coastal region (Fig.III-3)

This coastal sub-region was divided into three sub-areas (I, II & III) for the same reason described above, the difference of swath widths. The sub-areas are afterwards merged to make a single sub-region with the same properties. Fig.III 3 shows the original result and the offshore distance is not the same. It was necessary to take seven different widths for coastal sub-region (III) and three for coastal sub-region (II) and then compute the mean for each case. The tables below (tables.III 3-5) summarises the geographical coordinates and offshore distances taken into account.

Table.III-3 Coastal sub-region (I)

X1	Y1	X2	Y2	Distance (km)	Latitude
95	41	150	41	258.28	6.76°S
95	50	160	50	304.94	7.14°S
Average of the distance				281.61	
Swath width (I)				370-70=300 km	
Boundaries				latn =6.76°S	lats =7.14°S

Offshore distance is 300 km from 70 km offshore

Table.III-4 Coastal sub-region (II)

X1	Y1	X2	Y2	Distance (km)	Latitude
146	50	160	50	65.68	7.14°S
148	64	173	64	116.99	7.73°S
162	87	190	87	130.70	8.71°S
Average of the distance				104.46	
Swath width (II)				103	
Boundaries				latn =7.14°S	lats =8.71°S

The offshore distance is 103 km from 70 km offshore

NB. This distance is an average between coastal (II) e (III), therefore it was constant from 7.14°S to 17.37°S

Table. III-5 Coastal sub-region (III)

X1	Y1	X2	Y2	Distance (km)	Latitude
162	87	190	87	130.70	8.71°S
194	112	175	112	88.42	9.77°S
195	153	207	153	55.53	11.51°S
189	179	182	179	32.26	12.61°S
171	224	158	224	59.43	14.52°S
162	252	122	252	181.84	15.71°S
158	291	123	291	157.75	17.37°S
Average of the distance				100.85	
Swath width (III)				103	
Boundaries				latn =8.71°S	lats =17.37°S

The offshore distance was 103 km from the coast.

3.2.6.3.3 Boundaries of the offshore region (Fig.III 3)

Offshore sub-region (I)

No measurements were necessary, except for the latitudes. The swath width was computed as follows:

Swath width (I) = 370 - (70 + 103) = 197 km

Boundaries: latn= 7.14°S

lats= 8.71°S

The offshore distance was 197 km from 173 km offshore

Offshore sub-region (II)

Swath width (II) =370-103=267 km

Boundaries: latn =8.71°S

lats =17.37°S

The offshore distance was 267 km from 103 km offshore

3.2.6.3.4 Number and coordinates of pixels of the sub-regions

The number of pixels found in each sub-region in the original image was in the header file created by the cluster program. The original cluster image obtained (Fig.III 3 left) was used as a guide in order to draw a new cluster image (Fig.III 3 right) with boundaries (latitudes and offshore distance). The number of pixels found in the new cluster image was slightly higher than in the original. As cluster images were in 825 x 825 format, only the SeaWiFS-chlorophyll could use the pixel coordinates computed with cluster results.

For Meteosat-SST, the image was converted into (650 x 650) and the functions "SORT" and "UNIQ" were used to avoid duplication of pixels. That is why the number of pixels in the last column is almost half the number of pixel in the second column.

Sub-regions	Number of pixels in the original cluster	Number of pixels in the new cluster design (SeaWiFS-chlorophyll images)	Number of pixels in the new cluster design (Meteosat-SST images)
Northern	3119	4201	2612
Coastal	5829	6470	4062
Offshore	14337	13457	8379
Total (pixels)	23285	24128	15053

3.2.6.4 Variation of SST and chlorophyll-a in the sub-regions off Angola (Appendix #1, 2 & #8)

Monthly composite images from Meteosat-SST (1987-2002) and from SeaWiFS-chlorophyll-a were used as input to compute the mean-SST and mean-chl-a according to the pixels contained in each sub-region.

The size of the cluster images were converted from 825 x 825 into 650 x 650 for SST (Meteosat) while for the chlorophyll-a, they remained unchanged.

In all sub-regions, the mean was computed by using the principle of data extraction in a swath i.e knowing the northern and southern latitudes and the offshore distance.

Special techniques were used in IDL to merge pixels from two different subregions. (northern I & II; coastal I, II & III and offshore I & II) in order to output one mean value for the whole sub-region.

Surfer 8.0 was used to study the seasonal and inter-annual variation of SST and chlorophyll-a in the three different sub-regions.

Monthly averages were computed for the entire period (Eq 3.7) and three curves (one from each region) were plotted in a diagram in Microsoft Excell. It allowed observing the difference in temperature and in the concentration of chlorophyll-a in the three regions.

Anomalies for both parameters (SST & Chl-a) were computed using the Equation (3.13) with SST_j (from monthly images of a particular year) and SST_{ij} (Monthly averages computed for the whole period of study).

3.2.7 The Congo River plume.

Attempts (Fig.III 5) to identify and demarcate the Congo River plume consisted of two parts: in the first part, a cluster analysis was used exactly as described in the previous section. Instead of taking the entire Angolan coastline, only the region of the plume (5.02-9.1°S) was taken into consideration, up to 370 km as offshore distance.

- Using images of mean-chlorophyll-a for twelve months and generating twelve clusters.
- The same as (a) but generating eight clusters
- Using a combination of twelve images of each mean-chlorophyll and SST and generating twelve clusters.

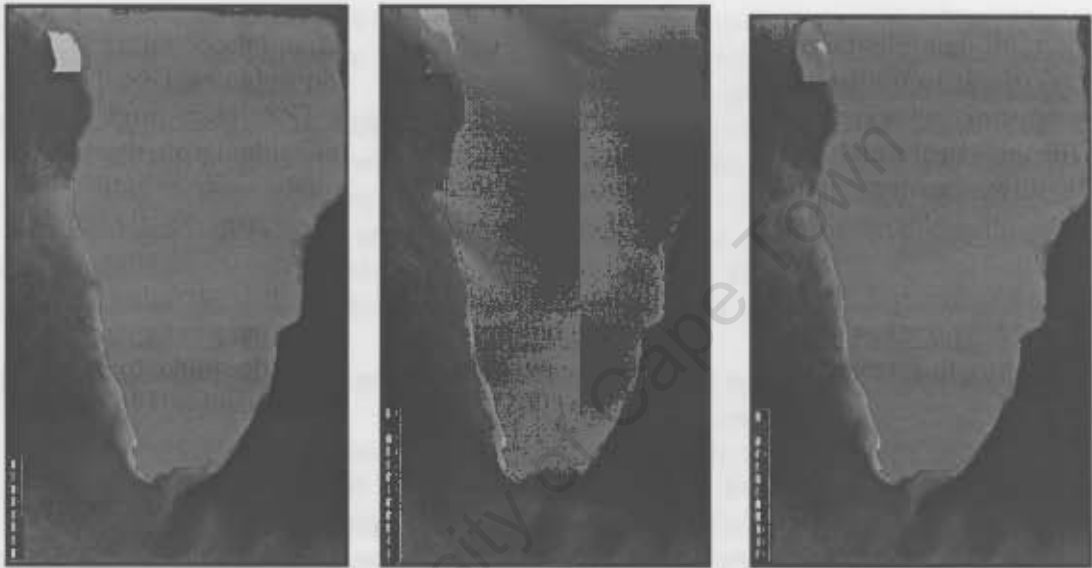


Fig. III-5. The original structure of the Congo river plume as obtained from the "Cluster Program"

- Only with Chlorophyll (12 images/12 clusters);
- Only with Chlorophyll (12 images/8 clusters)
- With Chlorophyll (12 images) and SST (12 images)/12 clusters

In the second part, salinity data from hydrographic transects through the plume was selected. SST as chlorophyll data were then extracted, at this position of the hydrographic station. From 5-day SST and 5-day chlorophyll images best corresponding in time with the time the hydrographic data were collected. Since the salinity data clearly identified the plume, the purpose of the exercise was to compare the salinity transects with SST and chlorophyll-a transects to determine whether the plume was detectable with the remote sensing data.

Both parts of this investigation essentially indicated that it is not possible to discriminate between water in the plume and the background ocean water on the basis of SST but that of chlorophyll-a concentration was fairly effective. These results agree with the findings of Hardman-Mountford et al., (2003).

Two IDL programs (Appendix # 14) and (Appendix # 21) were used to extract chlorophyll-a pixels from SeaWiFS images from geographical coordinates of the hydrogeographic salinity and to read the CTD data at a given depth respectively.

3.2.8 Angola-Benguela front

3.2.8.1 Position of the ABF obtained from SST and chlorophyll-a

Monthly composite images from Meteosat-SST (1997-2002) and SeaWiFS-Chlorophyll-a (1998-2003) were used to define the position of the Angola-Benguela frontal zone. The basic principle employed for this was to extract from each image a series (SST & chlorophyll-a) representing the alongshore variation of the parameter and then objectively locate the position of the maximum gradient. The alongshore series were obtained by averaging (Eq 3.7) on a distance of 60 km from the coast on all scanlines between 10-18°S. Veitch et al. (2006) who carried out a similar study, used a swath width of 30 km but this is equivalent to only 5-6 Meteosat SST pixels which was considered to be too small therefore 60 km swath was adopted.

The resulting SST and Chlorophyll curves were very spiky and therefore smoothed with a 11-point mean smooth (Eq 3.8). This proved to be insufficient hence a second 25-point smooth was performed (Fig.III-5a & 5b). This choice of a large smoothing interval was due to a better despiking effect without affecting the SST (Fig.III-6a). Since the objective was to locate the ABF and the front is but the highest SST-gradient, the gradient (Δ SST) was computed between the two consecutive scan-lines (6 km) (Eq 3.9).

However the highest SST-gradient (Δ SST) was considered as the position of the front. Fig.III-6a & Fig.III-6b, both show the results obtained using different δ SST (SST interval over which the gradient was computed) for the computation of SST-gradient. From a smoothed curve (averaging 25), first δ SST = 3 pixels was used with 11 and 25-smoothed SST curves, the results in Fig.III-6b, showed clearly so many peaks therefore it was difficult to choose the one related to the ABF. In order to reduce the number of peaks, without changing the latitudinal position, δ SST = 25 was found the most accurate and most reliable.

The original SST curve was smoothed by averaging 25 points and the interval δ SST was also 25. This second approach increased the amplitude of the peak without affecting the latitudinal position of the highest SST-gradient. The latter curve was well smoothed and contained a reduced number of peaks. Thus, the second approach was more accurate than the previous one.

The same procedure was used with chlorophyll. Fig.III-7a shows the original spiky curve which was afterwards smoothed (11 or 25 averages) in fig.III-7b. In Fig.III-8a, δ Chlorophyll=11 and δ Chlorophyll=25 which were compared to fig.III-8b where the interval between pixels was reduced to δ Chlorophyll=3. The latter result shows numerous peaks, which makes difficult the choice of the ABF. Like the SST, δ Chlorophyll = 25 was found the most accurate.

3.2.8.2 Locating the position of the ABF in SST.

As described in the previous section, the ABF was assumed to be located at the position of the largest SST gradient (Fig.III 7a) and the data series which seems most suitable for this purpose was δ SST series obtained using a 25-point smoothed SST series and computing δ SST from points 25 pixels apart (Fig.III 8a).

The choice of a peak was based in the following principles:

1. Previous research on the Angola Benguela front, Shannon et al. (1987), Meeuwis and Lutjeharms (1990), Mohrholz et al. (1999), Hardman-Mountford et al. (2003) and Veitch et al. (2006) found that the ABF shifts from 14.5°S to 18°S. Consequently, all peaks outside this acceptable range were rejected.

2. The choice of a position in a given month depends on the magnitude of the SST gradient and the deviation of the front position relative to the previous month.

3. If the shift in position exceeded 1° latitude, the first choice is given to the position with the second largest gradient, but it was necessary that the selected peak had a magnitude higher or equal to 60% of the maximum magnitude of a given month, otherwise the highest peak was taken regardless of the deviation.

4. The single peaks were selected without any condition and were used as references.

5. At last, the curve was plotted displaying the variation of the ABF within a year from January to December. The temperatures (Fig.III-9b & Fig.III-10b) corresponding to selected positions were also plotted.

The same procedure was followed from 1987 up to 2002, and then a monthly average, monthly and yearly standard deviations of both ABF and of temperatures were computed (Fig.V:44-45). Thereafter, all ABF and the corresponding temperatures (1987-2002) were used to compute the average monthly ABF and temperature. The average monthly positions of ABF and the corresponding temperature were used to compute the anomalies of ABF from 1987 to 2002.

3.2.8.3 Problems encountered with the chlorophyll images.

In addition to it being a short time-series (seven years), the SeaWiFS chlorophyll images were cloudy in some regions especially in the north of Angola with gaps in July, August and September of 1998, 2001-2003 which makes the series less suitable than the Meteosat-SST (Fig.III 2). The attempt of detecting the biological front as the highest chlorophyll-a gradient led to the existence of two distinct fronts in most cases. The first one around 15-16°S with low magnitude and the second one with higher magnitude observed around 17-18°S.

To overcome the problem, it was necessary to use two approaches:

- a. The first approach follows the same principles as applied with the Meteosat-SST (Figs. III 12a, 14a & 16a)
- b. The second approach differs a little bit from a) by the fact of rejecting the second factor dealing with the magnitude. The choice of the next position was governed only and simply by the closest peak regardless of the size of its magnitude (Figs. III 11a, 13a & 15a)

In terms of reliability and accuracy of the results, the second approach was adopted and it was suitable with the results obtained with Meteosat-SST' (Fig.IV 49). If the highest magnitude was considered, the front position was mistakenly moved southward by 17-19°S and one believed that this second front was related to the upwelling front of Cape Frio and the first to the ABF (Shannon, 1987). The concentration of Chlorophyll at the ABI' (Figs.III 11-16b) was done as with the Meteosat-SST'.

3.2.8.34 Diagrams referred to Angola-Benguela Front

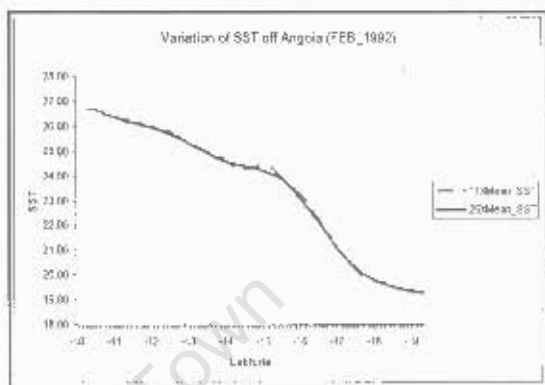
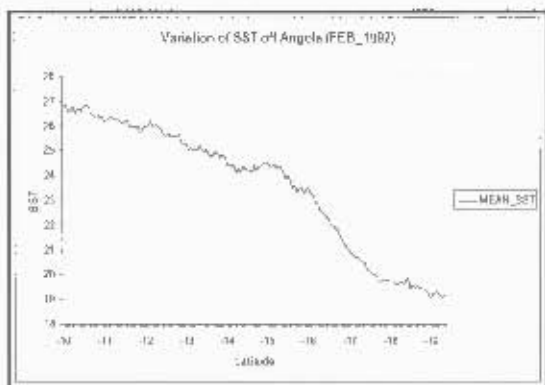


Fig.III-5a) Variability of SST off Angola (FEB-92)

Fig.III-5b) Smoothed SST (Averaging 11 and 25 pixels)

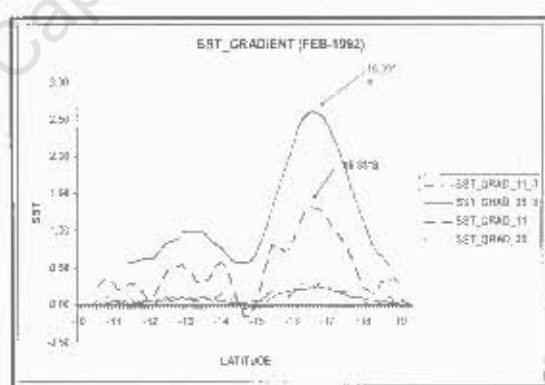
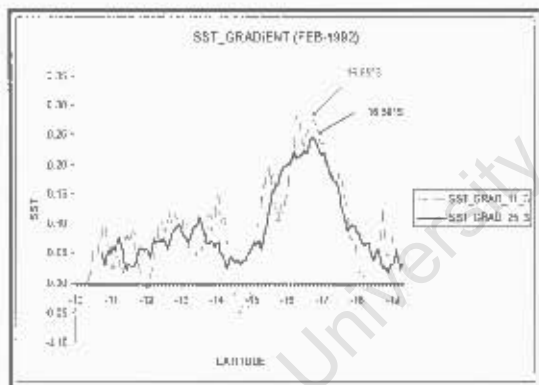


Fig.III-6 a) SST gradient using δ SST=11 and δ SST=25 computed from smoothed SST (11) and SST (25) respectively

Fig.III-6 b) SST gradient using δ SST=3 and δ SST=3 computed from smoothed SST (11) and SST (25) respectively

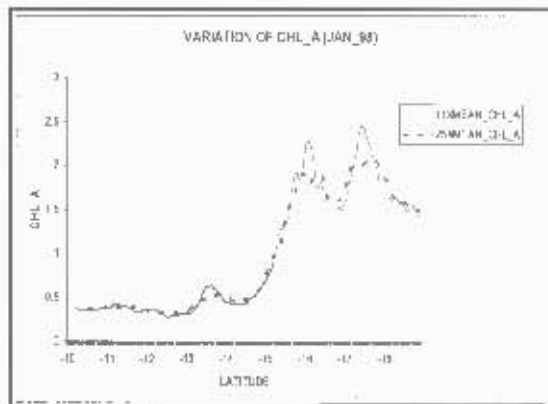
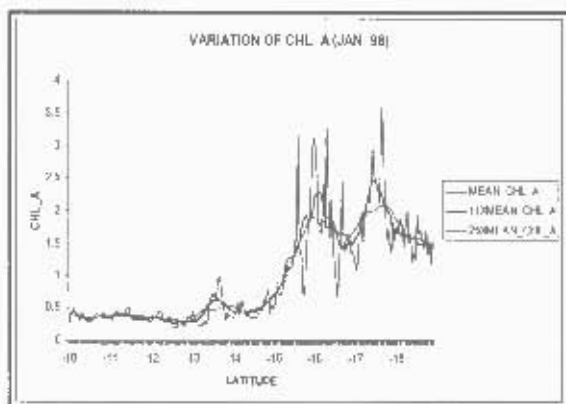


Fig.III.7.a) Variability of Chlorophyll off Angola (JAN-98)

Fig.III.7.b) Smoothed Chlorophyll (Averaging 11 and 25 pixels)

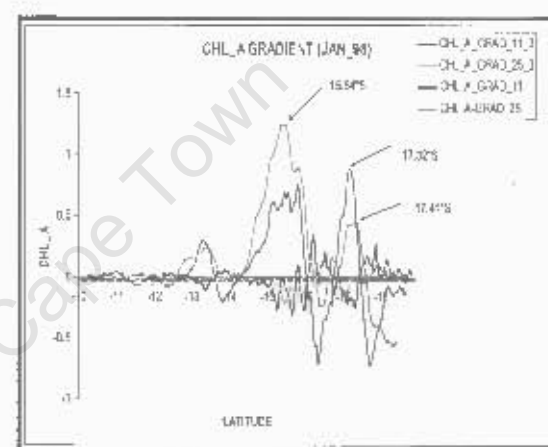
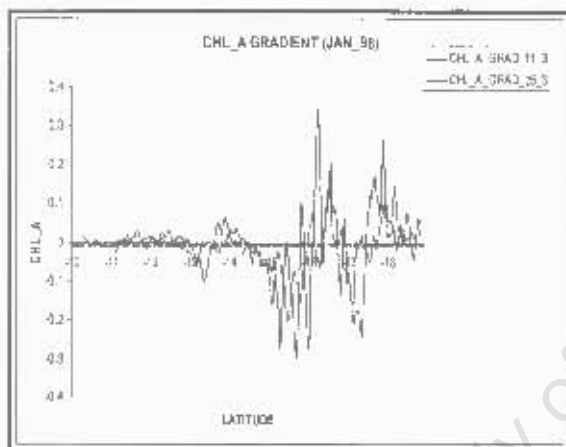


Fig.III.8.a) Chlorophyll gradient using δ Chlorophyll=11 and δ Chlorophyll=25 computed from smoothed Chlorophyll (11) and Chlorophyll (25) respectively

Fig.III.8.b) Chlorophyll gradient using δ Chlorophyll=3 and δ Chlorophyll=3 computed from smoothed Chlorophyll (11) and Chlorophyll (25) respectively

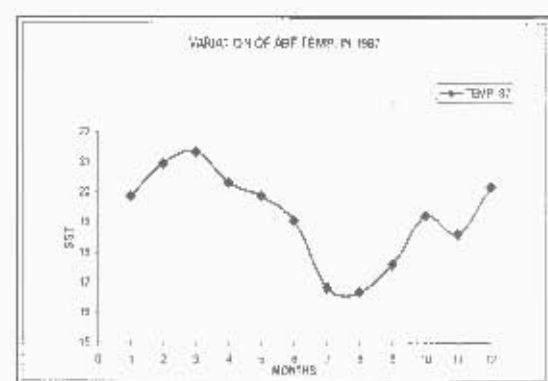
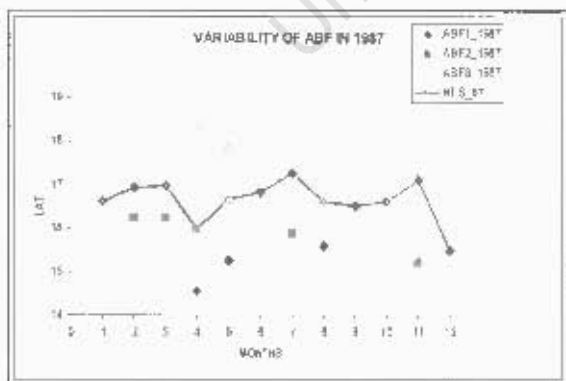


Fig.III-9 a) Position of the ABF (SST) in 1987

Fig.III-9 b) Temperature at the ABF in 1987

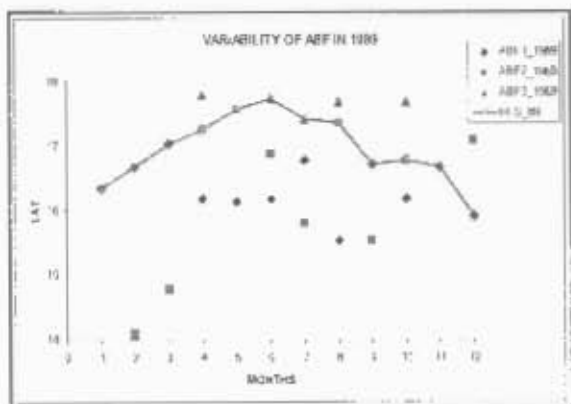


Fig.III-10 a) Position of the ABE (SST) in 1989

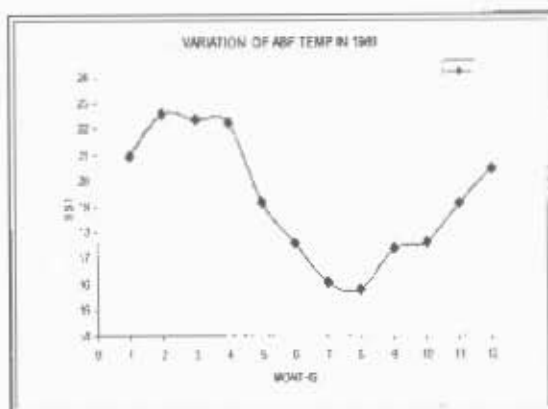


Fig.III-10 b) Temperature at the ABE in 1989

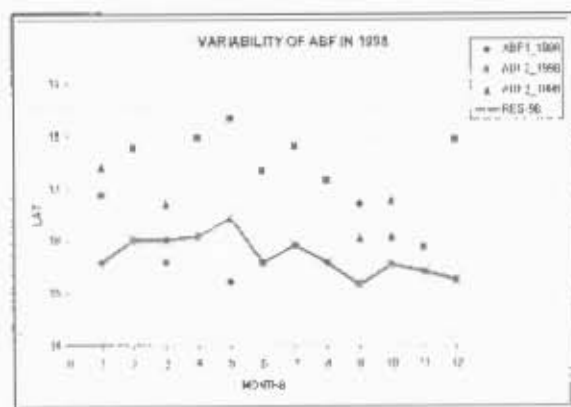


Fig.III-11a) Position of the ABE (Chlorophyll) in 1998. (2nd Approach)

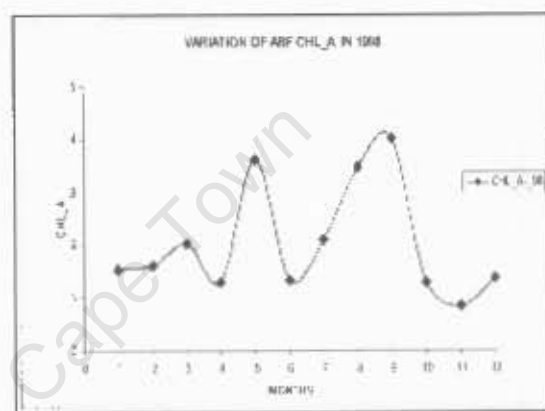


Fig.III-11b) Chlorophyll at ABE in 1998.

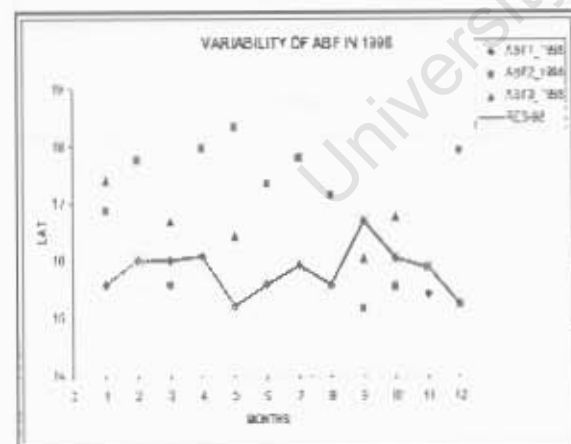


Fig.III-12a) Position of the ABE (Chlorophyll) in 1998. (1st Approach)

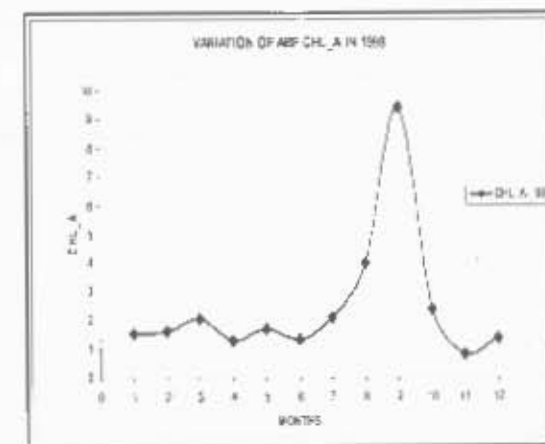


Fig.III-12b) Chlorophyll at ABE in 1998

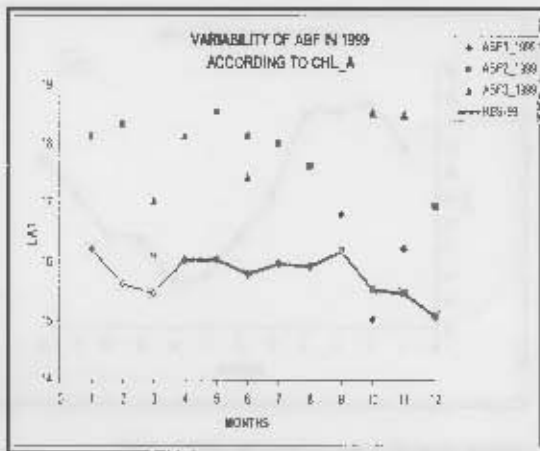


Fig.III-13a) Position of the ABF (Chlorophyll) in 1999 (2nd Approach)

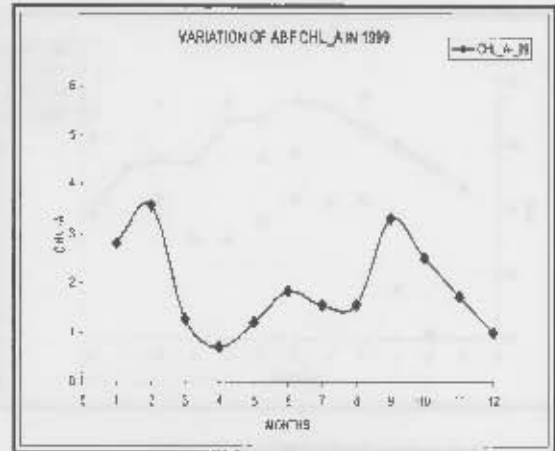


Fig.III-13b) Chlorophyll at ABF in 1999

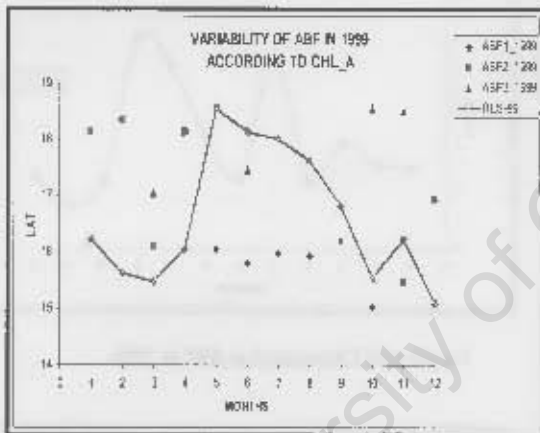


Fig.III-14a) Position of the ABF (Chlorophyll) in 1999 (1st Approach)

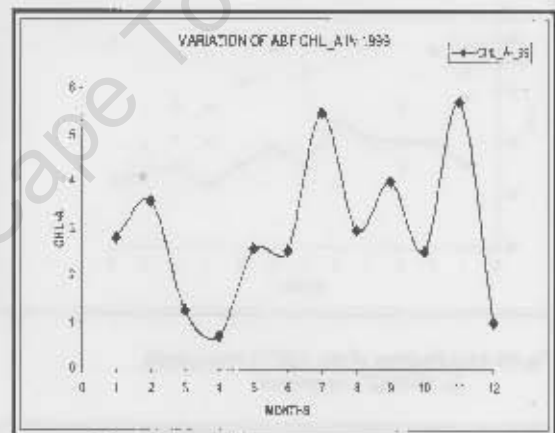


Fig.III-14b) Chlorophyll at ABF in 1999

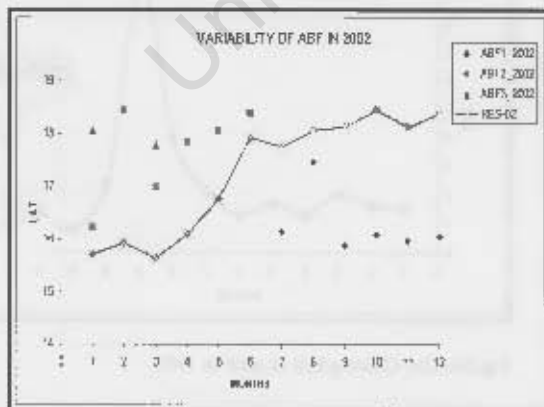


Fig.III-15a) Position of the ABF (Chlorophyll) in 2002 (2nd Approach)

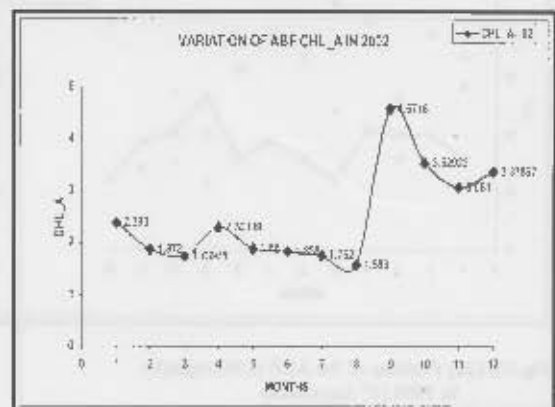


Fig.III-15b) Chlorophyll at ABF in 2002

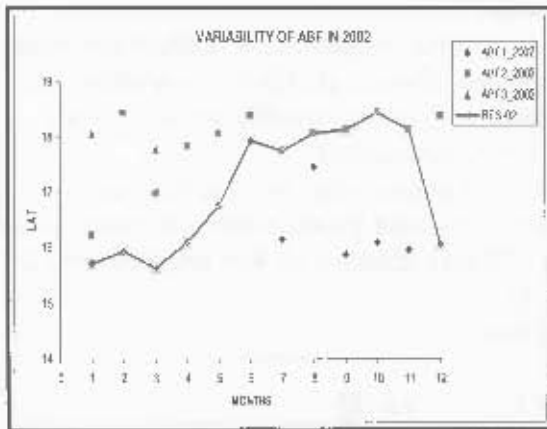


Fig.III-16a) Position of the ABF (Chlorophyll) in 2002 (1st Approach)

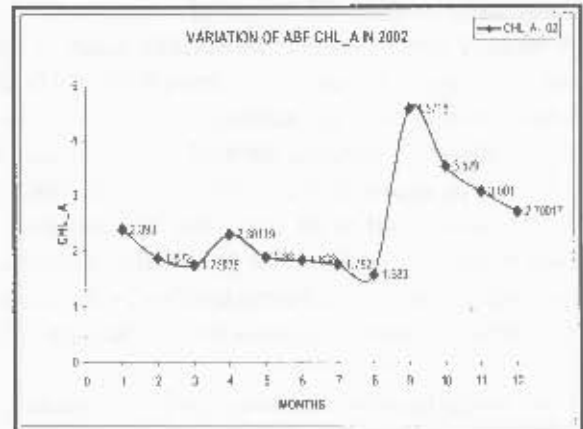


Fig.III-16b) Chl_a at ABF in 2002

3.2.9 Coastal Upwelling off Angola

Upwelling is a well known oceanographic process which lifts cold, nutrient-rich, bottom water to the surface layer. It occurs mostly at the coast but under certain circumstances in the open ocean (Gill, 1982; Pedlosky, 1987; Pond & Pickard, 1995 and Mann & Lazier, 1996).



Onshore swath for upwelling
Offshore distance: 12 km (2 pixels)
Swath width: 24 km (4 pixels)



Offshore swath for upwelling
Offshore distance (strip): 400 km
swath width: 24 km (4 pixels)

Fig.III-4 The onshore and offshore upwelling swath off Angola

In this study only coastal upwelling is examined and it is done by using an approximation of the cross-shelf SST gradient as an index of upwelling intensity and then describing spatial and temporal variation of this index.

Although this particular upwelling index is quite commonly employed, a method previously used in Angolan waters and described by Hardman-Mountford et al., (2003) was followed. Since they used high resolution AVHRR SST data, it was not possible to use exactly the same offshore distance. Instead, it was adapted to the Meteosat-SST:

For the onshore swath, an offset distance of 12 km (2 pixels) was used to remove any errors associated with coastline geo-location in the SST data product and the swath width was 24 km (4 pixels). For the offshore swath, an offshore distance of 400 km was used and the swath width was maintained to 24 km (Fig.III 4).

The equation below, allows to compute upwelling index

$$\text{Upwelling index} = (\text{onshore-SST}) - (\text{offshore-SST}) \quad (3.15)$$

The index was computed on all scanlines along the Angolan coast between 5.5°S and 17.3°S using monthly SST composite images. From the resulting 1987-2002 series monthly means were calculated and these served to identify three upwelling cells, which will be referred as the Cunene, Ambriz, and Cabinda cells. For each cell a time series was constructed by averaging the index values on the scanlines passing through the cells.

3.2.10 Benguela Niños.

Benguela Niño events were identified by examination of the SST and chlorophyll time-series for the three sub-regions, inter-annual variation in the position of Angola-Benguela front as well as inter-annual variation in the Congo River plume.

In the discussion of the Benguela Niños, special reference will be made to the Benguela Niño 94/95 by comparing 1994' and 1995' mean-SST from January to December. For this specific case, the principle of computing the mean-SST in a swath was used. The length of the swath was limited by the latitudes (5.02-17.3°S) and the width was equal to 60 km. The Meteosat monthly composites were used to compute the monthly mean-SST (Appendix #6). In addition, CTD temperatures at 20 m and salinity at 5 m depth were used to visualise the effect of the Benguela Niño 95.

CHAPTER IV RESULTS

4.1 Variability of SST and Chlorophyll in the longshore direction.

The variability of SST and Chlorophyll in the longshore and offshore directions was examined as a first approach to define the sub-regions off Angola, but these data also provide insight into the seasonal and inter-annual changes occurring along the Angola Coast. Three similar SST (Fig.IV 1) and Chlorophyll-a (Fig.IV 2) plots were constructed using data averaged over distances of 10 km, 20 km and 30 km from the coast. Between 5.02 °S and 17.3°S two main seasons were identified from the plots:

The rainy summer starting from January to April, features higher temperatures (24-28°C) with a peak in March/April (Fig.IV 1). During this season, the concentration in chlorophyll (Fig.IV 2) varies as follows:

- From 5-7°S, the concentration in chlorophyll ranges between 14-18 mg m⁻³ with a peak in March. The outflow of the Congo River is believed to be the source of this high concentration. At this latitude, SST varies between 26.5-27.5°C
- From 7-8°S, the concentration in chlorophyll ranges between 6-10 mg m⁻³ with a peak also in March. The Congo River plume extends up to this latitude. Relatively to the previous latitude, SST was almost similar (25.5-27.5°C)
- From 8-17.20°S, the concentration is lower than in the northern latitudes and is almost uniform varying between 2-8 mg m⁻³, although the southern part has higher chlorophyll than in central Angola. Meanwhile the SST varies between 21.5-27.5°C

The dry winter starting from May to August, features lower temperatures (16-22°C) with a trough in August (Fig.IV 1). During this season, the concentration in chlorophyll (Fig.IV 2) varies as follows:

- From 5-7°S, the concentration in Chlorophyll ranges between 10-16 mg m⁻³ with a peak in September (16 mg m⁻³) and the SST varies between 21-23.5°C.
- From 7-8°S, the concentration is almost uniform varying between 2-8 mg m⁻³, with a peak in August but the SST varies between 20.5-22.5°C.
- The concentration in Chlorophyll in the lower latitudes ranges between 8-12 mg m⁻³ with a peak also in August (18 mg m⁻³) while the SST varies between 16.5 and 22.5°C

The central Angola (11-13°S) shows high concentration in chlorophyll in this season and low in the south (14-17°S)

The longshore variation (Fig.IV 3) in SST and in Chlorophyll allowed identifying three sub-regions with the following characteristics:

- Northern sub-region (5.5-7.5°S), situated between Cabinda and Ambriz (Fig.II:1-2) is characterized by higher temperatures (22°C<T<28°C), heavier rainfalls ranging from 600-1200 mm year⁻¹ (Filipe, 1995) and higher

concentration in chlorophyll around the mouth of Congo River and along the Congo plume.

- Central or Meridional sub-region (7.5-13.5°S) which is situated between Ambriz and Benguela (Fig.11 1 & 2), is characterized by moderate temperatures ($22^{\circ}\text{C} < T < 26^{\circ}\text{C}$) in summer and ($18^{\circ}\text{C} < T < 20^{\circ}\text{C}$) in winter, rainfalls ranging from 200 to 600 mm year⁻¹ (Filipe, 1995) and the concentration in chlorophyll is almost constant ($2-6 \text{ mg m}^{-3}$) in all latitudes except at 7-8°S where the concentration is slightly higher than the rest of this sub-region.
- Southern sub-region (13.5-17.5°S) is situated between Benguela and Cunene River. It is characterized by lower temperatures ($19^{\circ}\text{C} < T < 23^{\circ}\text{C}$) in summer and ($18^{\circ}\text{C} < T < 26^{\circ}\text{C}$) in winter. The rainfall is less than 200 mm year⁻¹ (Filipe, 1995) and the concentration in Chlorophyll is higher ($2-8 \text{ mg m}^{-3}$) than in Central Angola. This concentration found in the South was half the amount in the North.

4.2 Diagrams relative to the variability of SST and Chlorophyll in the longshore direction

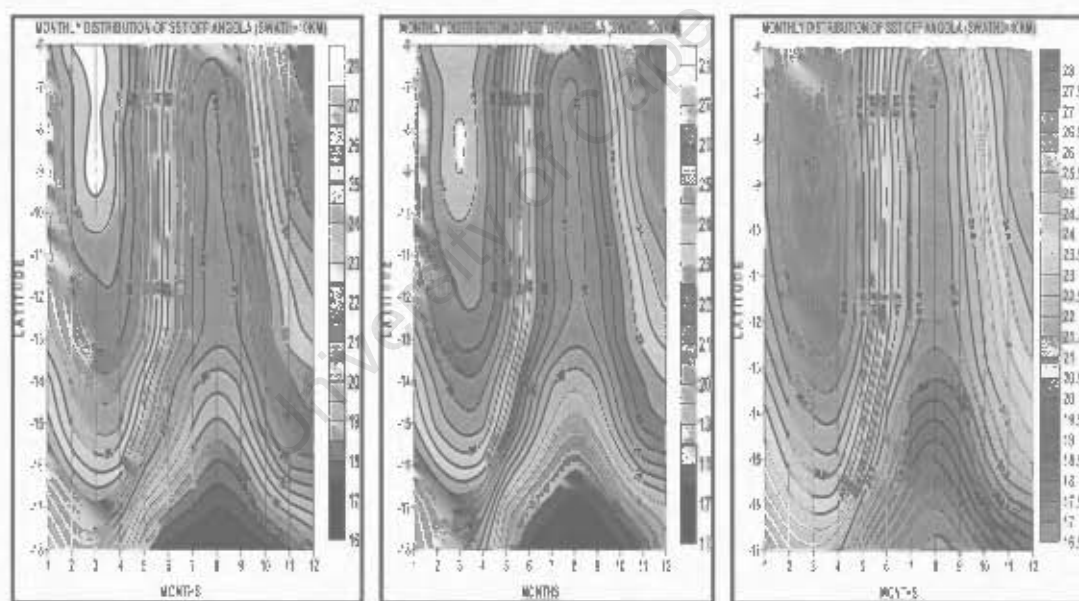


Fig. IV 1 Monthly variability of SST off Angola using three different swaths: (swath1=10km; swath2=20km/offshore distance =10km; swath3=40km/offshore distance=30km)

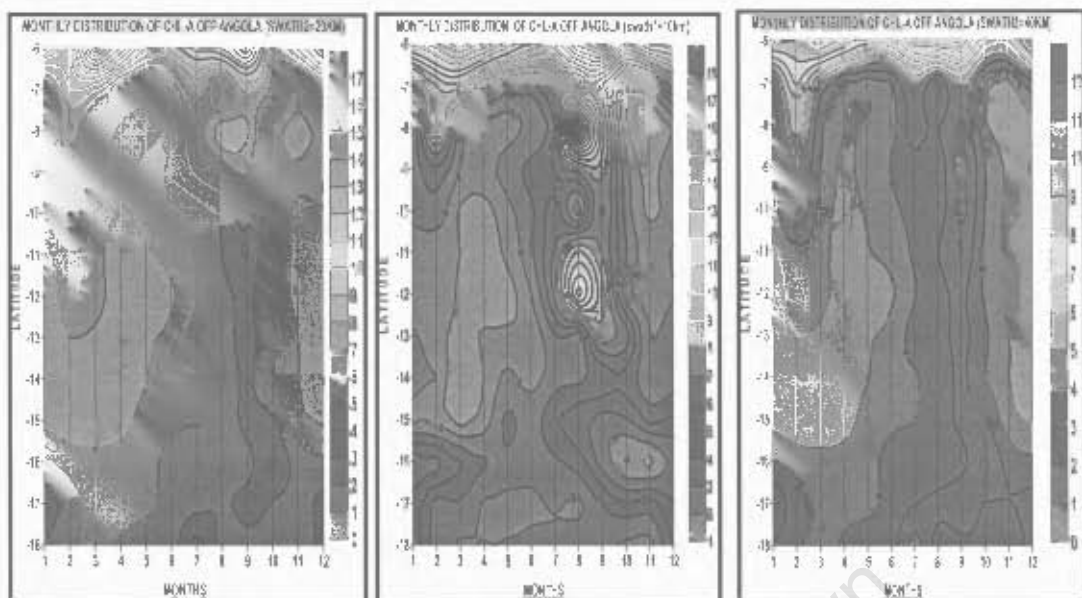


Fig.IV-2 Monthly variability of Chlorophyll off Angola using three different swaths; swath1=10km; swath2=20km/offshore distance=10km; swath3=40km/offshore distance=30km)

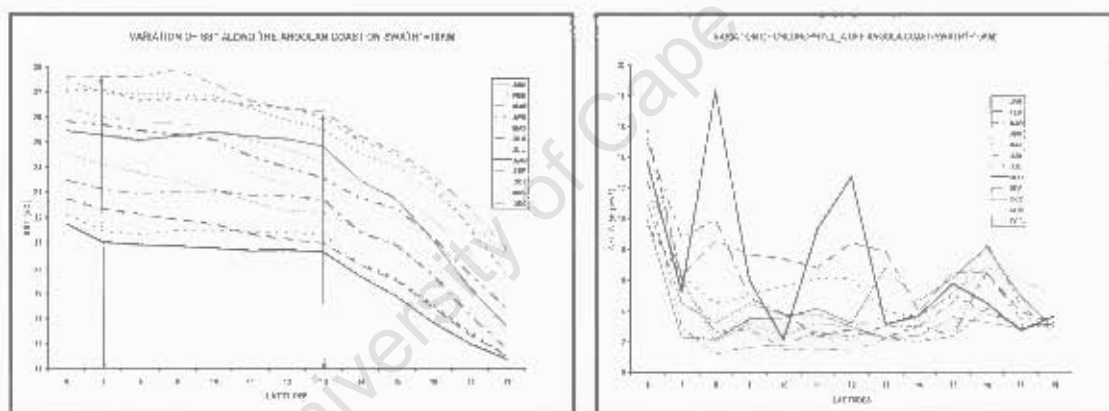


Fig.IV-3 Monthly variability of SST (left) and Chlorophyll (right) in longshore direction using a swath of 10km.

4.3 Variability of SST and Chlorophyll in offshore direction.

Monthly averaged SST (1987-2002) and chlorophyll (1998-2003) composites were used for this study. January and March for summer and July and August for winter were selected since the objective of this study was to find discontinuities in the offshore direction at each latitude (1°) and correlate the inflexion point or trend changes observed in given latitude to the next latitudes.

The choice of the offshore distance (300 km) was taken according to Exclusive Economic Zone (200 miles), which is the right width for the fisheries in Angola. At each latitude, an SST (chlorophyll) curve was drawn showing the variation of SST (chlorophyll) versus offshore distance. Thirteen curves (5-17°S) were obtained which were afterwards smoothed by averaging 5 pixels (Fig.IV 5 & Fig.IV 20).

In order to see the variation (trend changes) in SST (chlorophyll), it was necessary to compute anomalies versus offshore positions at each latitude (Fig.IV 6-18) for March and Fig.21-33 for July.

Comparing the results obtained with both parameters, the chlorophyll gave better results (uniformity in pattern) than SST. The anomalies obtained with SST in March (Fig.IV 6-18) were correlated from north to south (5.30°S -17°S) then four sub-regions were identified. Similar trend was observed in other months (January, July and August) although there were no uniformities in their pattern (Fig.IV:21-33). NB. Diagrams for January and August are not included in this report just to save the space.

The first sub-region has a negative trend and starts from the coast up to a certain distance offshore according to the latitude. This coastal sub-region was characterized by positive anomalies with chlorophyll (Fig.IV:6-18).

First sub-regions (I) starts from the coast with a negative trend with SST and a positive trend for chlorophyll-a								
Latitude	Meteosat-SST (xdim1 = 5.91)				SeaWiFS (xdim 1 = 4.56)			
	January	March	July	August	January	March	July	August
	Pixel	Pixel	Pixel	Pixel	Pixel	Pixel	Pixel	Pixel
5°S	1-26	1-8	1-24	1-26	1-26	1-20	1-25	1-10
6°S	4-29	2-31	1-29	6-32	1-31	1-10	1-20	1-13
7°S	1-32	1-18	1-21	1-23	1-32	1-6	1-15	1-25
8°S	1-21	1-21	1-20	1-21	1-26	1-5	1-15	1-31
9°S	1-25	1-22	1-15	1-25	1-17	1-11	1-18	1-28
10°S	1-21	1-20	1-16	1-20	1-15	1-22	1-19	1-28
11°S	1-10	1-17	1-12	1-10	1-14	1-33	1-19	1-25
12°S	1-10	1-8	1-2	1-2	1-15	1-43	1-18	1-20
13°S	1-6	1-14	0	0	1-10	1-22	1-24	1-17
14°S	1-3	0	0	0	1-10	1-15	1-16	1-6
15°S	0	0	0	0	1-14	1-6	1-22	1-22
16°S	0	0	0	0	1-6	1-10	1-40	1-15
17°S	1-8	1-8	2-30	0	1-31	1-28	1-44	1-25

Table-4.1. First sub-region

The correlations were more or less uniform in January and July with SST while in March and August there were some uniformities from north to south. Like the SST, chlorophyll was uniform in January and July (Fig.IV 21-33) with only two distinct sub-regions while in March (Fig.V 6-18) and August there were four sub-regions. The boundaries of each sub-region were summarized in table-1 (first sub-region), table-2 (second sub-region) and in table-3 (third sub-region).

The study made with both parameters allowed defining three distinct sub-regions in the offshore direction. The coastal sub-region starts from 5.30 down to 15°S, where it dies out and shows up again in south between 16.30 and 17°S. Between 15°S and 16°S, this coastal sub-region is replaced by the second sub-region (offshore). It is wider in the north (with 26 pixels = 138 km) and narrow (with 3 pixels = 30 km) in the south. It features SST negative anomalies which are presumed to be cold water (low temperature) and with positive chlorophyll anomalies which are believed to have high concentration.

The Angolan continental shelf (Fig II-1) presents the same pattern: wide in the north and narrow in south. The shelf is almost absent between 15-16.30°S. The longshore study showed high concentration of chlorophyll in the north and along the north of Luanda.

Second sub-regions (II) starts from offshore with a positive trend with SST and a negative trend for chlorophyll-a								
Latitude	Meteosat-SST (xdim1 = 5.91)				SeaWIFS (xdim 1 = 4.56)			
	January	March	July	August	January	March	July	August
	Pixel	Pixel	Pixel	Pixel	Pixel	Pixel	Pixel	Pixel
5°S	27-51	9-13	25-51	27-51	27-39	21-38	26-65	11-40
6°S	30-51	32-51	30-51	33-51	32-65	11-36	21-65	14-44
7°S	33-51	19-51	22-51	24-51	33-65	7-26	16-65	26-65
8°S	22-51	22-48	21-51	22-51	27-65	6-25	16-65	32-65
9°S	26-51	23-51	16-51	26-51	18-65	12-20	16-65	29-65
10°S	22-51	21-51	17-51	21-51	16-65	23-65	19-65	29-65
11°S	11-51	18-51	13-36	11-15	15-65	34-38	20-65	26-65
12°S	11-40	9-25	3-37	3-32	16-65	44-65	19-65	21-65
13°S	7-43	15-28	1-27	1-28	11-65	23-65	25-65	18-65
14°S	4-22	1-23	1-21	1-22	11-65	16-65	17-65	7-30
15°S	1-22	1-26	1-17	1-23	15-49	7-26	23-65	23-51
16°S	1-17	1-17	1-19	1-20	7-39	11-65	41-65	16-31
17°S	9-15	9-16	31-51	1-13	32-65	29-65	45-65	26-61

Table-4.2: Second sub-region

The second sub-region (offshore) is at the coast between 15°S and 16°S and moves offshore in other latitudes. From 5.30°S to 10°S, its extension is more or less 170 km, narrowing from 10°S to 17°S with a sharp curve between 15°S and 16°S. This second sub-region is characterized by warm water and low chlorophyll concentration.

The third sub-region (far offshore) is absent in the north (5-8°S) then it narrows from 8-13°S and widens from 13-16°S where it reaches the maximum width (34 pixels = 200 km). This region has the same feature than the coastal, except that the concentration in chlorophyll

is low in all seasons and the temperature is high in the north and low in south. Besides, in summer, the temperature increases with the offshore distance while in winter it decreases. To conclude, three sub-regions were defined along the coast and another three offshore. Both approaches did not allow defining with certainty the Angola waters; instead the results were used as a guide in the cluster analysis.

Third sub-regions (III) starts from offshore with a negative trend with SST and a positive trend for chlorophyll-a

Latitude	Meteosat-SST (xdim 1 = 5.91)				SeaWiFS (xdim 1 = 4.56)			
	January	March	July	August	January	March	July	August
	Pixel	Pixel	Pixel	Pixel	Pixel	Pixel	Pixel	Pixel
5°S	0	13-51	0	0	0	39-65	0	45-65
6°S	0	0	0	0	0	37-65	0	0
7°S	0	0	0	0	0	27-65	0	0
8°S	0	49-51	0	0	0	26-65	0	0
9°S	0	0	0	0	0	21-65	0	0
10°S	0	0	0	0	0	0	0	0
11°S	0	0	37-51	16-51	0	39-65	0	0
12°S	41-51	26-51	38-51	33-51	0	0	0	0
13°S	44-51	29-51	28-51	29-51	0	0	0	0
14°S	23-51	24-51	22-51	23-51	0	0	0	31-65
15°S	23-51	27-51	18-51	24-51	50-65	27-65	0	52-65
16°S	18-51	18-51	20-51	21-51	40-65	0	0	32-65
17°S	16-51	17-51	0	14-51	0	0	0	62-65

Table-4.3. Third sub-region

4.4 Diagrams relative to the variation of SST and chlorophyll-a in offshore direction

4.4.1 Variation of SST and chlorophyll-a in offshore direction (March)

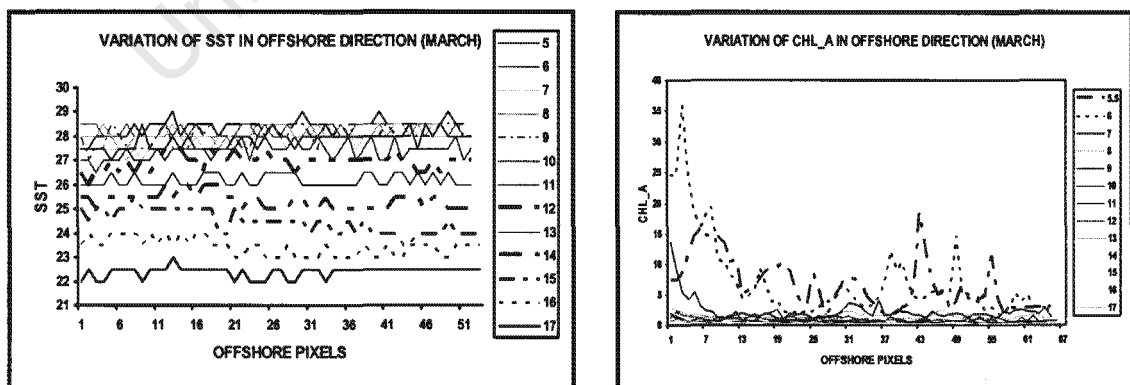


Fig.IV-4 Original SST (left) and chlorophyll-a (right) in offshore direction (March)

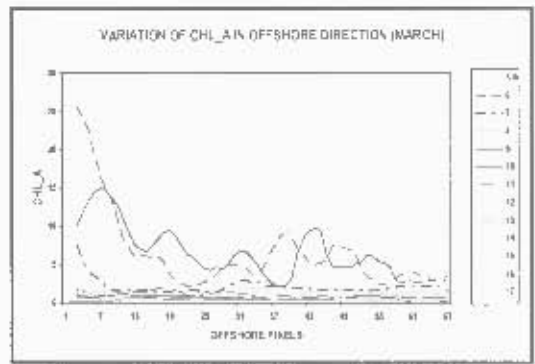
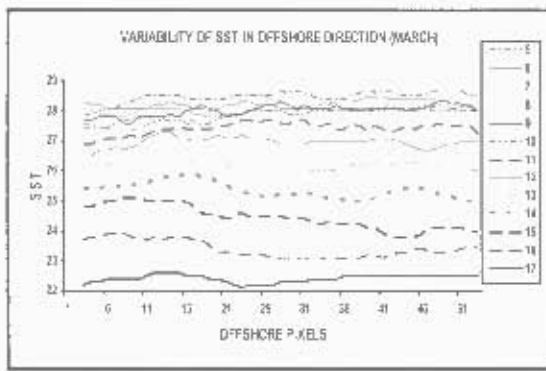


Fig.IV-5 Smoothed SST (left) and Chlorophyll-a (right) in offshore direction (March).

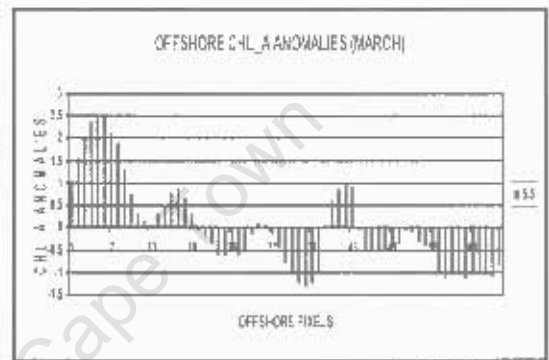
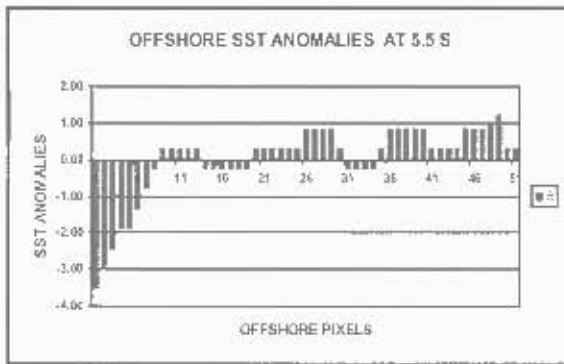


Fig.IV-6 Offshore SST (left) and chlorophyll-a (right) anomalies at 5.5°S

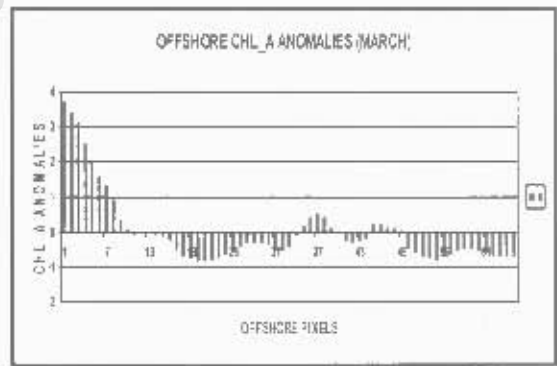
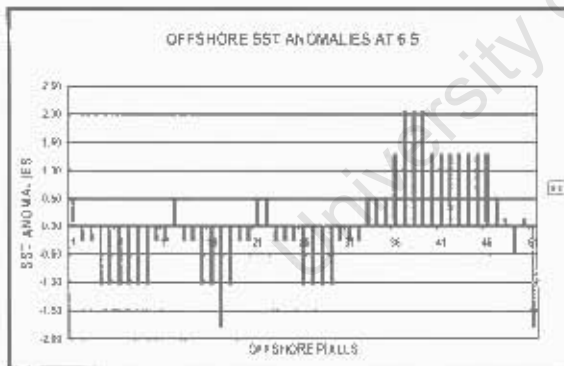


Fig.IV-7 Offshore SST (left) and chlorophyll-a (right) anomalies at 6°S

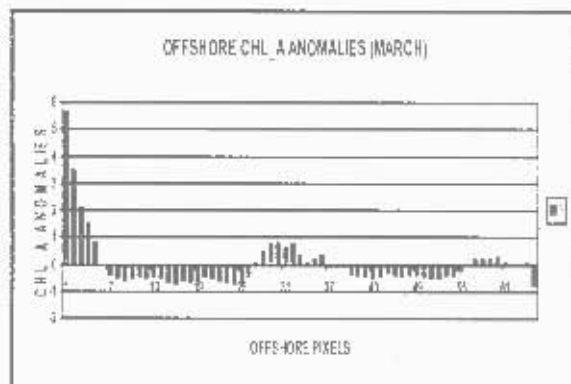
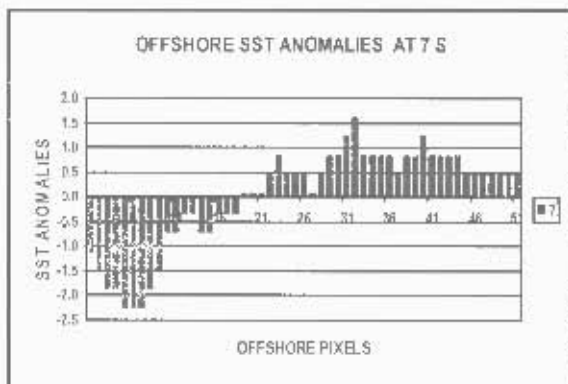


Fig.IV-8 Offshore SST (left) and chlorophyll-a (right) anomalies at 7°S

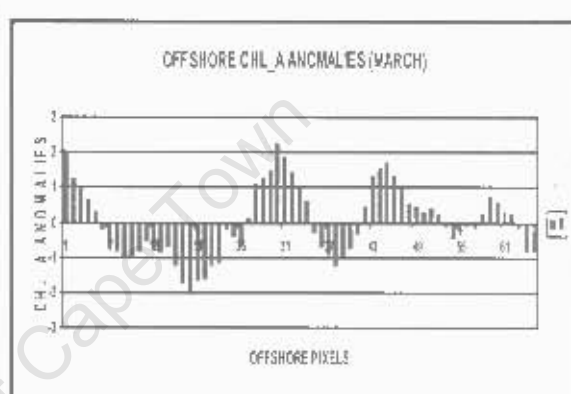
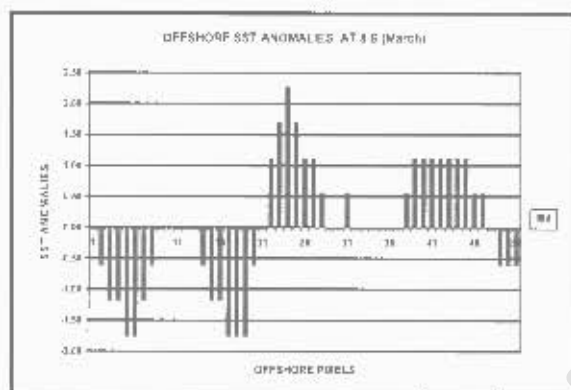


Fig.IV-9 Offshore SST (left) and chlorophyll-a (right) anomalies at 8°S

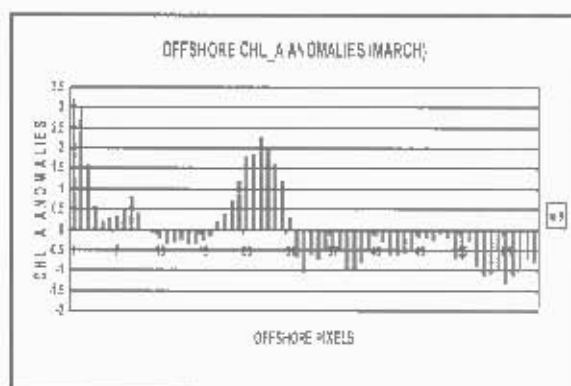
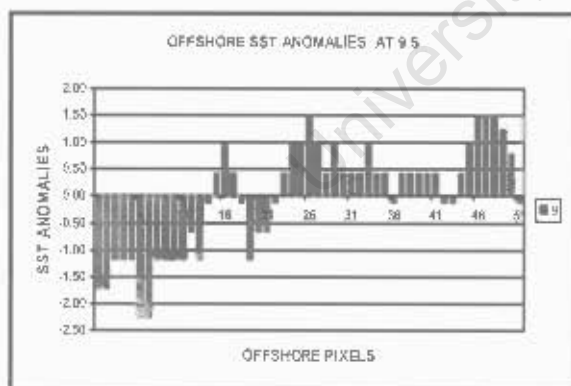


Fig.IV-10 Offshore SST (left) and chlorophyll-a (right) anomalies at 9°S

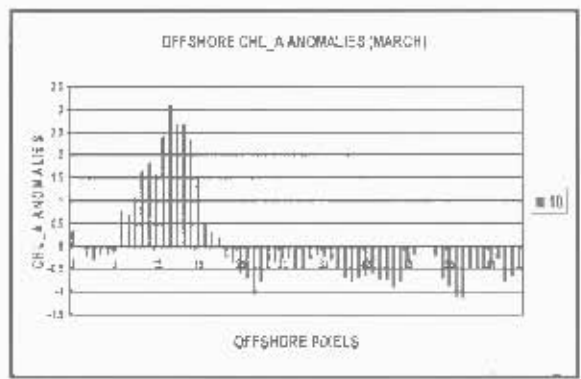
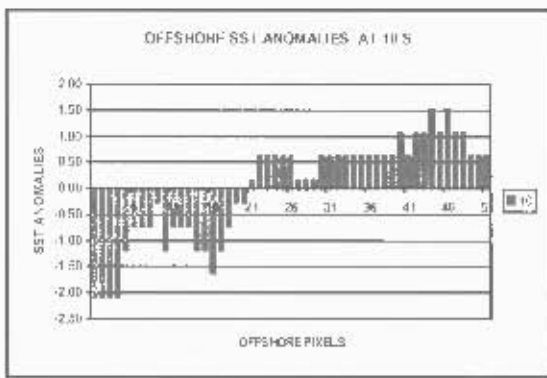


Fig.IV-11 Offshore SST (left) and chlorophyll-a (right) anomalies at 10°S

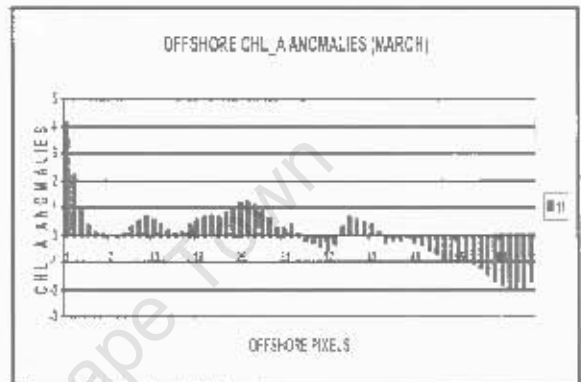
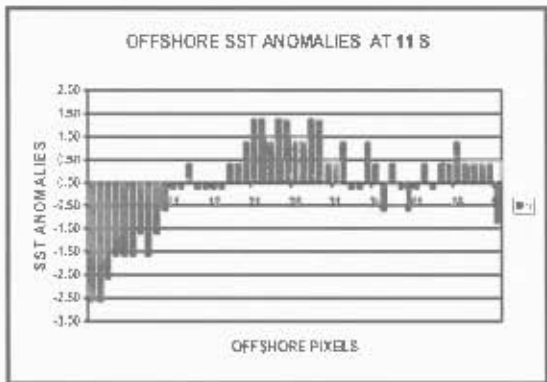


Fig.IV-12 Offshore SST (left) and chlorophyll-a (right) anomalies at 11°S

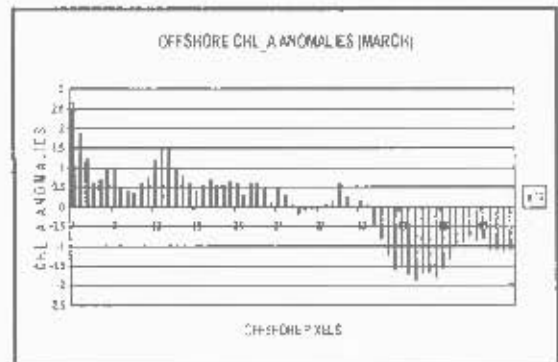
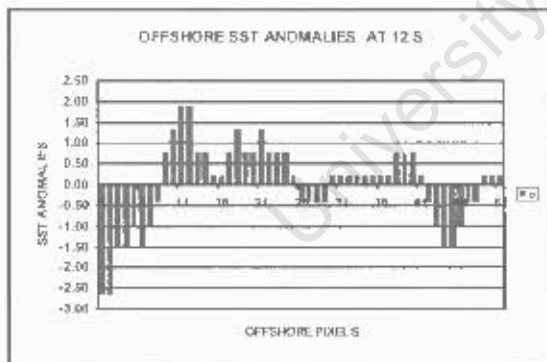


Fig.IV-13 Offshore SST (left) and chlorophyll-a (right) anomalies at 12°S

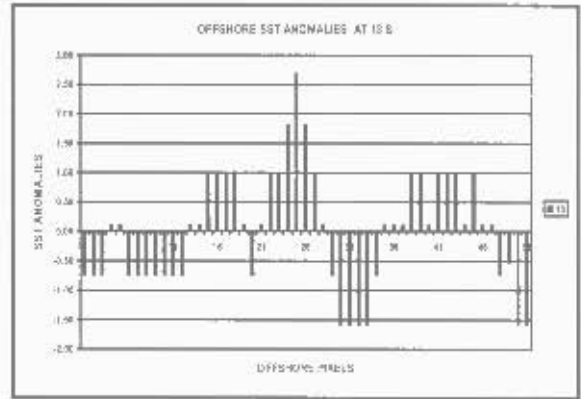
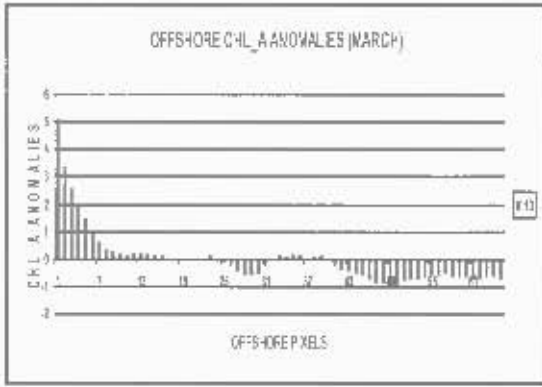


Fig.IV-14 Offshore SST (left) and chlorophyll-a (right) anomalies at 13°S

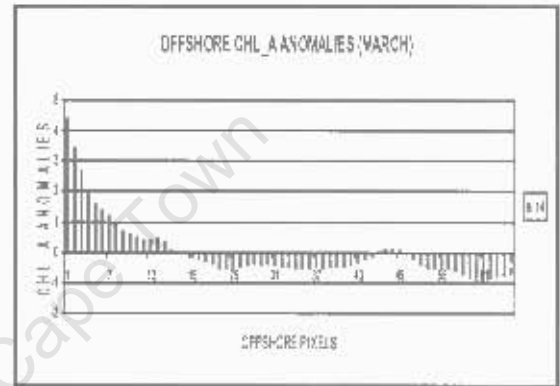
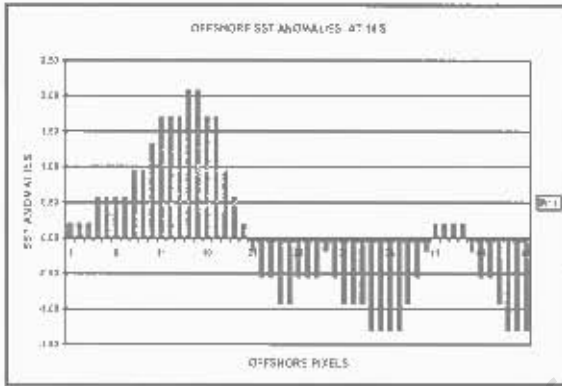


Fig.IV-15 Offshore SST (left) and chlorophyll-a (right) anomalies at 14°S

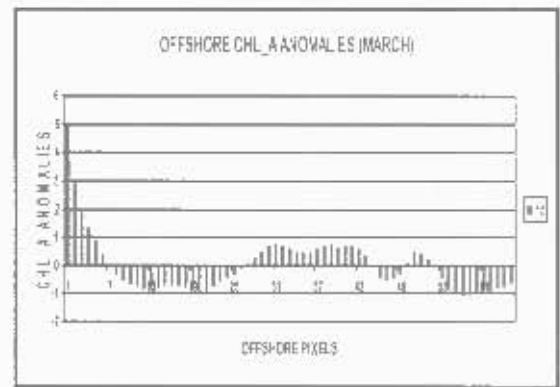
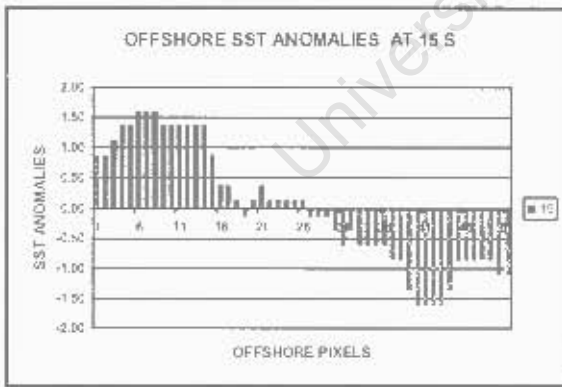


Fig.IV-16 Offshore SST (left) and chlorophyll-a (right) anomalies at 15°S

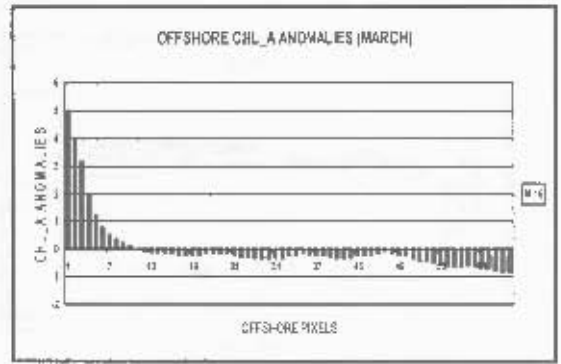
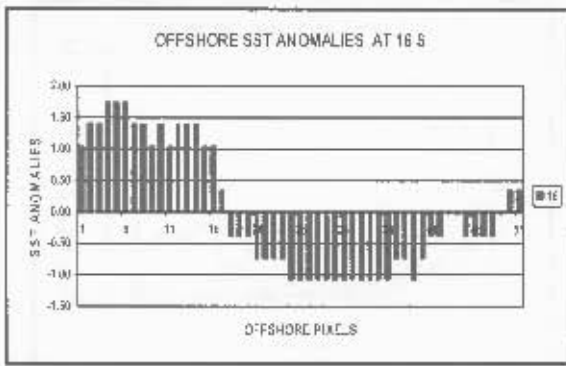


Fig.IV-17 Offshore SST (left) and chlorophyll-a (right) anomalies at 16°S

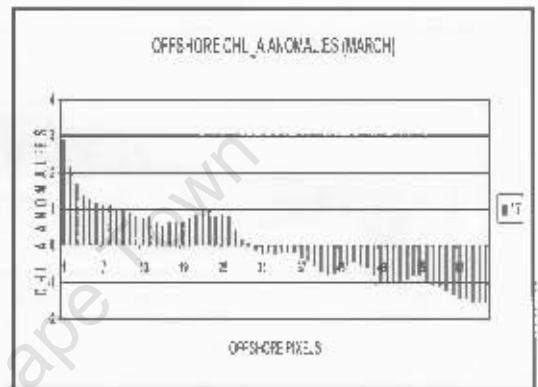
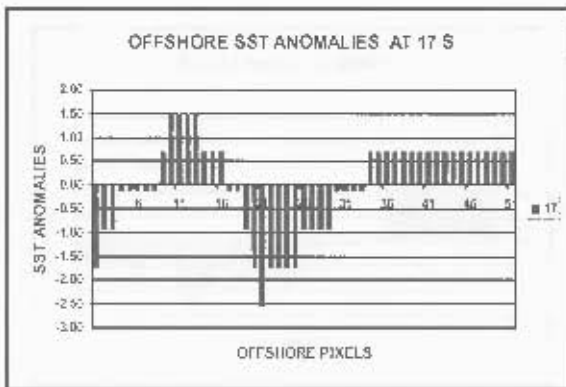


Fig.IV-18 Offshore SST (left) and chlorophyll-a (right) anomalies at 17°S

4.4.2 Variation of SST and chlorophyll-a in offshore direction (July)

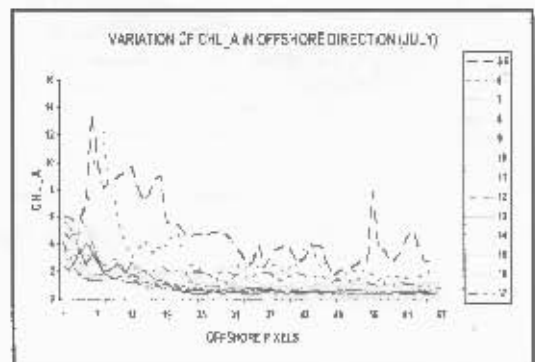
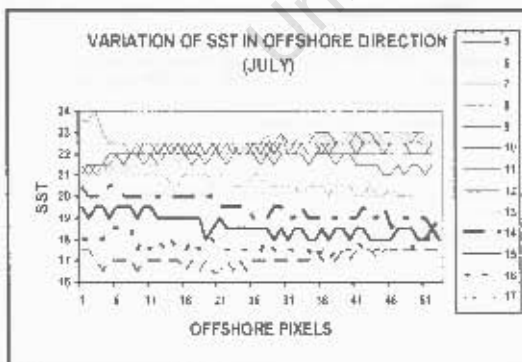


Fig.IV-19 Original SST (left) and chlorophyll-a (right) in offshore direction (July)

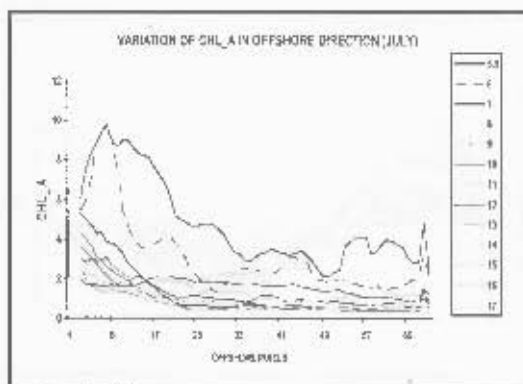
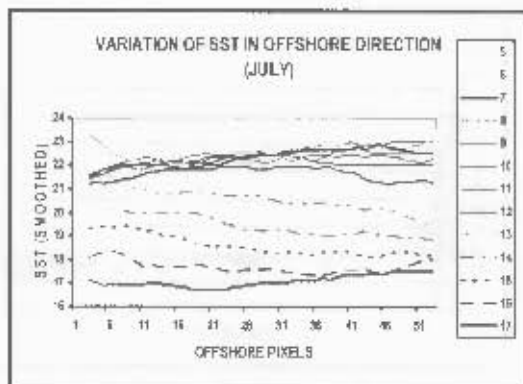


Fig.IV-20 Smoothed SST (left) and Chlorophyll-a (right) in offshore direction (July).

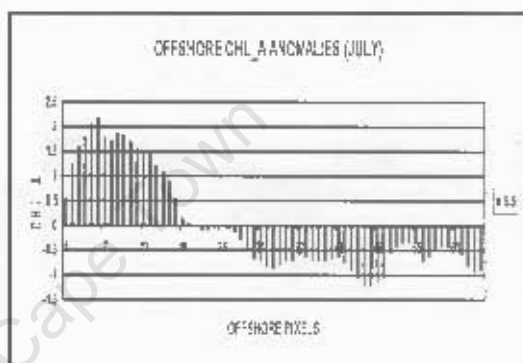
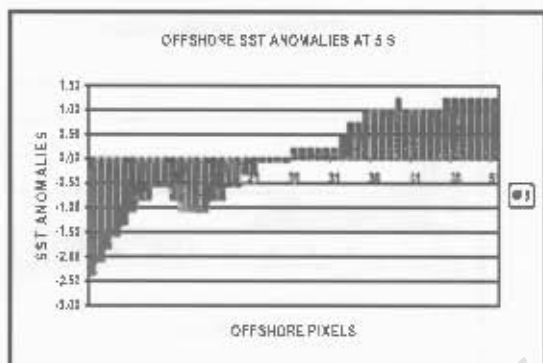


Fig.IV-21 Offshore SST (left) and chlorophyll-a (right) anomalies at 5°S

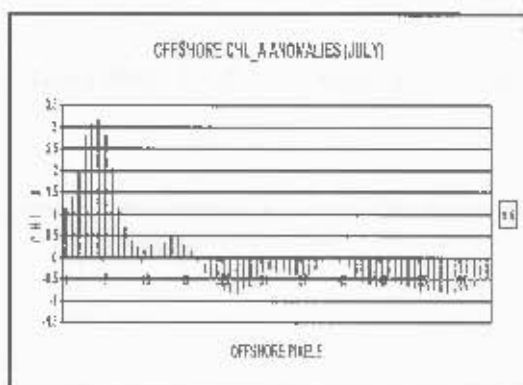
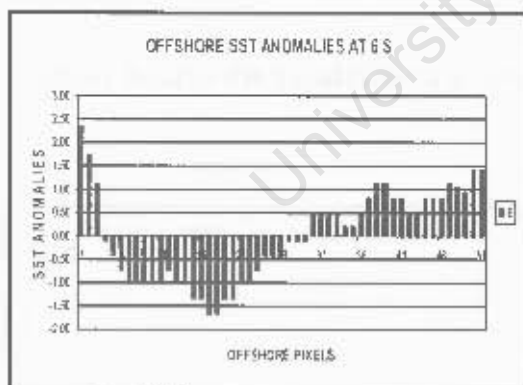


Fig.IV-22 Offshore SST (left) and chlorophyll-a (right) anomalies at 6°S

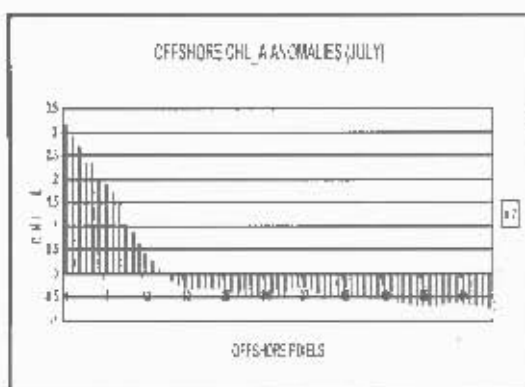
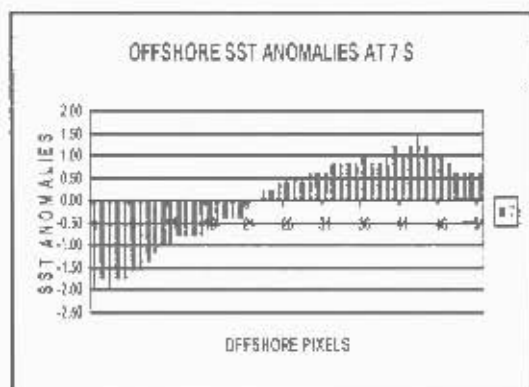


Fig.IV-23 Offshore SST (left) and chlorophyll-a (right) anomalies at 7°S

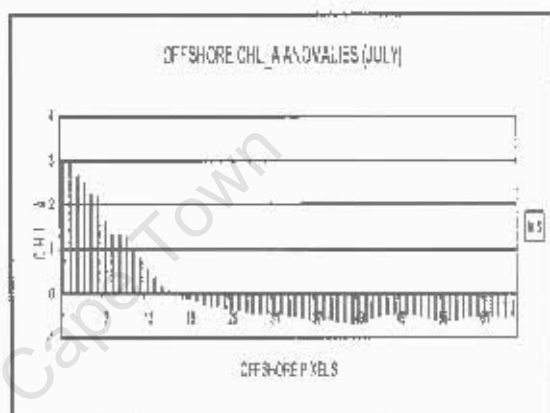
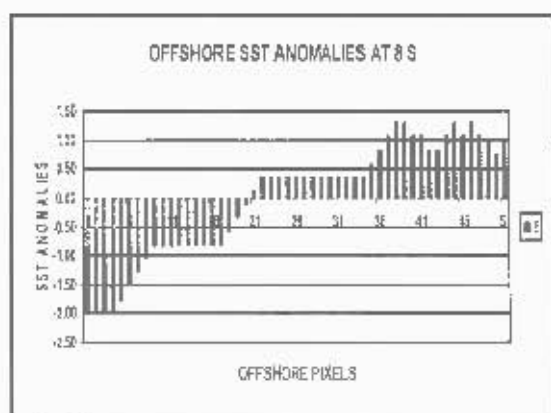


Fig.IV-24 Offshore SST (left) and chlorophyll-a (right) anomalies at 8°S

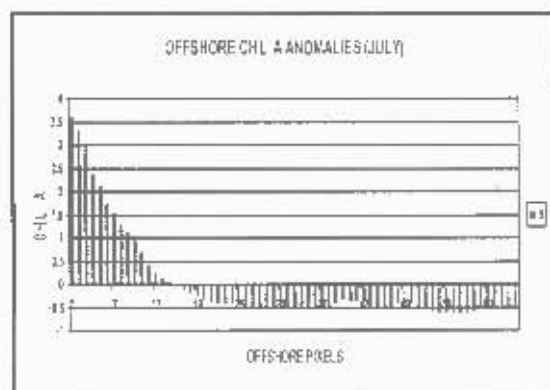
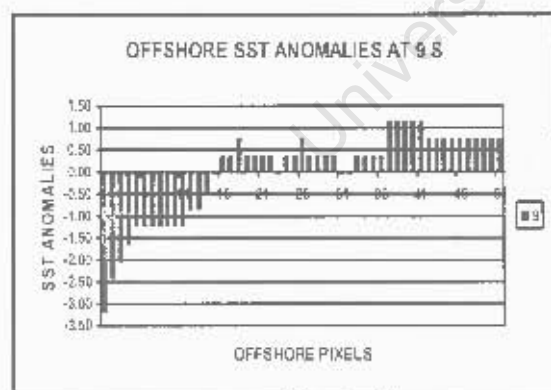


Fig.IV-25 Offshore SST (left) and chlorophyll-a (right) anomalies at 9°S

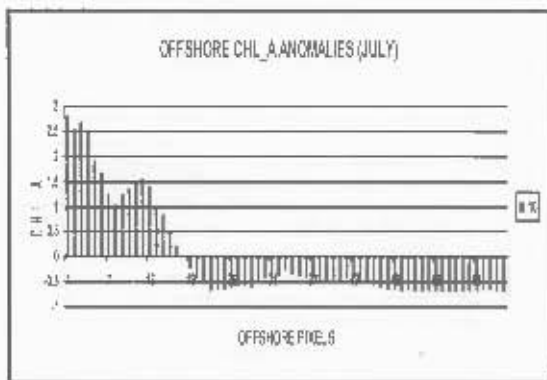
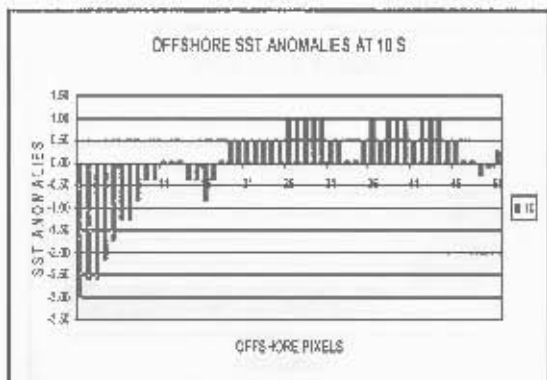


Fig.IV-26 Offshore SST (left) and chlorophyll-a (right) anomalies at 10°S

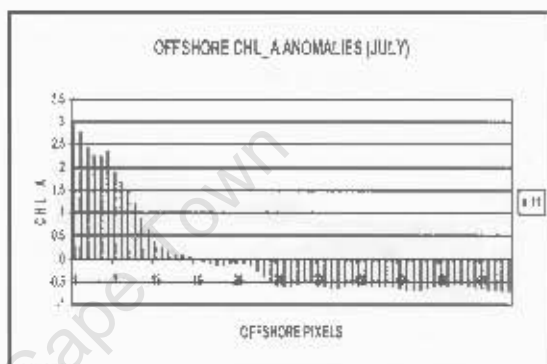
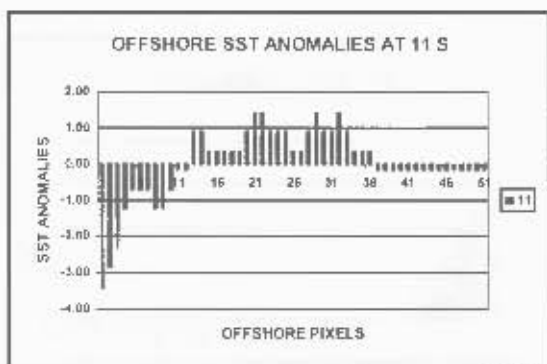


Fig.IV-27 Offshore SST (left) and chlorophyll-a (right) anomalies at 11°S

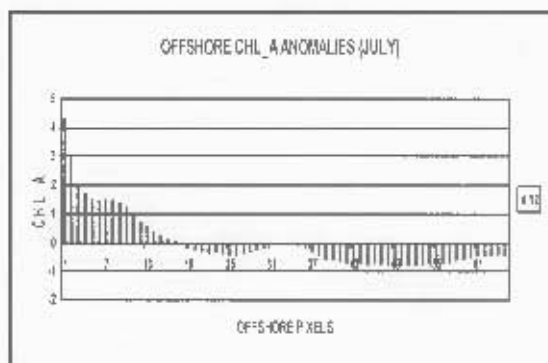
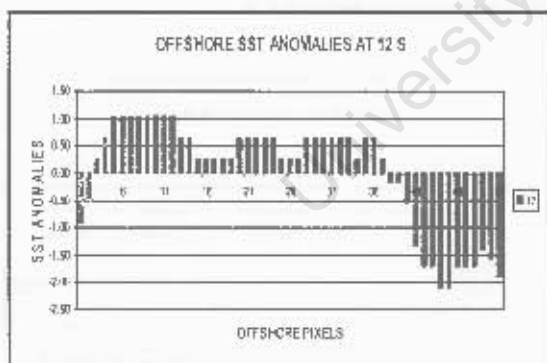


Fig.IV-28 Offshore SST (left) and chlorophyll-a (right) anomalies at 12°S

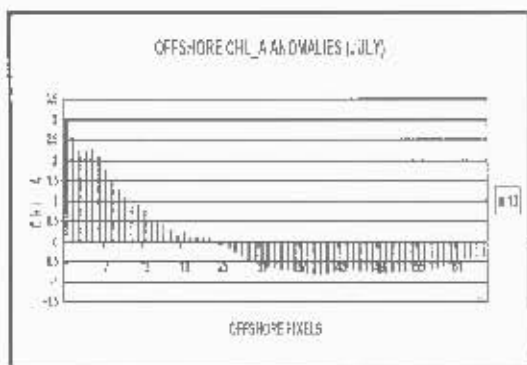
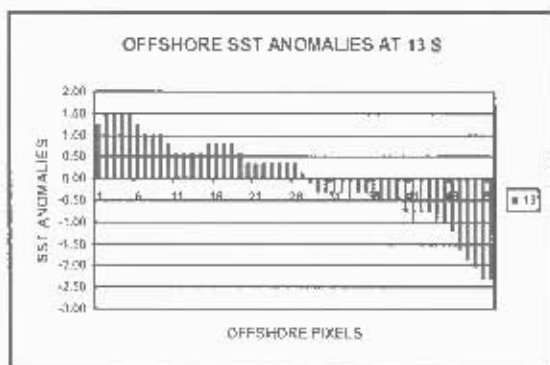


Fig.IV-29 Offshore SST (left) and chlorophyll-a (right) anomalies at 13°S

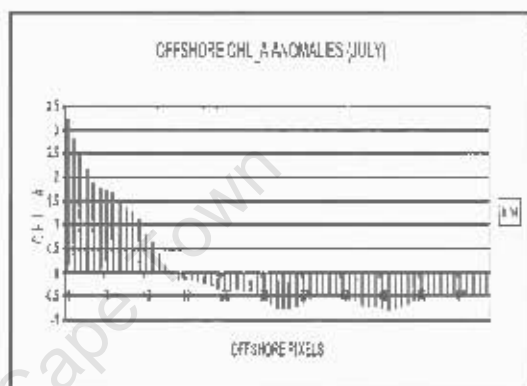
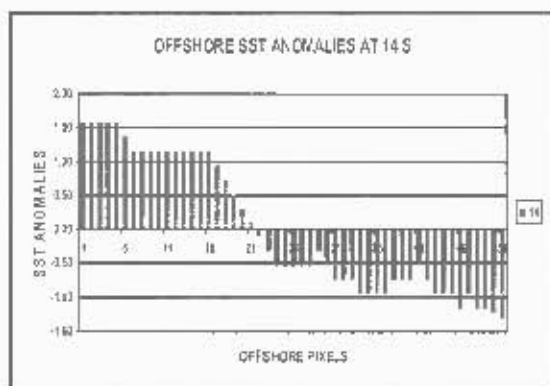


Fig.IV-30 Offshore SST (left) and chlorophyll-a (right) anomalies at 14°S

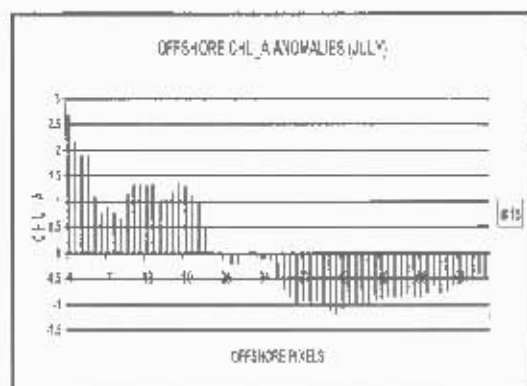
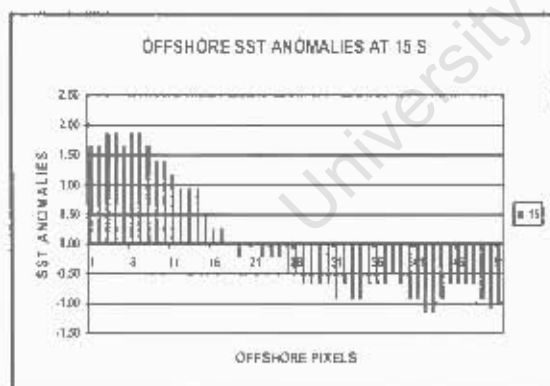


Fig.IV-31 Offshore SST (left) and chlorophyll-a (right) anomalies at 15°S

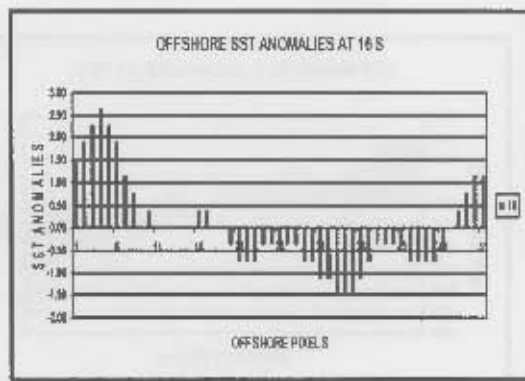
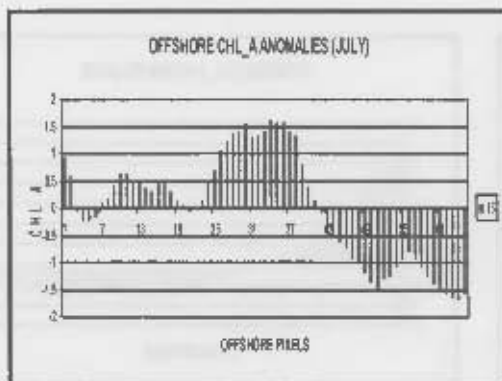


Fig.IV-32 Offshore SST (left) and chlorophyll-a (right) anomalies at 16°S

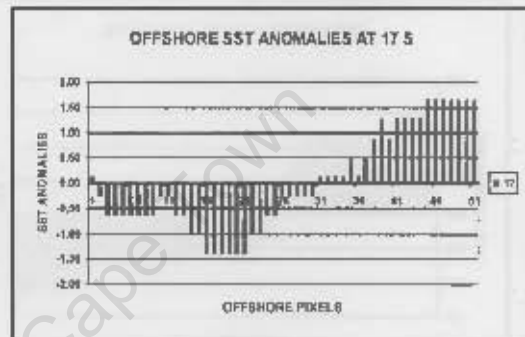
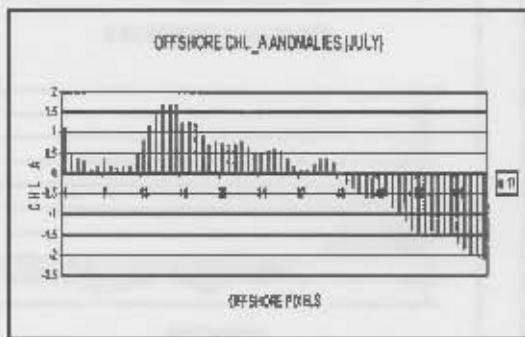


Fig.IV-33 Offshore SST (left) and chlorophyll-a (right) anomalies at 17°S

4.5 Variability of SST and Chlorophyll-a in sub-regions. (Cluster Procedure).

4.5.1 Results obtained with Meteosat-SST monthly composite images

Monthly SST composite images (1987-2002) were used to compute the mean-SST according to pixels of each sub-region. The size of the cluster images was converted from 825 x 825 into 650 x 650. The mean-SST in all sub-regions was computed by using the principle of data extraction in swath i.e. knowing the northern and southern latitudes and the offshore distance. Fig.IV 36 shows monthly variations of SST from 1987 to 2002.

The pattern of SST is bimodal and identical in the entire Angola, with high temperatures in summer (January-April) with a peak in March (28°C) and low temperatures in winter (May-August) with a trough in August (19°C). Spring (September-December) is a transitional period between summer and winter, during which the temperature is moderate (21-24.5°C). Winter is one month longer in offshore sub-region than in others.

In Fig.IV-38, the monthly temperature in the northern sub-region was 2°C higher than in two other sub-regions for all year. The coastal and offshore sub-regions have almost the same temperature except from August to December where $\Delta T \approx 1^\circ\text{C}$.

The SST anomalies observed in figs.IV 37 & figs. 38-40 show warm years with positive anomalies in one hand between 1987 and 1989 (+2°C) during twelve months, in 1995 (+1.5°C) from January to May and between 1998 and 2000 (+2°C) for twelve months. There are also some indications of warm years in fig.V 34, showing warm cells in 1988, in 1995 and from 1998 to 2000. But in the other hand, negative anomalies were also observed in the same diagram showing cool cells in 1992 (-1°C) for all year, 1996 (Nov-Dec), 1997 (-1.5°C) just from January to March and at last from 2001 to 2002.

A cycle of three years' warming was observed in 1987-1999 and another one in 1998-2000, both with an anomaly reaching (+2.5°C). Between the two periods, short periods of warming were observed in 1991 and in 1995-1996 with an anomaly of low magnitude (+1.5°C). Meanwhile the cool periods observed in Angolan waters were very short just in 1992 (one year) and in 1997 (one year) but both with high magnitude (-2°C), then in 2001-2002 (2 years) with the same magnitude than the previous. Warm and cool years were also observed in offshore regions, but with a very low magnitude. The changes observed at the coast are not as intense as in offshore (180 km offshore).

The well documented Benguela Niño (Gammelsrød et al., 1998) stroke the Angola Coast in 1994/1995. The intrusion of warm water in the north, takes at least a month or two to reach the central part of Angola. The SST anomalies (Fig.IV 37-40) show warming starting in September 94 in the north and proceeding until April 1995, afterwards the situation returned to normal. Meanwhile in the coastal and offshore sub-regions, the same warming (due to El Niño) was observed one month later in October 94 proceeding in 1995 (all year) and 1996. The periods 1987-1989 and 1999-2000 with higher warming magnitude than in 1995, should be considered as El Niño years although not well documented and 1992 and 1997 as la Niña.

4.5.2 Results obtained with SeaWiFS Chlorophyll composite images.

As with Meteosat-SST images, the SeaWiFS Chlorophyll monthly composite images were used to compute the monthly mean-chlorophyll from 1998 to 2003. The occurrence of high or low concentration of chlorophyll does not depend on the seasons as the SST. In fig V-35, showing the distribution of chlorophyll in the three sub-regions, one can observe a three months' cycle of high and low Chlorophyll. High chlorophyll is observed in January to March (summer) followed by a low concentration in April-July (autumn/winter). Another high is observed in August-October (winter/spring) followed by a low in November-December (spring).

Higher concentration in chlorophyll (Fig.IV 41-44) is observed in the Northern with two maxima, one in March (7.09 mg m⁻³) and another in August (7.401 mg m⁻³) while the minima are found in June (4.034 mg m⁻³) and November (2.80 mg m⁻³).

In the Coastal sub-region, the chlorophyll is lower relatively to the northern. The maxima in chlorophyll are observed in February (2 mg m⁻³) instead of March and in September (3.3 mg m⁻³) instead of August. The minima are observed in April (0.85 mg m⁻³) and in November (1.15 mg m⁻³).

The lowest concentration in chlorophyll is observed in the offshore sub-region with two maxima; one in February (1.37 mg m⁻³) and the other in September (1.48 mg m⁻³). The minima were observed in April (0.55 mg m⁻³) and in December (0.608 mg m⁻³).

The overall analysis made on the Chlorophyll anomalies (Fig.IV 35 & Figs.IV 41-44) shows no uniformity in different sub-regions off Angola.

In the northern sub-region, positive trends were observed in summer of 1998, 2000 and 2002 and in all year in 1999 and 2003. But in coastal sub-region, 1998, 2000 and 2003 shows a negative anomaly for all year. The negative trend was observed mostly in winter (1998, 2000 and 2002) and occurred exceptionally in summer (2004).

From 1998 to 2001, negative trends of chlorophyll were observed in the Coastal sub-region independently of the seasons. These negative trends corresponded with the positive trends with SST in the same sub-region. But in 2001 to 2004, positive trend was observed in all year but with exceptional occurrences of negative trends. The SST anomalies were negative in 2001 to 2002.

In offshore sub-region, negative and positive trends were alternating from one year to another between 1998 and 2001 while the SST remained positive during this period of time. The trend with chlorophyll remained positive but the SSTs were negative between 2002 and 2004.

In the last two sub-regions (coastal and offshore), low temperatures (negative anomalies) were always accompanied with high (positive anomalies) concentration of chlorophyll except in the north where this rule could not be applied.

4.5.3 Diagrams relative to results obtained with Cluster Procedure.

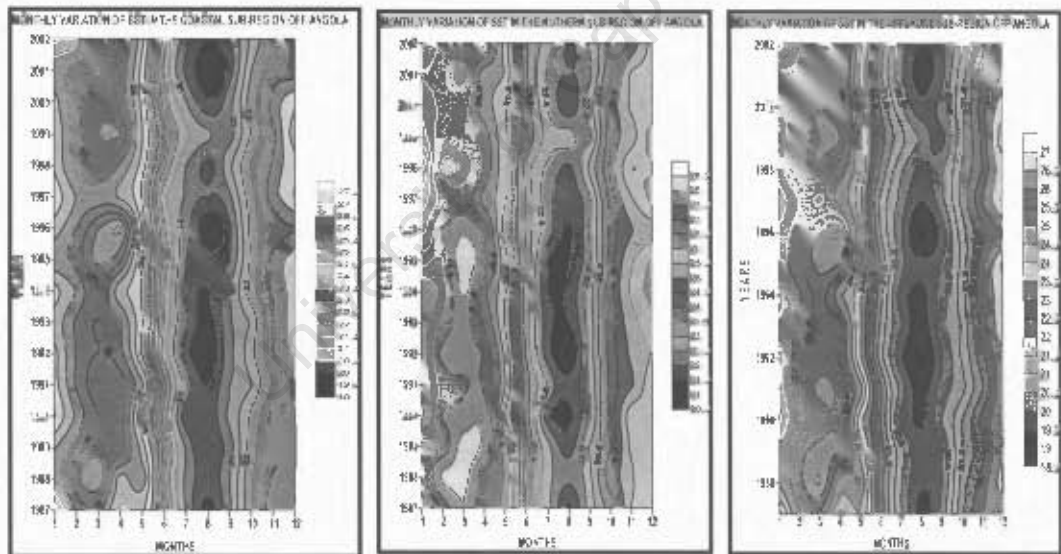


Fig.IV-34 Monthly variation of SST in the coastal, northern and offshore sub-region off Angola.

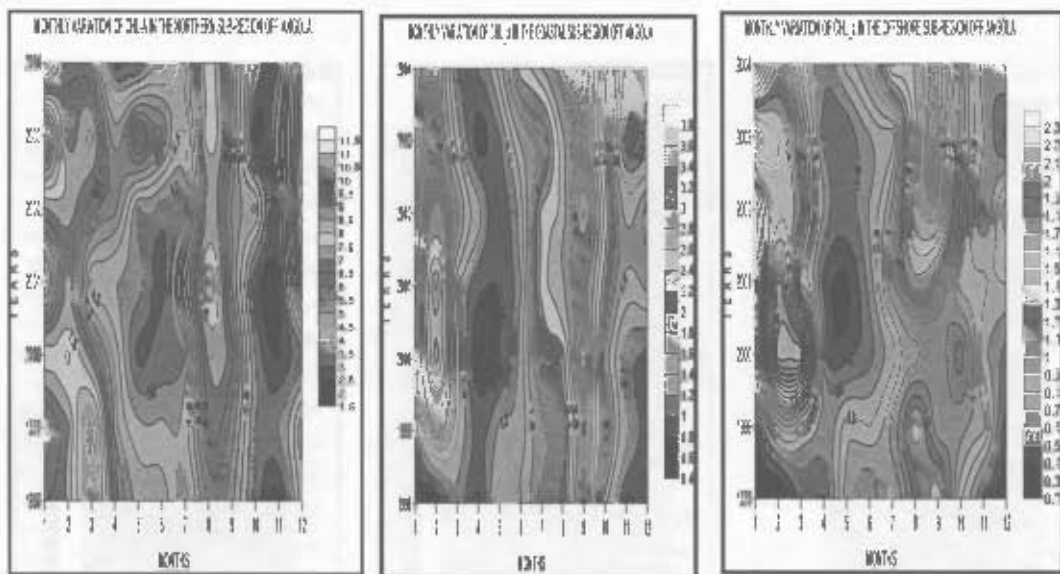


Fig.IV-35 Monthly variation of the concentration of Chlorophyll in the northern, coastal and offshore sub-region off Angola.

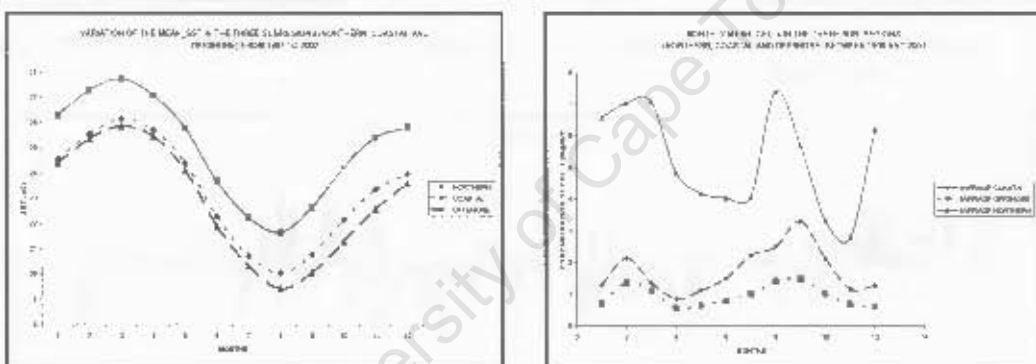


Fig.IV-36 Monthly variation of the mean-SST (left) and the mean-concentration of Chlorophyll (right) in the northern, coastal and offshore sub-regions off Angola.

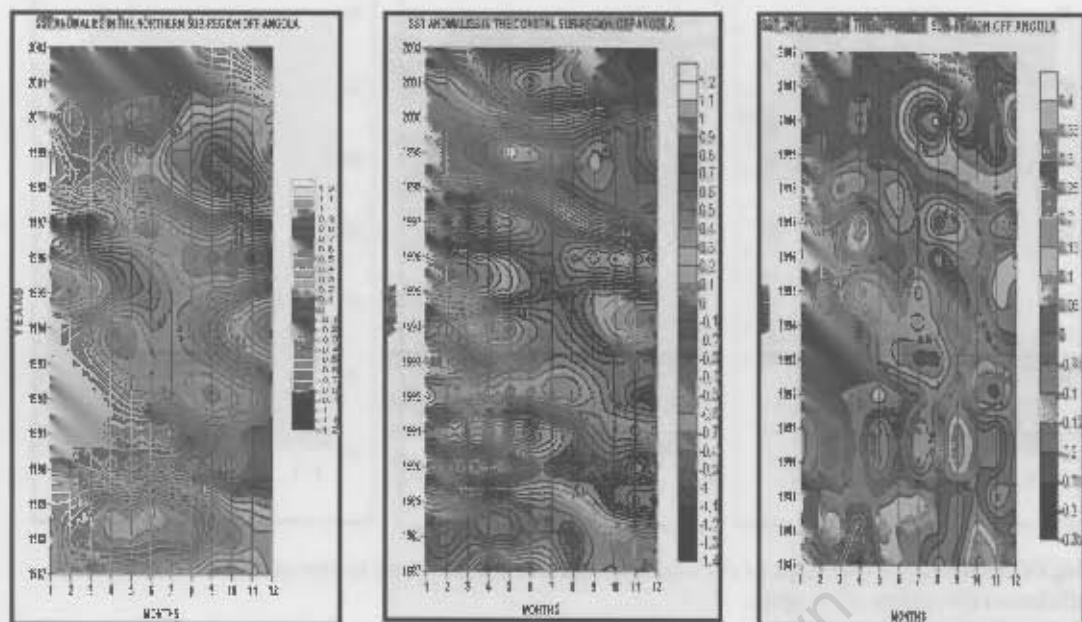


Fig.IV-37 Monthly SST anomalies in the northern (left), coastal (middle) and offshore (right) sub-regions off Angola.

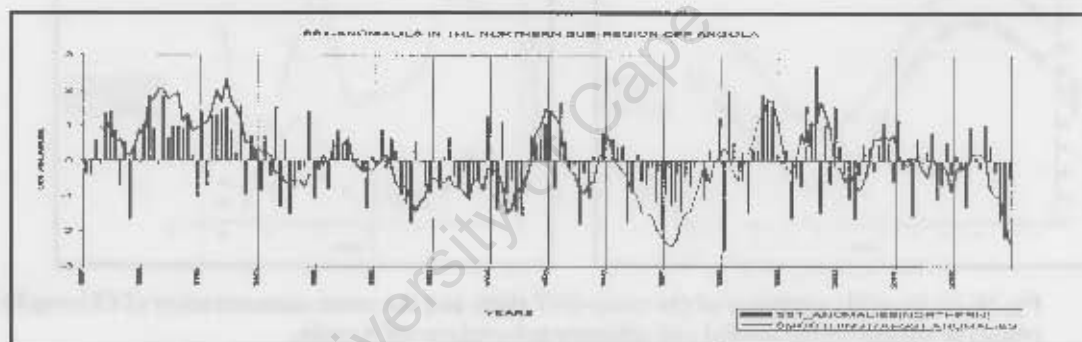


Fig.IV-38 SST anomalies in the northern sub-region off Angola.

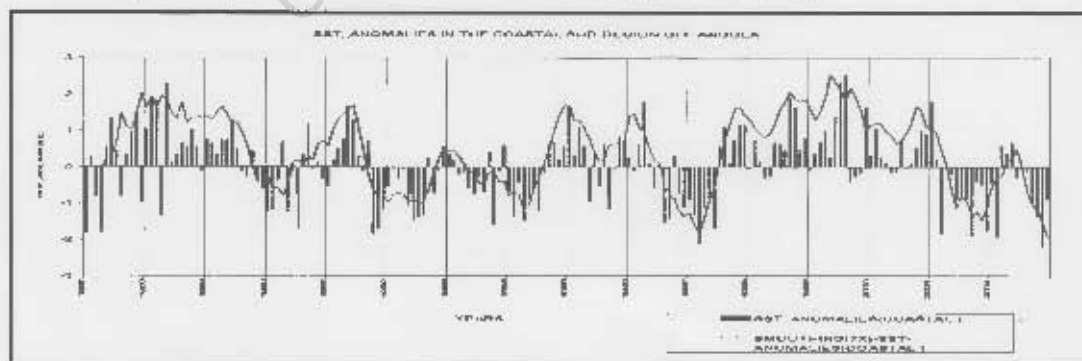


Fig.IV-39 SST anomalies of in the coastal sub-region off Angola.

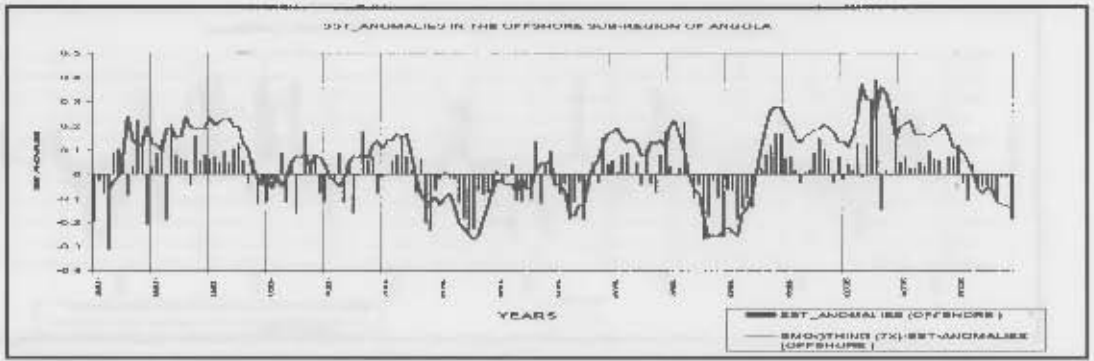


Fig.IV-40 SST anomalies in the offshore sub-region off Angola

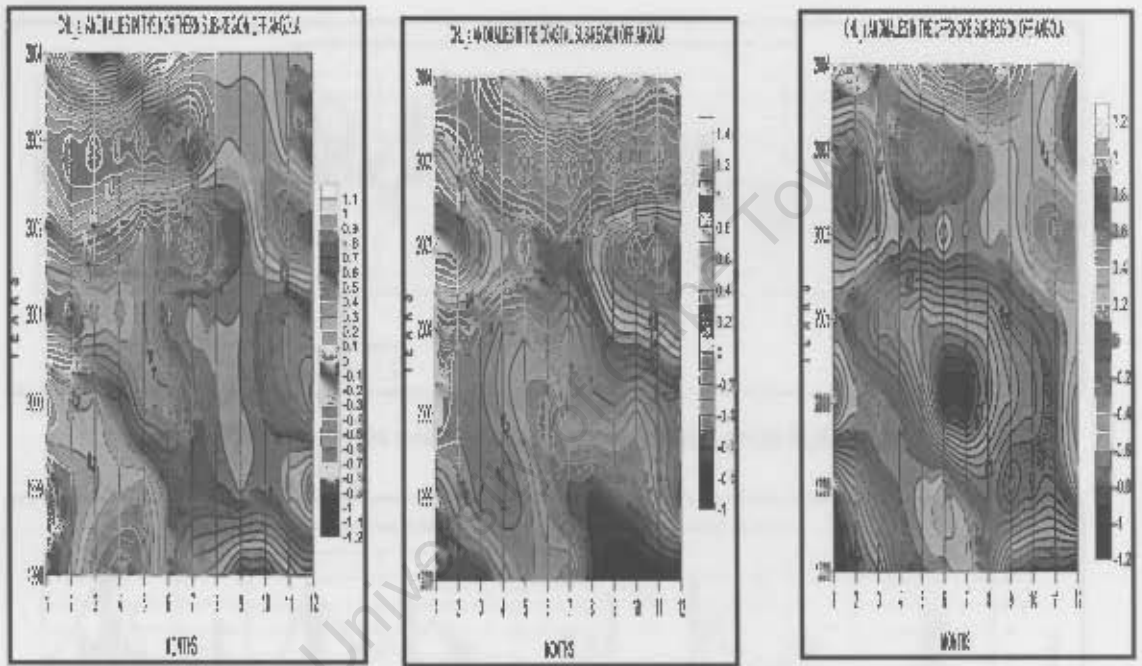


Fig.IV-41 Monthly anomalies of Chlorophyll in the northern (left), coastal (middle) and offshore (right) sub-regions off Angola.



Fig.IV-42 Chlorophyll anomalies in the northern sub-region off Angola

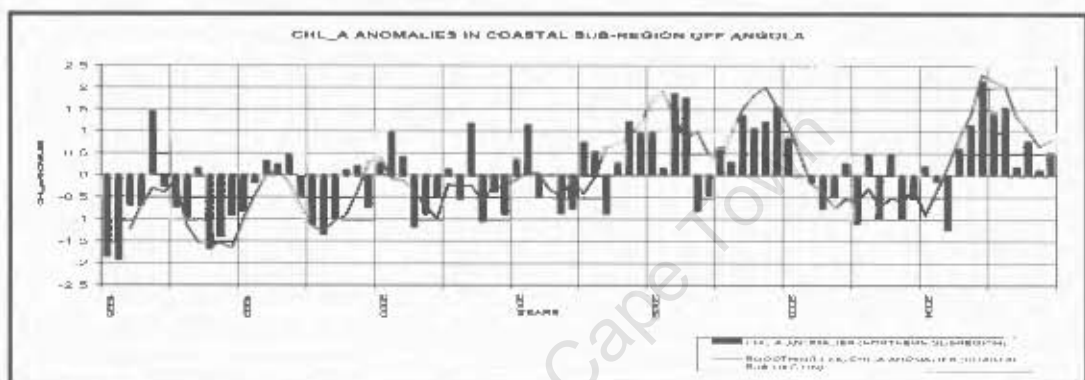


Fig.IV-43 Chlorophyll anomalies in the coastal sub-region off Angola

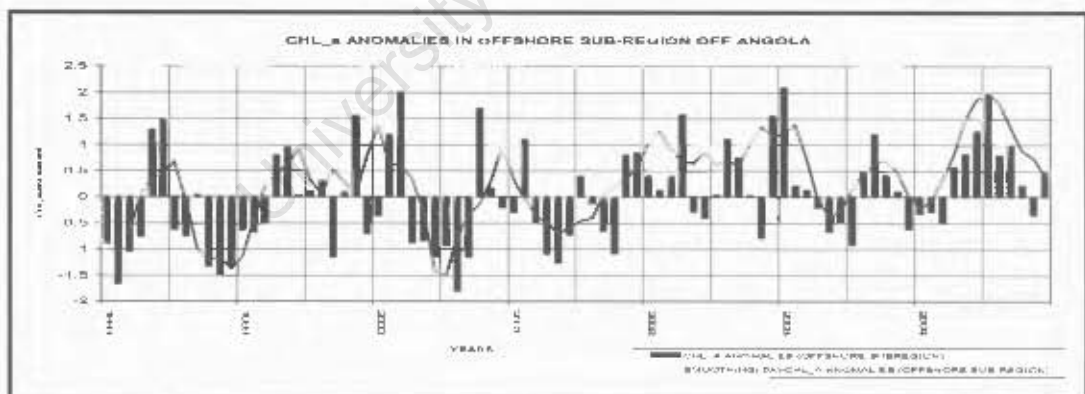


Fig.IV-44 Chlorophyll anomalies in the offshore sub-region off Angola

4.6 Position of the thermal Angola-Benguela Front

The Angola-Benguela front is an important oceanographic thermal feature and it is considered as a convergence zone between the Angola and the Benguela currents. This front fluctuates between 15°S and 18°S.

In order to define its monthly positions and its inter-annual variability, monthly Meteosat-SST composites (1987-2002) were used. The mean-SSTs were computed between 10°S and 18°S, at each scan-line (≈ 22 pixels/lat) using 60km (≈ 1 pixels) as the offshore distance. More details are provided in chapter III.

The average position of ABF (Angola-Benguela front) shows that it fluctuates between 16°S and 17°S (Fig.IV 45). It is obvious that in summer of the southern hemisphere (January-April), the ABF is in its most southern position shifting from 16.60°S to 16.86°S with a peak in March while in Winter (May-September), it is in its most northern position (16.45-16.72°S) with a trough in August and October. On the average, the range of the shift is just 0.41°S.

The largest fluctuations of the front are observed in winter (July, August and September) where the standard deviations (Fig.IV 46) vary from 0.6 to 0.8 except for May and June (0.5 for both) while in summer (December, January, February and March), the fluctuations are small with a standard deviation varying from 0.3 to 0.6 except for April (0.6). Throughout the years (1987-2002) of study, the temperature at the ABF (Fig.IV 47) complies with the tropical patterns: high temperatures in summer (January-April) ranging between 20-24°C with a maximum in March and low temperatures in Winter (May, June, July, August and September) ranging between 15-19°C with a minimum in August. This observation was not just on the average but also on yearly basis.

Following strictly the principles established (see methodology), it was observed each year a slight shift of ABF either southwards or northwards, but just between 15°S and 18°S. Between 1987 and 2002 (Fig.IV 54 & Fig.IV 57), the ABF was in its southernmost positions (17-18°S) in 1987-1989 (May-August), in 1995-1996 (February-April), in 1996-1997 (August-December), in 1999 and 2001 (February-April) but the northernmost positions were observed in 1990-1991 (August-September), in 1993-1994 (July-October) and in 2000-2002 (July-November).

It looks like a cycle of every 4 years although within a year there are shifts in different directions. But one looks at the anomaly, taking the ABF average at 16°S the southward shift has its maximum at 18.30°S and the northward shift has its minimum at 14.30°S. ABF should be in summer of each year above 16°S (south) and be under (north) in winter. But other factors (i.e. El Niño, weather) can affect the sea and break the rules.

The temperature anomalies (Fig.IV 55) at the ABF show negative anomalies (low temperatures) when the ABF is in its most southern positions (1987-1989) and in 1997-1998) but they show positive anomalies (high temperature) when the ABF is in its most northern positions (1990-1991, 1994 and in 2000-2001). This rule was not observed in 1992, 1995 and 1996. In 1992 which was considered as a cool year, the ABF was in its most northern position (14.30°S) but the temperature has a low anomaly (-1.5°C). In 1995 and in 1996

which were considered as an El Niño years, the ABF reached its most southern position (17°S) but the temperature in both years had a positive anomaly of about (1°C).

4.7 The Angola-Benguela biological Front obtained from SeaWiFS Chlorophyll-a data.

It is obvious that the ABF as a thermal oceanographic feature, can be detected only and simply with SST (temperature). Besides the temperature, Shannon et al., (1987) and Meeuwis & Lutjeharms (1990) could identify the front with salinity data up 200 km offshore and down to 50 m depth. The assessment of the concentration of Chlorophyll at the ABF has been done by various scientists (John et al., 2004; Mitchell-Innes, 2001), but this biological parameter has never been used to detect the position of the ABF (Mitchell-Innes, 2001?).

This particular research attempts to use chlorophyll to detect the position of ABF according to the principles established in chapter III (Data and Methods).

Monthly SeaWiFS chlorophyll composites (1998-2004) were used to compute the mean-chlorophyll between 10-18°S, at each scan-line (25 pixels/latitude). The offshore distance was 60km (13 pixels). The methodology is based on the identification of the highest chlorophyll gradient, which is the position of ABF (chlorophyll-a).

Using the first approach (see methodology) throughout the seven years, it was possible to identify two fronts (Fig.III 11a-16a), one with a low magnitude at 15-16°S and the second with a high magnitude at 17-18°S. In terms of percentage the first chlorophyll gradient represents less than 50% of the second. Automatically the second peaks are rejected which in fact will not give reliable results. For this reason, a second approach was adopted which only and simply consider the closest peak.

It is believed that the first front observed at 16°S of weak intensity was connected to the thermal Angola-Benguela front while the second observed at 17-18°S was connected to the upwelling front of Cape Frio (Shannon, 1987).

The results (Fig.IV 50) show a gradual and steady shift southwards from January reaching its southernmost position in July (16.2-16.9°S). From August to December, there is change of direction; the front starts to move northwards (16.8°S) back to its initial position in December (16.1°S). The shift is very slow from one month to another (0.20°S month⁻¹ in maximum). The concentration of chlorophyll (Fig.IV 52) is the lowest in March (1.4 mg m⁻³) which is the warmest month of the year and in this month that the ABF (SST) reaches its most southern position (Fig.IV 49). But the Chlorophyll reaches its maximum (5.1 mg m⁻³) in October.

As believed previously, the ABF (SST) and ABF (chlorophyll) do not have the same pattern (Fig.IV 49), but it is observed that when the ABF (SST) moves southwards, the ABF (Chlorophyll-a) moves northwards. From January to June, the ABF (SST) is in southern position (16.61-16.7°S) while the ABF (chlorophyll-a) is in northern positions (16.2-16.6°S). From July to October, the ABF (chlorophyll) is in southern positions (16.9-16.6°S) while the ABF (SST) moves northward (16.6-16.44°S). Fig.IV 59 shows two maps: one showing the ABF (SST) from 1987-2002 and the other, the ABF (chlorophyll-a) from 1998-2003. Both present the same range of fluctuations: 15-18°S with the mid-position at 16°S.

The position of the ABF is not the same at a given time from both parameters; in most cases when the ABF (SST) is in its southernmost position, the ABF (chlorophyll-a) is in

its northernmost position except in 2000-2001, where both moved in the same direction. Time-series of chlorophyll was very short (7 years) in order to draw scientific conclusions.

The same figure (Fig.IV-59) shows the northernmost positions of ABF (chlorophyll-a) in 1999-2000 (February-May, October-December) while the southernmost positions occurred in 2001 (July), in 2002 (July-December) and in 2003 (January-December). The largest fluctuations (Fig.IV 52) of the ABF (chlorophyll) were observed from August to December (standard deviation: 1.178-1.4018) while the smallest were observed from January to May (standard deviation=0.94-1.17).

4.8 Diagrams relative to positions of the ABF

4.8.1 Thermal (SST) and biological (Chlorophyll) ABF

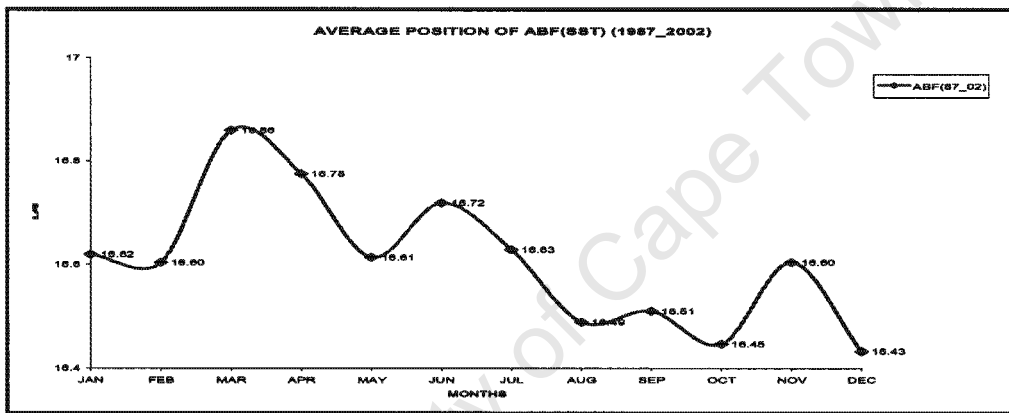


Fig.IV-45 Average position of ABF (SST) (1987-2002)

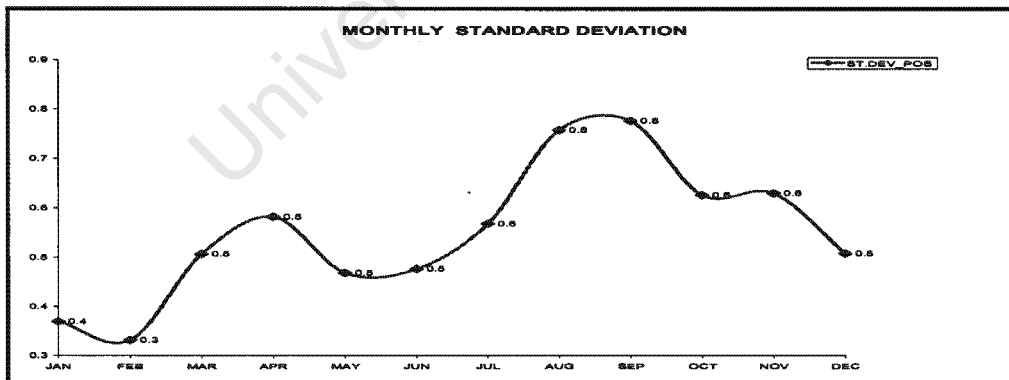


Fig.IV-46 Monthly Standard deviation of ABF (1987-2002)

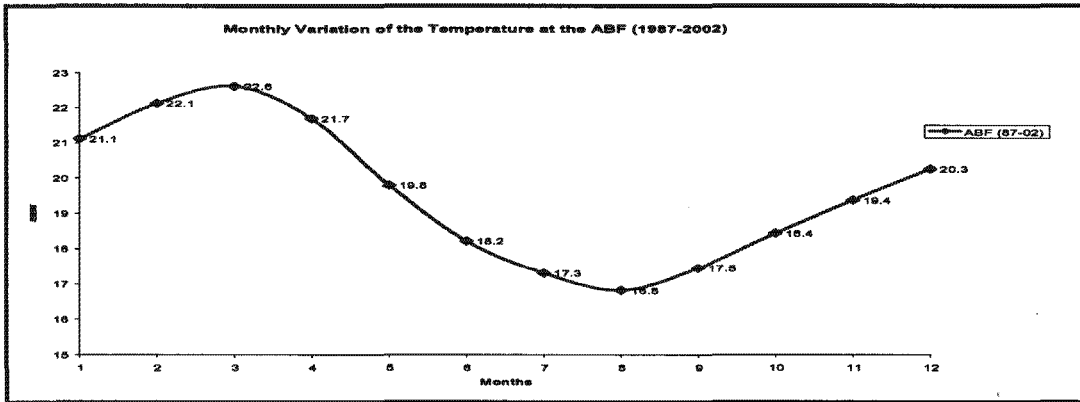


Fig.IV-47 Temperature at ABF (1987-2002)

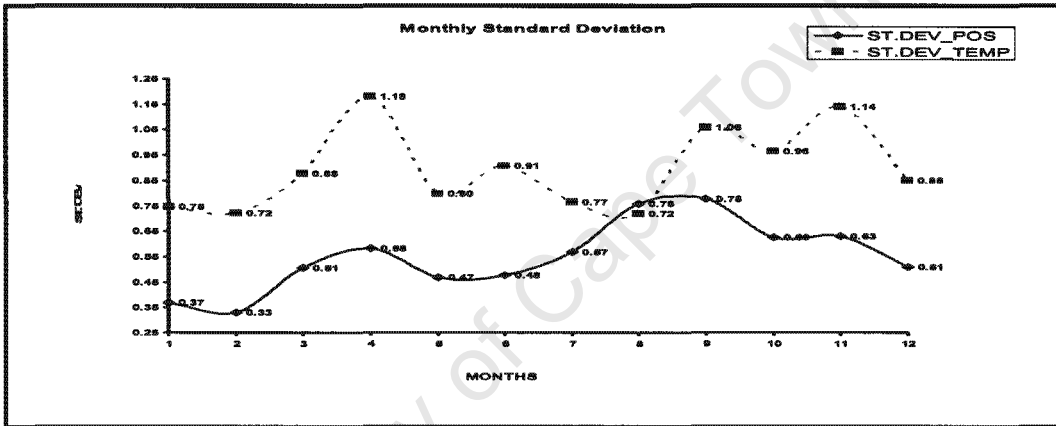


Fig.IV-48 Monthly standard deviation of the ABF and Temperature at the ABF (1987-2002)

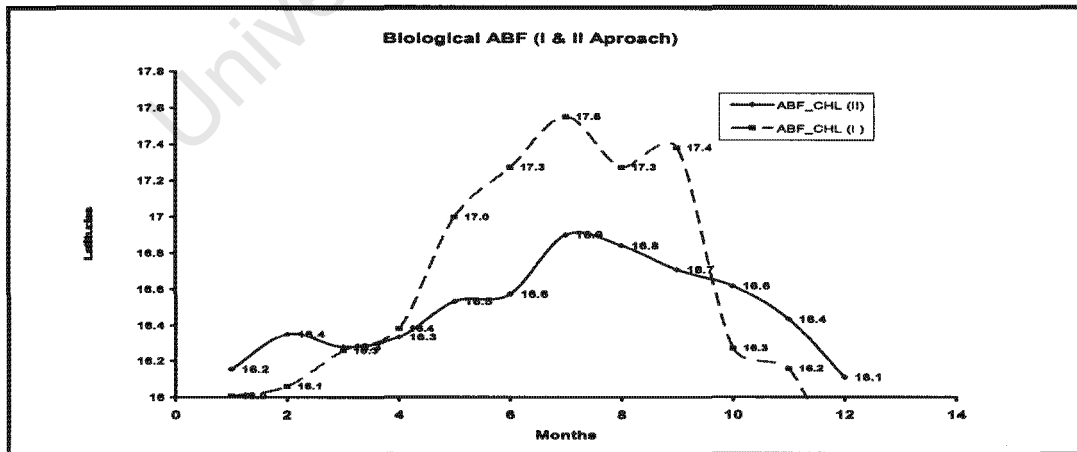


Fig.IV-49 Biological ABF (Comparison between the two approaches)

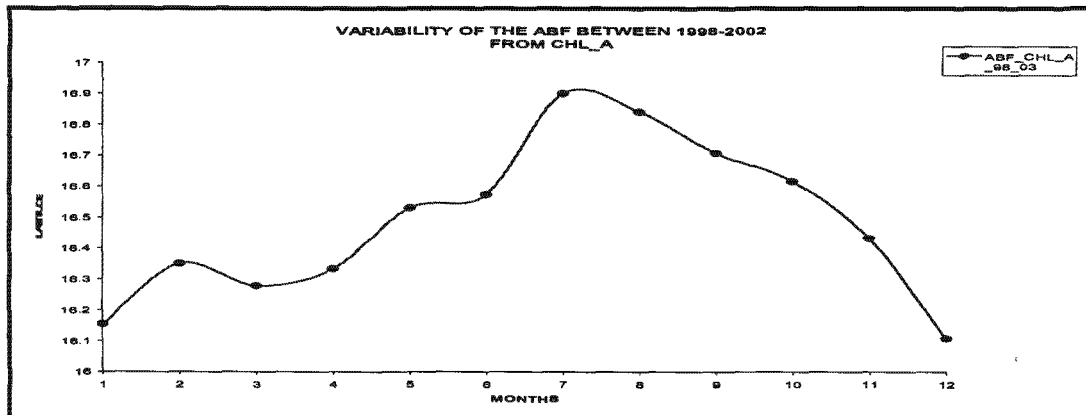


Fig.IV-50 Average position of ABF (Chlorophyll) (1998-2003)

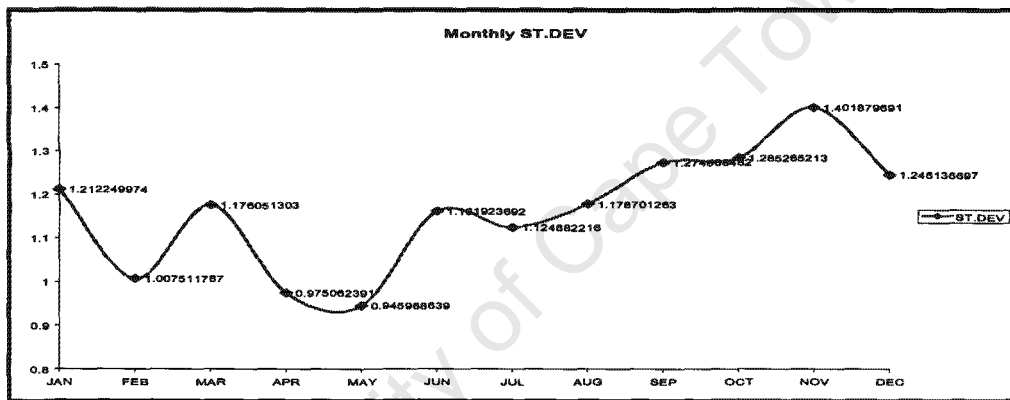


Fig.IV-51 Monthly Standard deviation of ABF (Chlorophyll) (1998-2003)

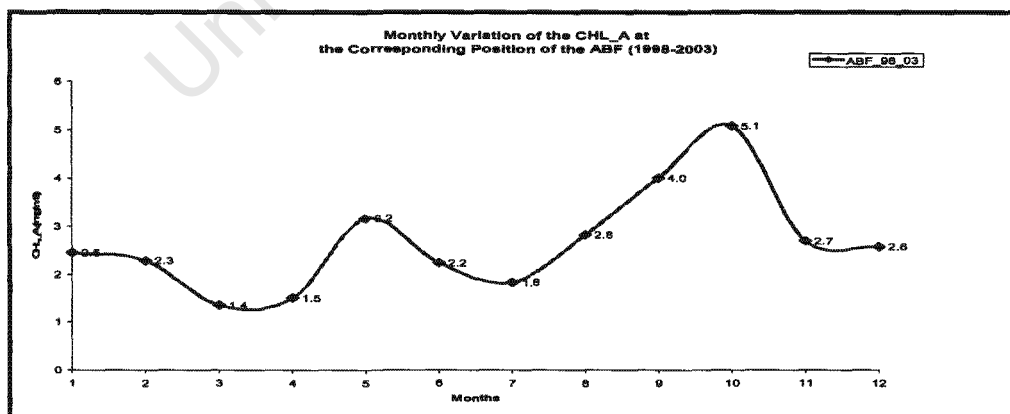


Fig.IV-52 Concentration of Chlorophyll at ABF (1998-2003)

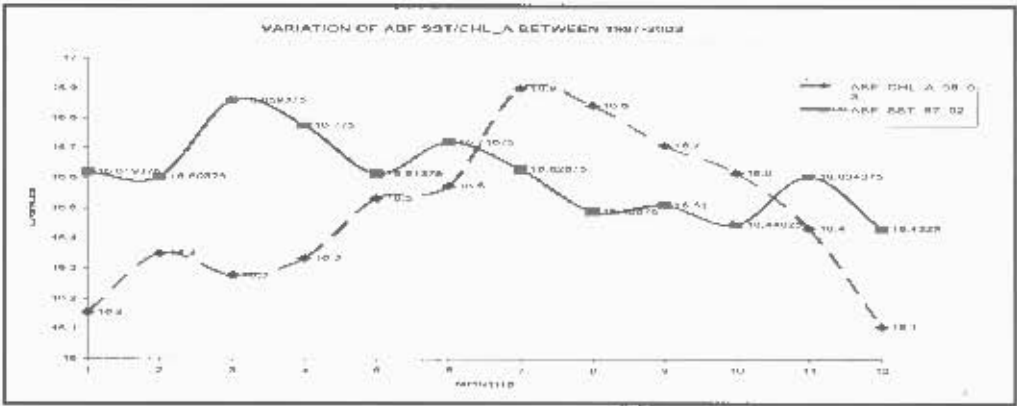


Fig.IV-53 Comparison between ABF (SST) and ABF (Chlorophyll)

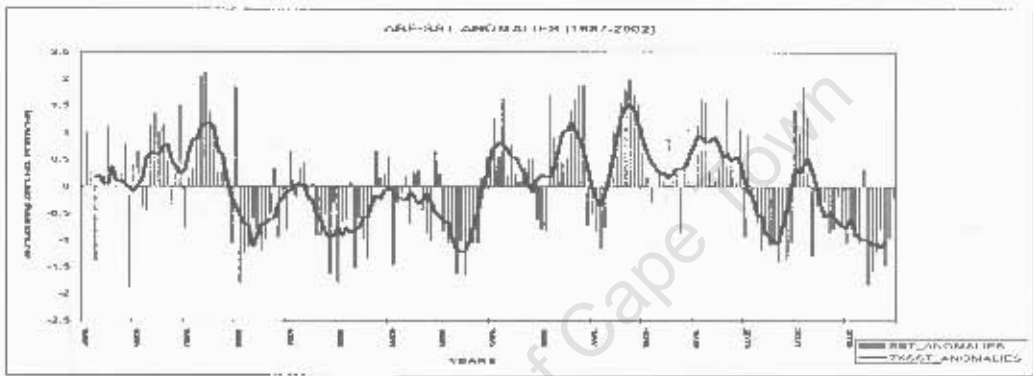


Fig.IV-54 SST anomalies at ABF (1987-2002)

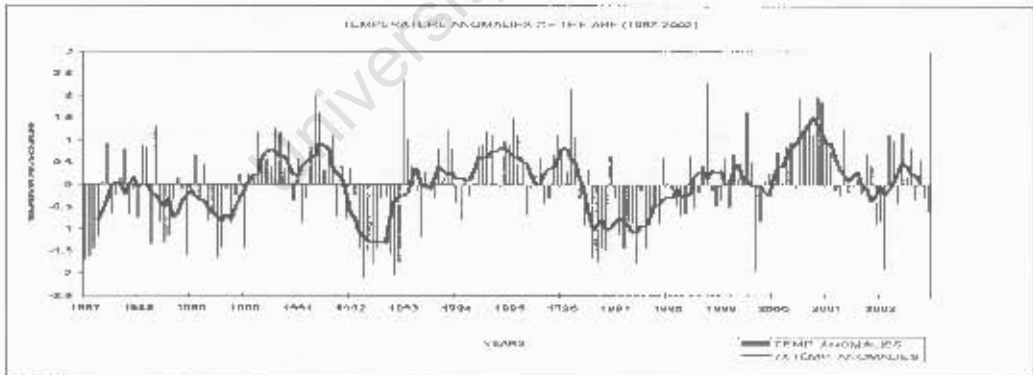


Fig.IV-55 Temperature Anomalies at ABF (1987-2002)

Chlorophyll anomalies at ABF (1998-2003)

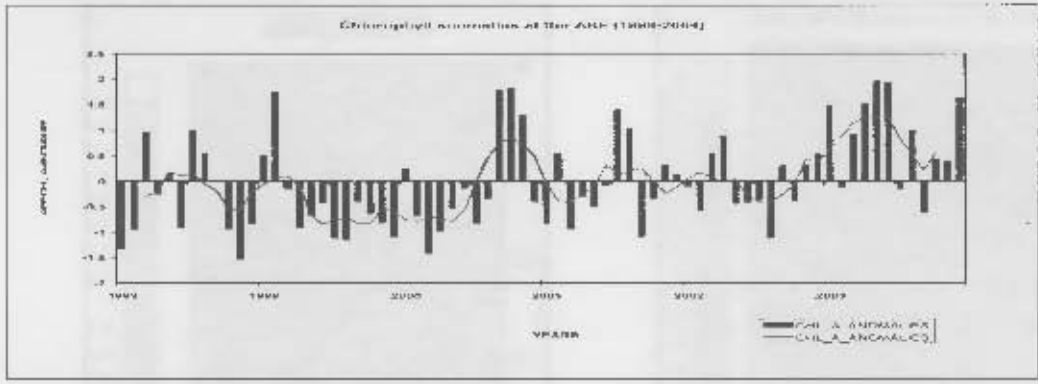


Fig.IV-56 Chlorophyll anomalies at ABF (1998-2003)

ABF - CHLOROPHYLL ANOMALIES (1998-2003)

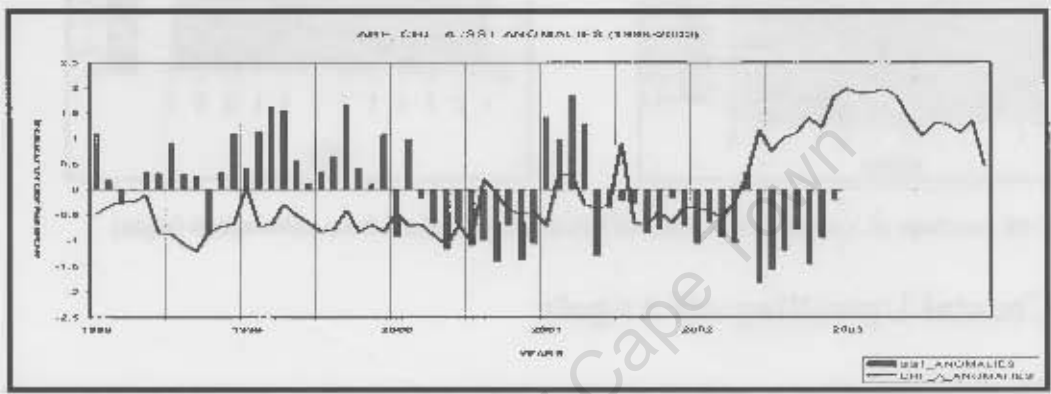


Fig.IV-57 Chlorophyll and SST anomalies at ABF (1998-2003)

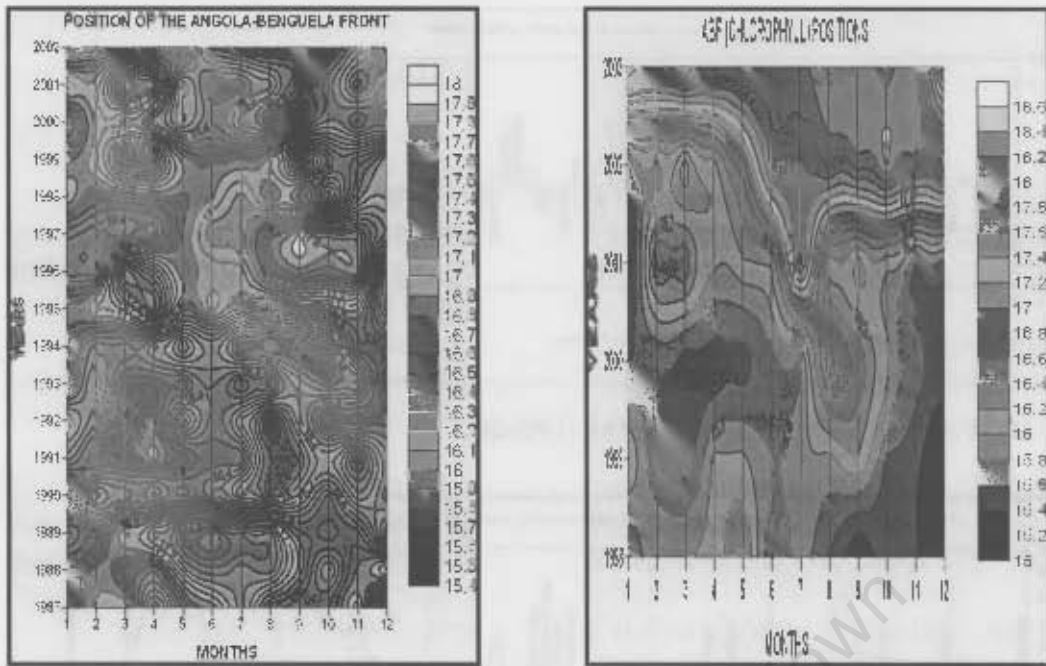


Fig.IV-58 Positions of ABF obtained from SST (left) and obtained from chlorophyll (right)

4.9 Coastal Upwelling off Angola

Coastal upwelling as explained earlier is an oceanographic process, which consists in a vertical motion of cold water, rich in nutrients to the surface layer. This upwelling happens only when the driving force, the windstress is strong enough to move offshore the surface and coastal warm water. The wind blows parallel to the coast and because of Coriolis force; the Ekman transport is perpendicular to the coast.

This particular research does not aim to make a deep study of coastal upwelling. Instead, it is limited to locate upwelling cells off Angola regardless of windstress, coastal topography or other factors which can affect its magnitude, extension and frequency of occurrence.

Hardman-Mountford et al.,(2003) used a simple method, which computes the upwelling index as an SST-gradient between the onshore-SST and the offshore-SST. Negative SST-gradient indicates an occurrence of upwelling (cold water at the coast) and positive SST-gradient is warm water (no upwelling).

Three main upwelling cells were identified (Fig.IV 59 & Fig.IV 61): Cabinda (5-5.30°S), Ambriz (7-8°S) and Cunene (16.5-17.5°S). The cell names are connected to the latitudes where the cells are located. Lutjerharns & Meeuwis (1987) have identified the same cells (same latitude) off Angola and accidentally used the same names (Cabinda, Luanda and Cunene). The cell situated at 7°S, is off Ambriz while Luanda is situated at 9°S. This study will use "Ambriz" instead of "Luanda" as termed by Lutjerharns & Meeuwis (1987), although unknown in the world.

The only wind-induced upwelling cell off Angola is that of Cunene (Shannon, 1985, Boyd, 1987; Lutjerharns & Meeuwis, 1987; Hardman-Mountford et al., 2003; Risien et al.,

2004), Cabinda and Ambriz cells are believed to be driven by Equatorial Kelvin waves (Berrit, 1976; Picaut, 1983; Ajao & Houghton, 1998; Hardman-Mounford et al., 2003).

Cabinda cell has a maximum (highest upwelling index) in July (-1.2°C) and a minimum in February-March ($+0.2^{\circ}\text{C}$) and in October ($+0.01^{\circ}\text{C}$). Ambriz cell has also a maximum in July (-1.5°C) and a minimum in October (-0.1°C). The upwelling occurring in both cells seems to be permanent all year although the upwelling index is low. Cunene has a maximum in May (-2°C) and a minimum in October ($+0.5^{\circ}\text{C}$). Upwelling occurs in this cell only from January to July and from August to November, the coastal waters are warm (Fig.IV 60)

The upwelling index anomalies (Fig.IV 62-64) made from 1987 to 2002 show periods of no upwelling (warm years) and cold periods (intense upwelling). This observation was made over the three upwelling cells:

Coastal warming (absence of upwelling) was observed in 1987-1989, in 1994-mid-95, mid-97-1998 and in 1999-2001 in Cabinda cell (Fig.IV 59 & Fig.IV 62). While intense upwelling were observed in 1991-1992 (February-April), in 1995 (February), in 1996 (February-April) and in 1997 (February-April) corresponding to cool years.

In Ambriz cell (Fig.IV-60, 63), the whole period is made by short fluctuations of upwelling indices (-0.5°C ; $+0.5^{\circ}\text{C}$) from 1987 to 1989 followed by another period of very short fluctuations (-0.2°C ; $+0.2^{\circ}\text{C}$). But the highest warming started in 1994 up to May 1995.

This high warming was followed by an intense upwelling the same year between June and December. Only in 2000 when another upwelling of high magnitude occurred in this cell just for two months (February-April) followed by a relaxing period.

In Cunene cell (Fig.IV 60 & Fig.IV 64), the only wind driven upwelling of Angola; intense upwelling were observed in mid-89 (January-February), in 1990 and 1992 (January-June), in 1993 (all year), in 1994 (January-April) and at last in mid-2001-2002. Periods relative to coastal warming were observed in 1991 (Feb-Oct), in 1992 (July-Dec), in 1994 (May-Dec) and in 1995 (January-October). A long warming period was also observed from 1997 until mid-2001, followed by another long cool period (2001-2003).

4.10 UPWELLING INDICES.

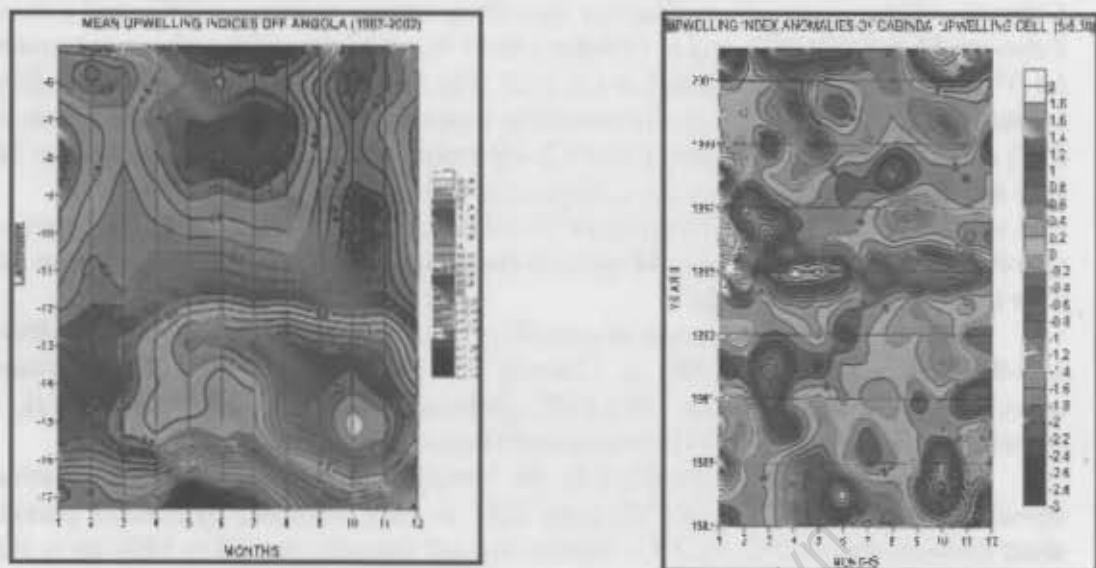


Fig.IV-59 Mean monthly upwelling indices off Angola in (left) and Upwelling index anomalies (1987-2001) of the Cabinda upwelling cell (right)

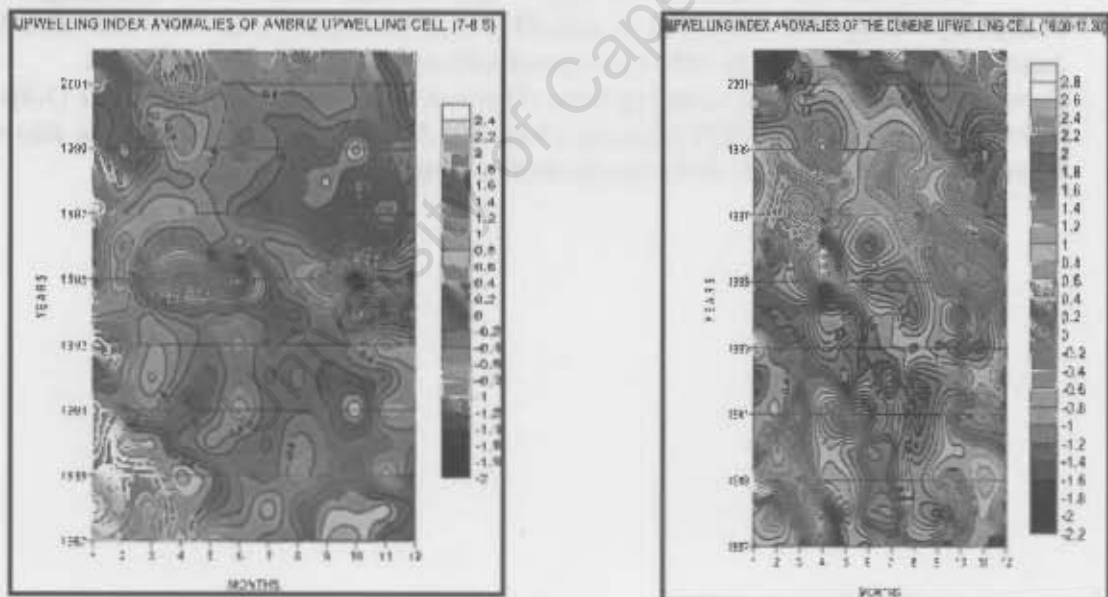


Fig.IV-60 Upwelling index anomalies (1987-2001) of the Ambriz (left) and Cunene upwelling cells (right)

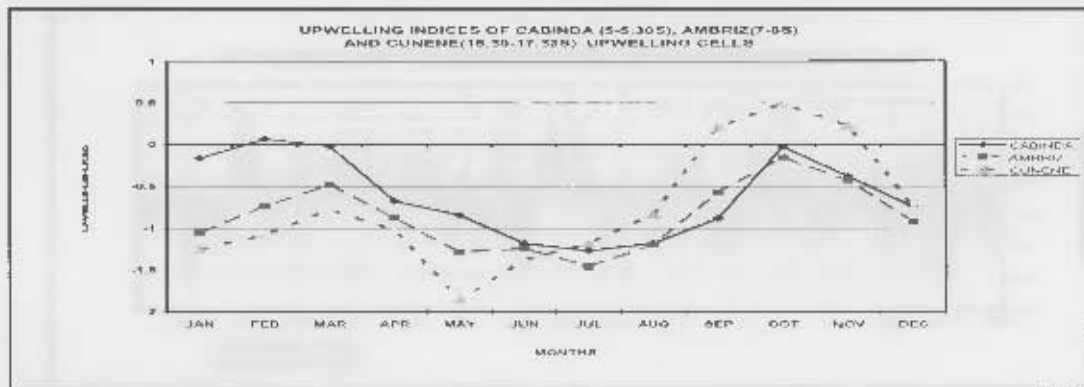


Fig.IV-61 Mean monthly upwelling indices of Cabinda, Ambriz and Cunene upwelling cells

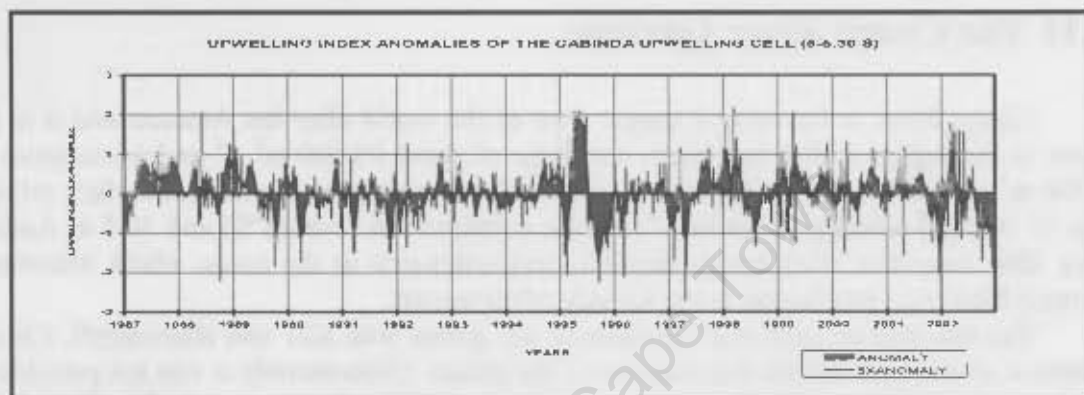


Fig.IV-62 Upwelling index anomalies (1987-2001) of the Cabinda upwelling cell

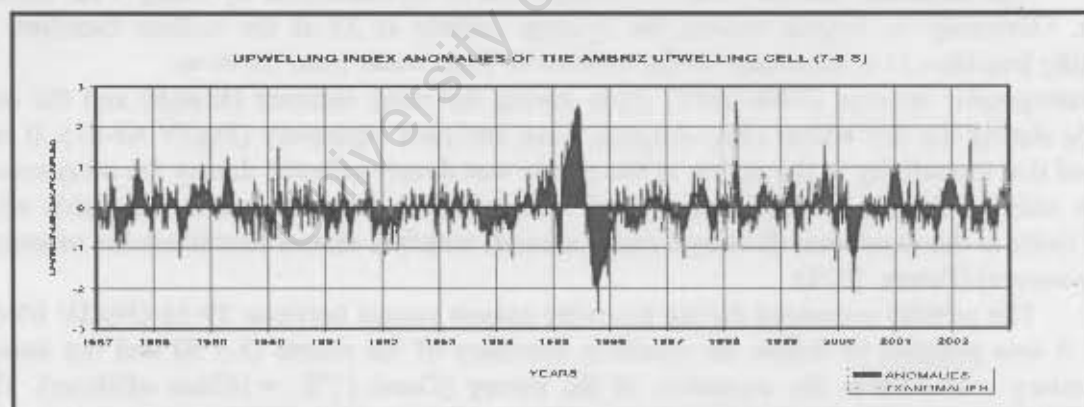


Fig.IV-63 Upwelling index anomalies (1987-2001) of the Ambriz upwelling cell

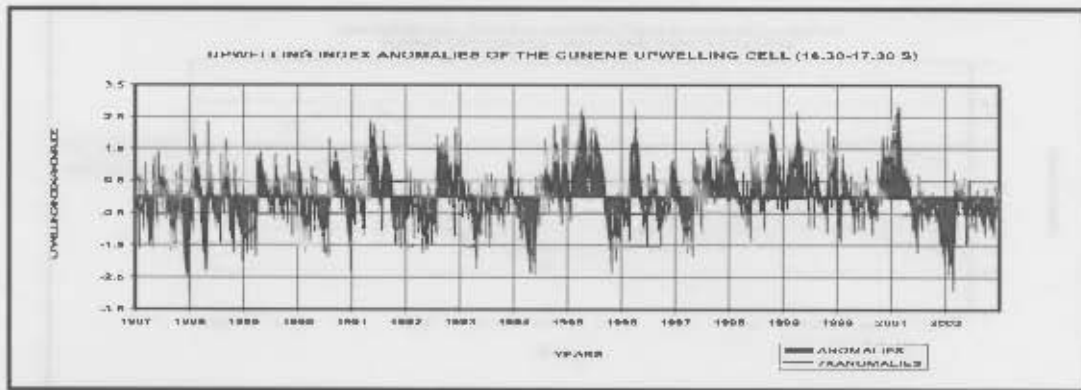


Fig.IV-64 Upwelling index anomalies (1987-2001) of the Guinea upwelling cell.

4.11 The Congo River Outflow.

Congo River is the second largest river of the world after the Amazon and it is the largest in the region with a maximum discharge of about $90,000 \text{ m}^3 \text{ s}^{-1}$ and a minimum of $23,000 \text{ m}^3 \text{ s}^{-1}$ (Peters, 1978). This outflow of fresh water reduces the normal surface salinity from 35 (normal salinity) down to 27.6 at the mouth of the river (6°S) and 30.3 at Ambriz (8°S). This important river brings nutrients and sediments to the ocean which afterwards enhances biological production in the vicinity of the mouth.

The aim was to study the extension of the plume with SST and chlorophyll. Cluster procedure was used to define the structure of the plume. Unfortunately it was not possible to detect the plume either with SST or a combination of SST and chlorophyll (Fig.III 3c). The structure was defined by using only the chlorophyll images (Fig.III 3a, b).

This structure defined with chlorophyll has to be confirmed by using CTD salinity data. Obviously in Angola waters, the average salinity is 35 at the surface therefore all salinity less than 33 is associated to the outflow of fresh water from the river.

Oceanographic surveys (1998-2001) made during the rainy summer (March) and the ones made during the dry winter (July-August) were analysed separately (Fig.IV 65-67). It was found that the salinity in the region of the plume was deeply affected during the rainy season (low salinity) than in the dry season (high salinity). This situation is understandable when one looks at the maximum discharge (rainy season) which is almost four times the minimum (dry season) (Peters, 1978).

The salinity measured during the rainy season ranges between 29-33 (Fig.IV 65-66) and it was possible to define the southern boundary of the plume (8.5°S) and the eastern boundary is limited to the extension of the survey (Coast- $11^\circ\text{E} \approx 165\text{km}$ offshore). This particular research project was limited to 370 km (Fig.III 3) however the plume extends beyond this offshore distance (Bennekoum & Berger, 1984; Iperen et al., 1987; Peters, 1978). The measurements made during the dry season (Fig.IV 67) show high salinity (34.8-35.25) in this particular region and the river outflow does not affect the salinity or affect slightly ($\Delta \text{salinity}=0.45$).

Since the objective of the research was to use only and simply satellite derived images, it was necessary to find out how chlorophyll is associated to salinity in the plume (Fig.IV 68). CTD data are limited to oceanographic stations; therefore few pixels of chlorophyll could be used to match the salinity data.

Fig.IV 70 shows more concentration of chlorophyll between 33.5 and 35 during summer and during winter (Fig.IV 71), chlorophylls are associated to salinity between 35.7-35.8. This study did not allow deciding whether chlorophylls were associated to low or high salinity. Obviously, fig.IV 2 shows high concentration of chlorophyll all year in the Congo River plume either with high or low salinity. Two other plots (Fig.IV 68) were made in order to analyse the correlation existing between the concentration of chlorophyll-a with salinity and SST. The first one shows the salinity overlaying the chlorophyll in the region of the plume defined by the latitude and longitude. It is clear that the high chlorophyll ($> 8 \text{ mg m}^{-3}$) is associated to low salinity (31-33). The second one deals with the three parameters in one plot. One can see that the higher concentration of chlorophyll-a ($14\text{-}20 \text{ mg m}^{-3}$) is connected with low salinity (30-33) and low temperature ($25\text{-}27^\circ\text{C}$) during the rainy season (March, 1999). In the same plot, the low chlorophyll ($0\text{-}13 \text{ mg m}^{-3}$) is associated with high salinity (33.5-35.5) and high temperature ($27\text{-}28.5^\circ\text{C}$). These observations match up with Mann & Lazier (1996) statement saying that the chlorophyll-a concentration decreases as the salinity increases. Further details about this matter are provided in the discussion.

4.12 Diagrams referred to the Congo River Plume

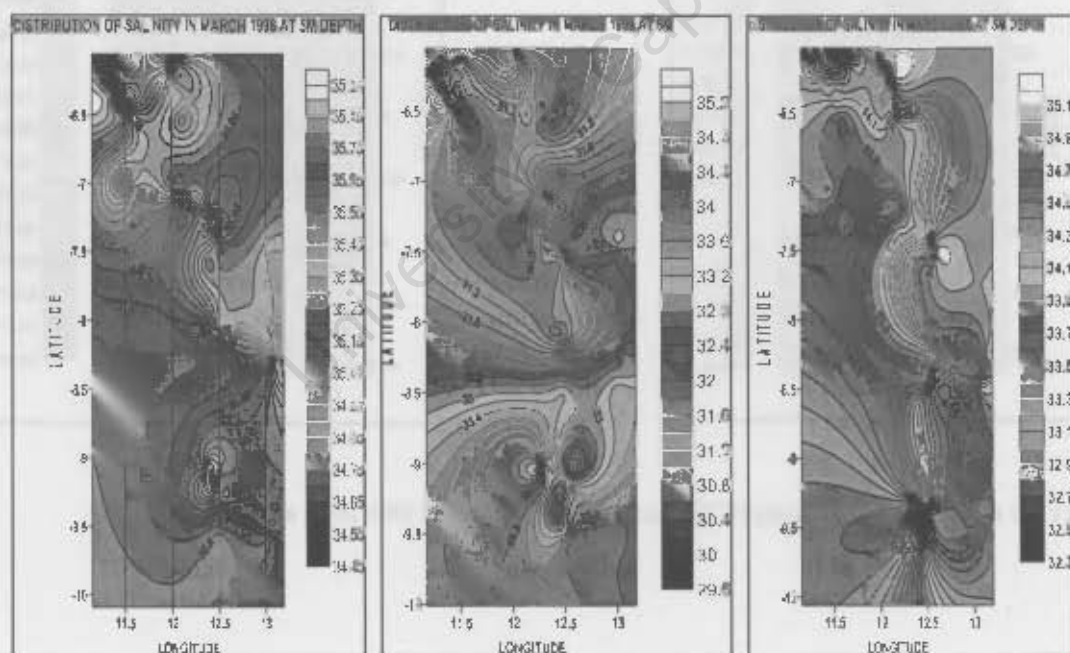


Fig.IV-65 Distribution of salinity (CTD) at 5m depth in March 1998, 1999 & 2000 (rainy season)

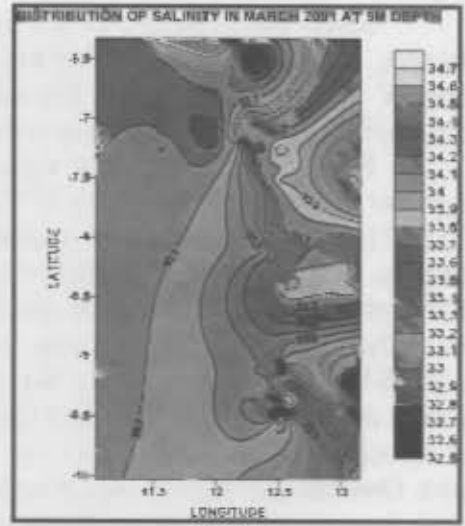
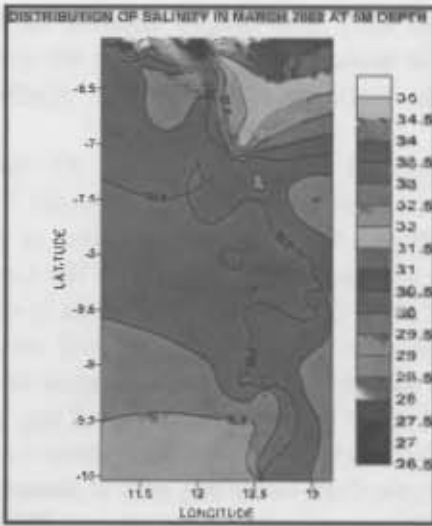


Fig.IV-66 Distribution of salinity (CTD) at 5m depth in March 2001 & 2002 (rainy season)

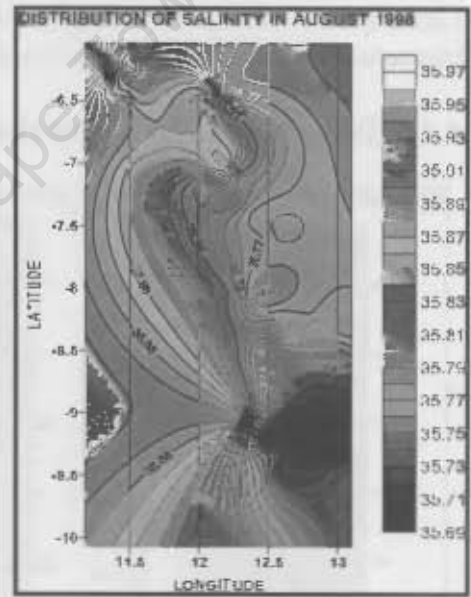
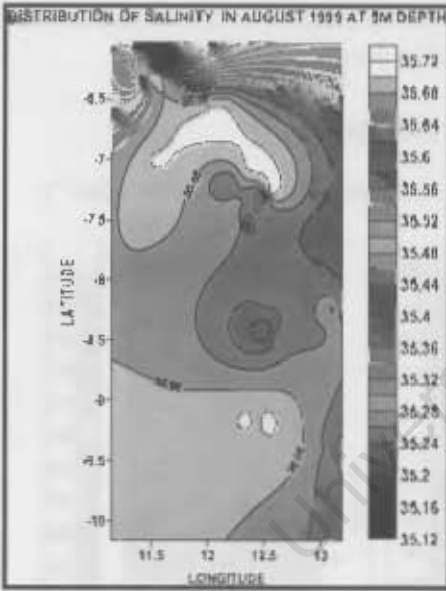


Fig.IV-67 Distribution of salinity (CTD) at 5m depth in August 1999 (left) and in 1998 (right)

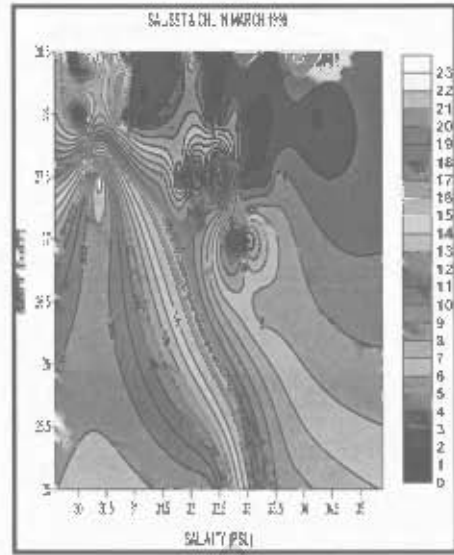
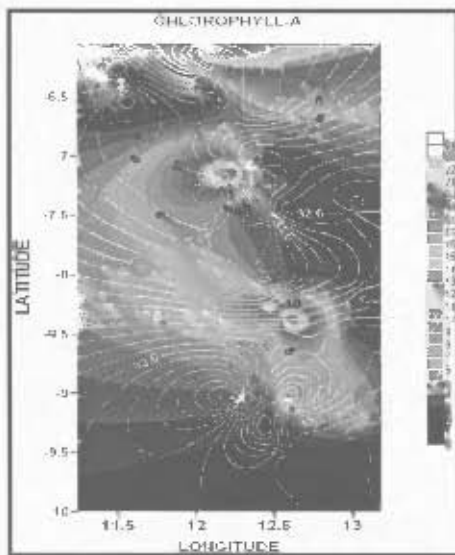


Fig.IV-68 Correlation between salinity (CTD) with SeaWiFS chlorophyll-a (left) and Correlation between SST, salinity (CTD) and chlorophyll (right) in the region of the Congo River plume.

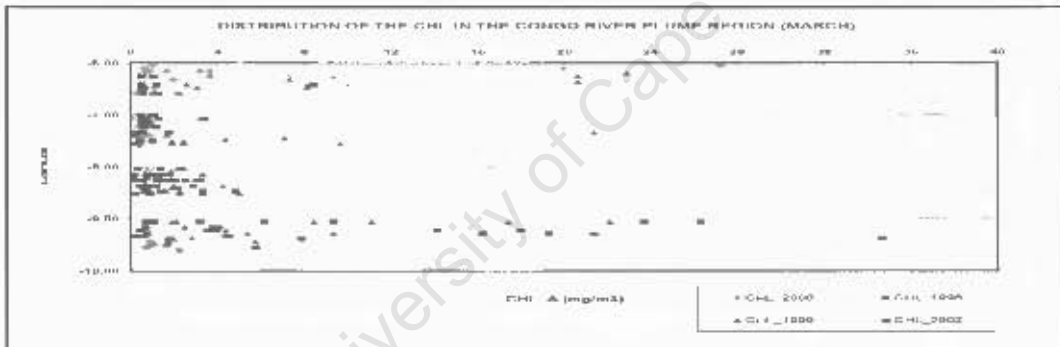


Fig.IV-69 Distribution of Chlorophyll-a in 1998-2000 relatively to the salinity (CTD stations)

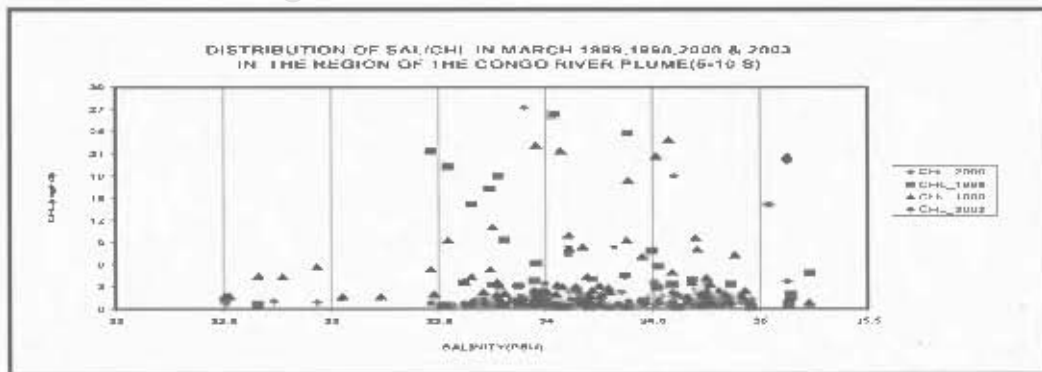


Fig.IV-70 Distribution of Chlorophyll versus salinity (CTD) in March 1998, 1999, 2000 & 2002

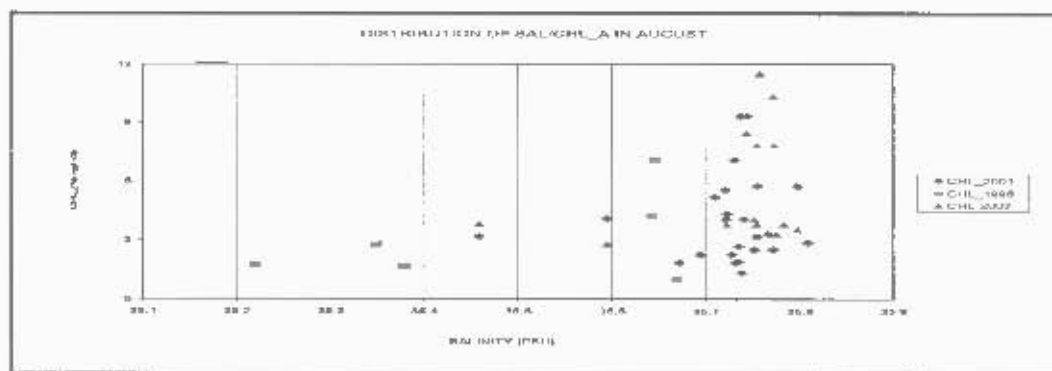


Fig.IV-71 Distribution of Chlorophyll versus salinity (CTD) in August 1998, 1999, 2000 & 2002

4.13 BENGUELA NIÑOS

Warm events occurring in the Pacific have their counterpart in the Benguela region. Off Angola, they feature higher temperature and low salinity relatively to normal. The thermocline depth deepens and heavy rainfalls are recorded (Gammelsrød et al, 1998). Shannon et al. (1986) and Boyd et al. (1987) reported the intrusion of warm and saline waters from Angola into the Namibian Coast in 1984. Other well-documented Benguela Niños occurred in 1934, 1949, and 1963. The last well-documented El Niño occurred in 1994/95 and Gammelsrød et al.,(1998) gave a thorough description of the event.

This particular research does not aim to study the physics of “El Niño” but just to detect the “warm and cold periods” related to Benguela Niños and Ninas. Some of them are well documented, others not. It is obvious that not all warm or cold events are considered as Niños.

A warm event along the Angola coast is not a Benguela Niño unless it substantially perturbs the ABF and impacts the Namibian coast.

According to the Climate Prediction Center (2006), a warm event is regarded as an El Niño only if the temperature anomaly is positive and is greater than or equal to $+0.5^{\circ}\text{C}$. A cold event is La Nina if the temperature anomaly is negative and is less than or equal to -0.5°C . In both cases, to be classified as a full-fledged “El Niño” or “La Niña” episode, these thresholds must be exceeded for a period of at least five consecutive months.

This phenomenon affects all oceanographic (temperature and salinity, Angola-Benguela front, upwelling indices, Congo River plume), meteorological (atmospheric temperatures and rainfalls) and biological (phytoplankton, zooplankton and fish abundance) features.

The SST anomalies (Fig.IV 37-40) obtained in each sub-region off Angola allow detecting the warm and cold events from 1987 to 2002:

Three warm events were recorded during this period:

In 1987-1989 (January-December) with SST anomalies (-0.5°C , -1.2°C)

In 1994 (Oct-Dec)-1995 (Jan-May) with SST anomalies (-0.7°C , $+1.2^{\circ}\text{C}$)

In 1998-2000 (Jan-Dec) with SST anomalies ($+0.9^{\circ}\text{C}$, -1.2°C)

Only two cold events were recorded during this period.

In 1996 (Sept-Dec)-1997(Jan-May) with SST anomalies (-0.8°C , -1.4°C)

In 2001(Aug-Dec)-2002 (Jan-Dec) with SST anomalies (-0.7°C,-1.4°C)

These observations were made only in northern and coastal sub-regions since warming or cooling does not affect the offshore region situated at about 170 km away of the coast.

Warm period (1987-1989)

This warming was observed in the northern and coastal sub-region of Angola. The temperature anomalies at the surface layer ranges between +0.5°C to 1.2°C and last three years without interruption.

During this period, the Angola Benguela front (Fig.IV 54) was further south (17-18°S) and no upwelling was observed in any of three Angolan upwelling cells.

Warm period (1994-1995)

As the previous El Niño, this warming was observed in northern and coastal sub-region. Off Angola it started earlier in October 1994 and ended in May 1995. It lasted almost nine (9 months). Between June-December'95, this warming died out and appeared again in the first quarter of 1996. Benguela Niño '95 is discussed fully in Gammelsrød et al., (1998).

In order to see the effect of El Niño which occurred in 1994/1995, mean-SST were computed at each scanlines from 6°S to 18°S with an offshore distance of about 60km. SST curves (94/95) were plotted for comparison.

Higher temperatures (Fig.V 73-78) were observed in January-April/95 of about $\Delta T=2^{\circ}\text{C}$ than in 1994, then from May-August, this ΔT was reduced to zero and at last from September to December, $\Delta T < 0$ which means the El Niño took place just in 95 in Angola waters and lasted just four months (January to April 95).

The ABF (SST) anomalies (Fig.IV 54 & Fig.IV 58) show clearly a northernmost position at 14.30-15°S in August-December'94. In early 1995, the ABF reached 17.5°S in April. Comparison made between ABF-94/95, shows that in March and April 1995 (Fig.IV 72 & Fig.IV 74), the ABF reached its southernmost position at 17.14°S and 17.73°S respectively while at the same period of time, the ABF was at 16.33°S and 16.17°S respectively in 1994.

Gammelsrød et al., (1997) could not identify the El Niño at 5m depth in Central Angolan waters but found a large $\Delta T=8^{\circ}\text{C}$ in the same area at 30m depth ($\Delta T = T_{95}-T_{94}$).

The real effect of El Niño was observed in the south of Angola (Fig.IV-37), where the warming started in November 94, continued to increase up to April 95, and ceased from May 95 which was reported earlier.

Salinity at 5 m depth dropped down from 35 in 1994 to 31 in the region of the Congo River plume (Fig.IV-80). Low salinity (32.2) was observed in Luanda due to heavy rainfalls while in Namibia, waters were highly saline.

No upwelling was observed during this warming period, instead coastal waters were highly warm. The upwelling index anomalies in the three upwelling cells (Fig.IV:62-64) showed the highest positive magnitude in the whole time-series (1987-2002).

Warm period (1998-2000)

This warming was steady in coastal and offshore sub-region of Angola, but with fluctuations in the north. The temperature anomalies at the surface layer ranges between $+0.5^{\circ}\text{C}$ to 1.2°C and lasts three years without interruption.

During this period, the concentration of chlorophyll (Figs.IV 42-44) was very low (anomaly $=-0.2, -1$) and the Angola-Benguela front (Fig.IV 54) was further south ($17-17.5^{\circ}\text{S}$) in 1998-1999 but shifted northward in 2000 reaching 15°S . No upwelling was observed in any of the Angolan cells and the salinity went down to 30psu at the Congo River mouth in March 1999 and in March 2000 (Fig.IV- 66).

Cold period (1996-1997)

This cooling started in September 1996 and ended in May 1997 without interruption. The cold event is clear in the north and at the coast, but not in offshore. The temperature anomalies at the surface layer range between (-0.8°C , -1.4°C) and last nine (9) months without interruption.

During this period, the Angola-Benguela front (Fig.IV 55) was fluctuating between 16 and 17.5°S . It moved northwards (15.5°S) just for a short period (January-February 1997) and a strong upwelling (Fig.IV 59) was observed in the entire coast from May-Dec 95. In 1996 and 1997, a slight upwelling was observed in the three cells.

Cold period (2001-2002)

This cooling started in August 2001 and ended in December 2002 with SST anomalies ranging between -0.7°C and -1.4°C . The cold period lasted 16 months without interruption. During this period the Angola-Benguela front (Fig.V 54) was fluctuating between 14.30°S and 16°S . The chlorophyll was high (anomaly= 1.4 mg m^{-3}) in coastal and offshore sub-regions. Strong upwelling (-2°C) was observed at Cunene (Fig.IV 64) but nothing similar was found in Cabinda and Ambriz cells (Fig.IV:62-63).

4.14 Diagrams relative to Benguela Niños

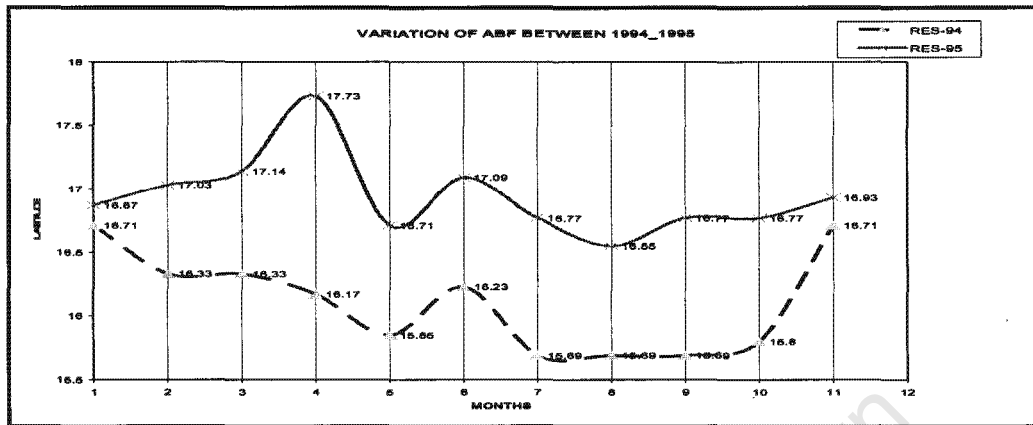


Fig.IV-72 Comparison between ABF (1994) and ABF (1995)

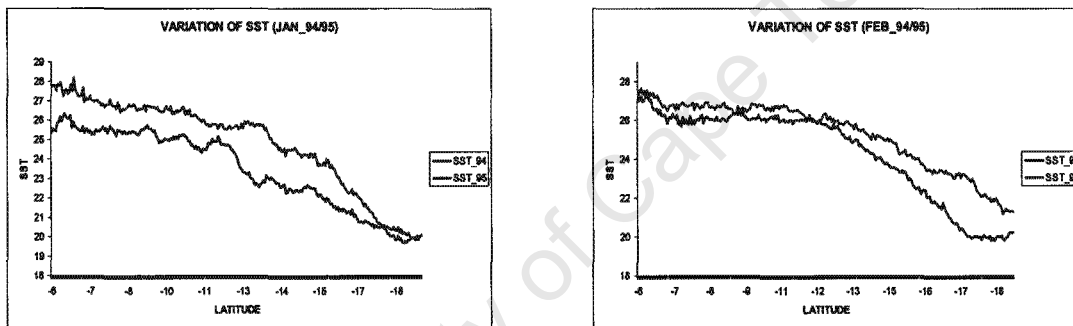


Fig.IV-73 Variation of the Mean SST (94/95) in January and February

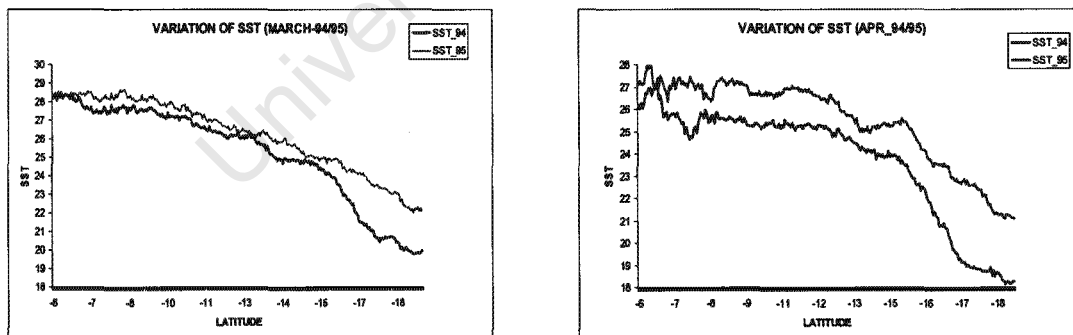


Fig.IV-74 Variation of the Mean SST (94/95) in March and April

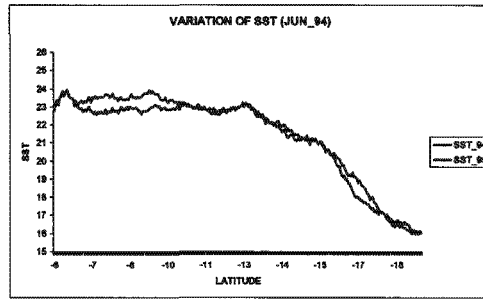
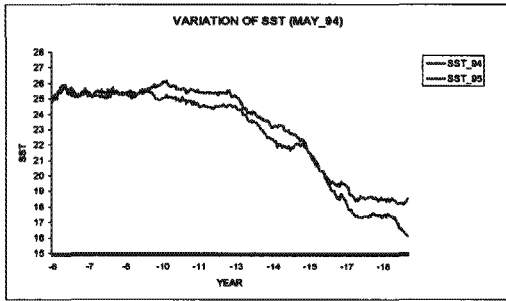


Fig.IV-75 Variation of the Mean SST (94/95) in May and June

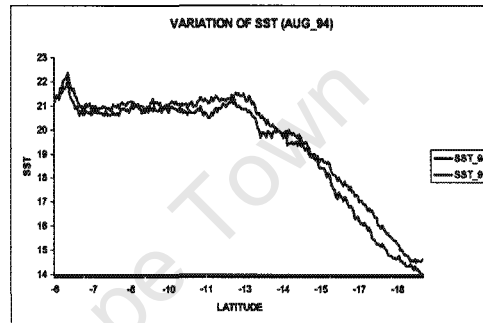
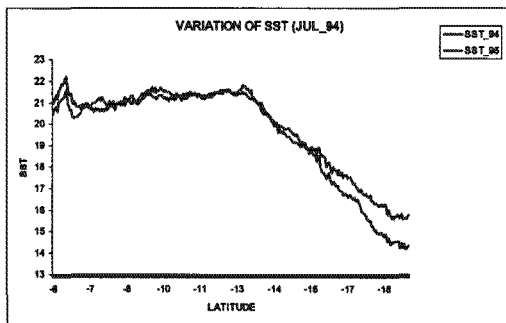


Fig.IV-76 Variation of the Mean SST (94/95) in July and August

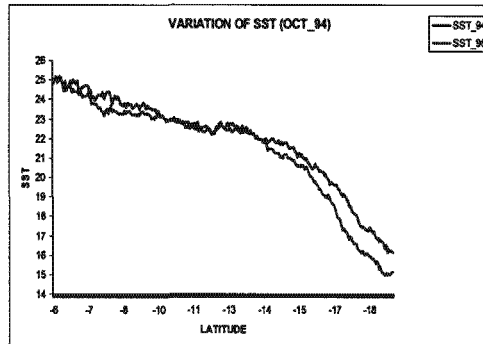
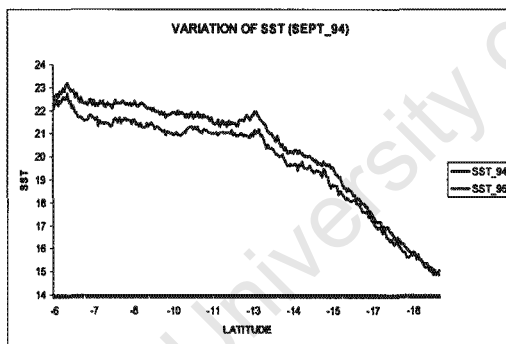


Fig.IV-77 Variation of the Mean SST (94/95) in September and October

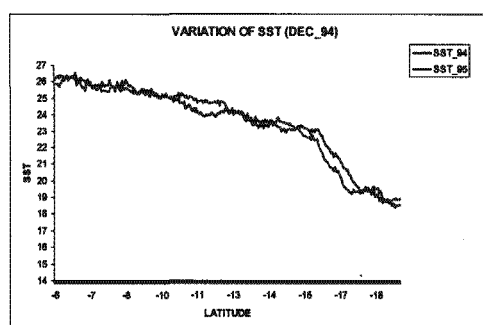
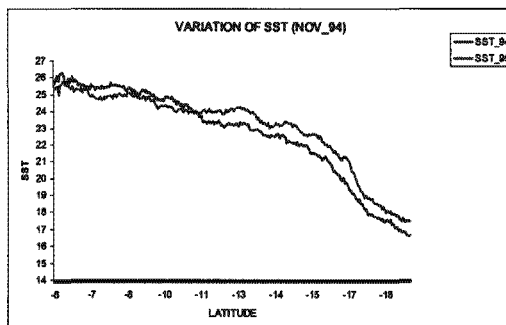


Fig.IV-78 Variation of the Mean SST (94/95) in November and December

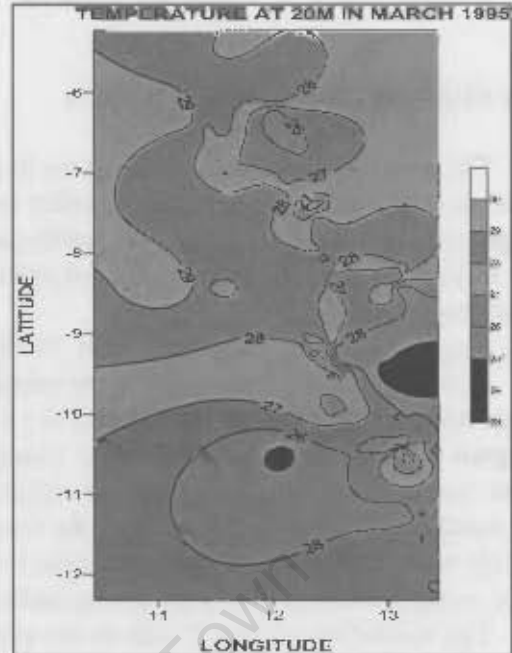
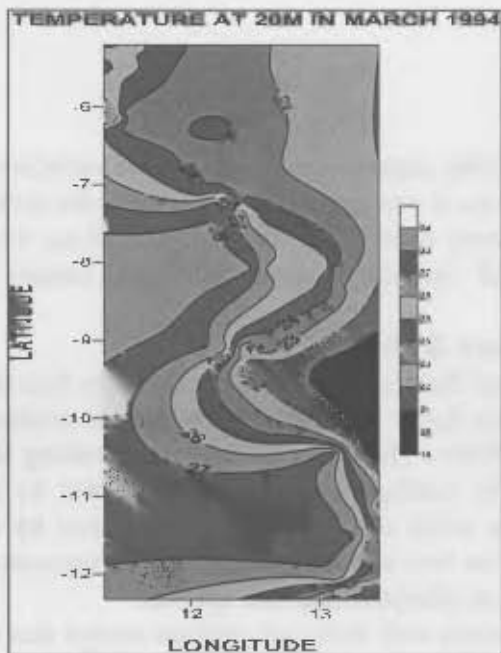


Fig.IV-79 CTD temperature at 20m depth in March 94/95

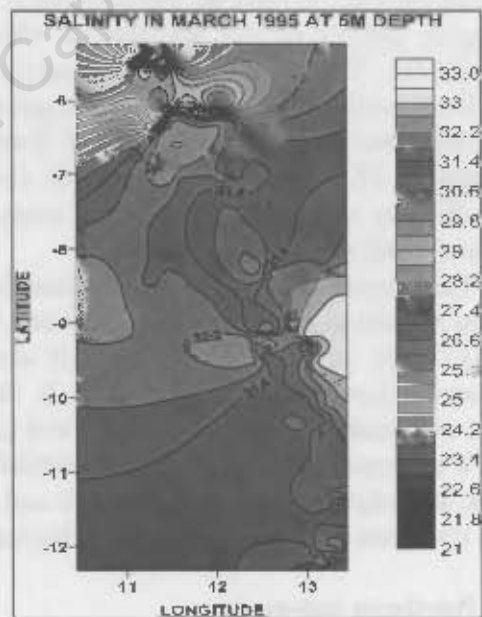
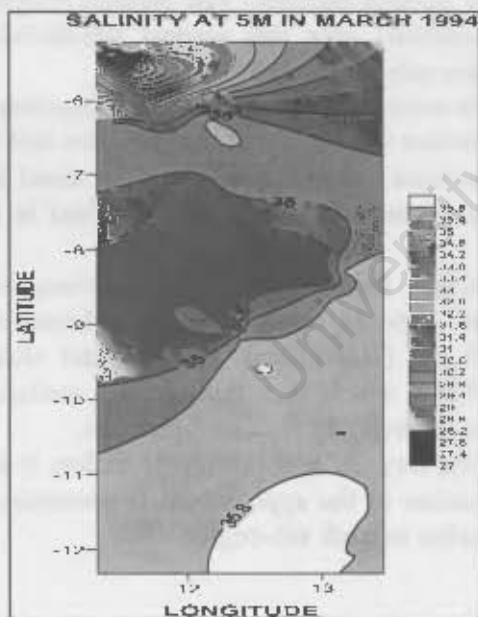


Fig.IV-80 CTD salinity at 5m depth in March 94/95

CHAPTER V DISCUSSION

5.1 SUB-REGIONS OFF ANGOLA

The main purpose of this study was to describe seasonal and inter-annual variation of the marine environment off Angola. In order to do so, it was necessary to partition the area in homogeneous sub-regions. Only two parameters were used (SST and Chlorophyll-a), while some missing parameters (salinity, oxygen and nutrients) could have an impact in partitioning the area.

So far, Angola uses two divisions (Berrit, 1958; Berrit & Dias, 1977):

The first one is based on the Ecosystems and therefore it can be divided into two sub-regions: northern sub-region is between the Congo River and the ABF while the southern sub-region is between the ABF and the Cunene River. The partition was made taking into account the main current affecting the region. The northern sub-region is affected by the south equatorial currents and the Angola currents while the southern is influenced by the Benguela current. As stated in the introduction, the two sub-regions differ in temperature, salinity, oxygen content, rainfalls; phytoplankton, zooplankton and fish species.

The second one is also based on the ecosystems with three sub-regions except that the northern sub-region was divided into two different sub-areas: the northern (Congo River to Luanda) influenced by the Congo River and the equatorial currents and the centre (Luanda-Benguela) influenced only by the equatorial and the Angola currents. The Nansen Program (Norwegian branch of the Institute of Marine Research) uses this second sub-division: northern (5.02 - 9°S), centre (9 -15 °S) and the southern sub-region (15 - 17.33°S).

Both partitioning approaches are good, but in none of them there is an indication of the offshore extension. It is believed that these approaches were made at the coastline and the continental shelf. Most of oceanographic research cruises are made between the coast and 11°E, which is almost 120-180 miles away in maximum. This width (180 miles) is the maximum width of the Angolan shelf.

The results obtained in this research project are far better than the previous ones based on empirical methods. The approach took into account two parameters (chlorophyll and SST) with an offshore distance of about 370 km (200 miles). Besides, the cluster procedure (Bryan et al., 2001; Sneath & Sokal, 1973), which is a multivariate statistical method, was guided by the results observed in the longshore and offshore directions.

The lack of some environmental parameters (salinity, oxygen and nutrients) makes it less accurate. In order to find out limitations and inaccuracies of the approach, it is necessary to analyse common environmental and biological properties in each sub-region.

5.1.1 Northern sub-region

This sub-region with its new boundaries corresponds to the division made or used by the Nansen Program. The area is influenced by the outflow of the Congo River plume and the Equatorial Current and its branches (SEC, SEUC, and SECC).

Berrit, (1964), Molinari (1982), Picaut (1983), Wacogne & Piton (1992), Gordon & Bosley (1990), Peterson & Stramma (1991) just to cite a few, have described the components of the Equatorial currents: South equatorial current (SEC), the South equatorial Under-

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Current (SEUC) and South Equatorial counter Current (SECC). These currents are characterized by high temperature (25-28°C), low salinity affected by the Congo River (29-33) and high oxygen content (5ml l⁻¹). Heavy rainfalls are recorded in this area reaching 180 mm year⁻¹ (Filipe, 1995). Some of the results obtained in this research project and related to the sub-areas will be discussed under other subject: Congo River plume, Benguela Niño, Upwelling indices and the Angola-Benguela front to avoid repetition.

The Congo River is the second largest river in the world and affects strongly the salinity and the primary production of the northern region. Due to oil prospecting, many scientists (Peters, 1978; Eisma & Bennekomp, 1978; Meulenbergh J., 1968) were interested to study the extension of the plume and the sediments transported by the river.

Phytoplankton distribution: the subregion was found to be the most productive in terms of primary production (Cadée, 1978) and it was found that the chlorophyll concentration was the highest off Angola (Boltovosky et al., 1999; Hardman-Mountford et al., 2003)

Upwelling: Cabinda and Ambriz are two upwelling cells identified in the region (Lutjeharms & Meeuwis; 1987). It was found that the windstress was too weak to drive Ekman transport (Shannon, 1985; Riesen et al., 2004) but Berrit (1966), Moore et al., (1978) and Picaut, (1983) found that the upwelling occurring in the north of 15°S, were driven by remote forcing. This remote forcing takes place at the Eastern Atlantic and propagates up to the African coast as Kelvin waves. This hypothesis was largely accepted by many other scientists in the region e.g. Shannon, (1985); Hardman-Mountford et al., (2003) and Ajao & Houghton, (1998).

5.1.2 Coastal sub-region

In terms of fisheries, it is the most important sub-region off Angola. It can be divided into two ecosystems: the Angola system dominated by the Angola Current and the Benguela system dominated by the Benguela Current. The two systems are separated by the Angola-Benguela front.

The Angola current is deeply discussed in depth by Bubonov (1970), Moroshkin et al., (1970), Wacogne (1990) and Peterson and Stramma (1991). They found that the current features high temperature (>24°C), high salinity (>35) and has an average of oxygen content of 5ml/l. The results obtained in this study showed that the SST is bimodal and it is 2°C cooler than the northern region (Fig.IV 34). The temperature (Fig.IV 36) varies between 22° and 26°C in summer and with a minimum of 20°C in winter (August), which agrees with the observations of the authors cited above.

The southern area is dominated by the Benguela Current which was described e.g. by Hart and Curie (1960); Defant, (1961); Shannon, (1985); Stramma & Peterson, (1989); Nelson and Hutching, (1983). The temperature associated with the current varies between 16.5-22 °C in winter and 22-24.5 °C in summer.

The Cunene upwelling cell located in this sub-region (Fig.IV 60 & Fig.IV 64) is the only wind driven upwelling cell and it was found to be seasonal (Shannon, 1985; Boyd, 1987; Lutjeharms & Meeuwis, 1987; Riesen, 2003). Further details are discussed in a separate chapter.

The Angola-Benguela front as well as Benguela Niños are also discussed as a separate chapter later in this document.

The concentration of chlorophyll in this sub-region is midway between the northern and offshore sub-regions. The average concentration in the sub-region (Fig.IV-35) is between 1-5 mg m⁻³. To the south of the ABF, the chlorophyll concentration reaches 10 mg m⁻³. Boltovosky et al., (1999) discusses the distribution of chlorophyll off Angola.

This sub-region is the only one, which has no uniformity. The environment (temperature, salinity, wind, upwelling) and the biota (chlorophyll, phytoplankton, zooplankton and fish species) differ from the north of the sub-region. ABF is the boundary separating the sub-region into two distinct parts. Unfortunately cluster procedure did not allow having a fourth sub-region, since the south of the ABF had several different small clusters. It was not possible to make of each one of them a sub-area. They were afterwards smoothed and are merged in a single sub-area.

5.1.3 Offshore sub-region

With inshore boundary located at 165 km from the coast, this sub-region is not very important in terms of fisheries but oceanographically very important because of the prominent oceanographic feature, the Angola Dome located in it (Mazeika, 1967; Voituriez, 1981; Voituriez & Herbland, 1982; Gammelsrød et al., 1997; Filipe, 1998; Mohrholz et al., 1999 and Veitch, 2004). However as mentioned earlier, the Dome is a subsurface feature, not detectable with SST or surface chlorophyll-a images and will therefore not be discussed.

The SST in this sub-region is much less variable than in the coastal sub-region (Fig.IV 34). During summer, SST in the offshore sub-region are generally 1-2°C cooler than in the near-shore region, while in winter offshore SSTs are warmer than in the near-shore sub-region (Fig.IV 1 & Fig.IV 4).

Chlorophyll concentration in this sub-region is the lower than in the other two sub-regions and ranges between 0.5-1.5 mg m⁻³. Upwelling has less impact at this distance than in the coast therefore biological productivity is low. This sub-region, like the coastal sub-region is divided into two systems by the ABF, which extends to at least 250 km from the coast (Meeuwis & Lutjeharms, 1990).

5.2 CONGO RIVER PLUME

Cluster analysis was used to try and detect the extension of the plume. The procedure did not produce satisfactory results when using SST or the combination of SST and chlorophyll as input variables. This is in agreement with Hardman-Mountford et al. (2003), who found that the Congo River plume could only be detected with chlorophyll-a and not with the temperature or sea level data.

By using only chlorophyll images it was possible to identify the structure of the plume. But these results have to be verified with CTD salinity data, which is an indicator of fresh, brackish or saline water, and have been used along with chlorophyll to detect the plume. This region is characterized by salinity, which is low, and chlorophyll, which is high, compared with other region off Angola.

In this study, it was found that the low salinity (<33) is confined to the plume (Fig.IV 65 & Fig.IV 66) and occur only during the rainy summer (January-April). In the dry winter

content, about ten times higher than that in the slope sediments recovered from elsewhere on the southwest African margin. Only off Cunene River and on the shelf beneath the coastal upwelling area of Walvis-Bay (23°S) does the opal content reach values as high as those in the Congo River fan sediments. This high opal values in the Congo fan are related to riverine input of silicate and to river-induced estuarine upwelling (Van Bennekom, 1996).

Cadée (1978) correlated salinity with chlorophyll and he found that from 15 to 18, chlorophyll-a decreases almost linearly with salinity and has a maximum between 20-34. The reason for this being that freshwater phytoplankton entered with the river discharge give rise to high chlorophyll concentration but the fresh water plankton rapidly dies and disappears as the river water penetrate the ocean and salinities increase. A bloom of marine phytoplankton develops in the plume but it takes time to build up hence a peak of marine phytoplankton biomass is only found when salinity increases to 20. In the region with a salinity of 30 (150-200 km from the river mouth), the plume broadens and a maximum in primary productivity and in diatom cell numbers is found (Cadée, 1978).

Correlation carried out between salinity and chlorophyll-a concentration in this present study (Fig.IV 68) indicate high concentration of chlorophyll in the range of 30-33.5 (brackish water) and low chlorophyll-a concentration in both low salinity water (28-32) and in high salinities (33.5-36). This result agrees with those of Cadée (1978).

5.3 ANGOLA-BENGUELA FRONT

The convergence zone between Angola and Benguela currents is an oceanographic thermal feature, which shifts northwards or southwards according to the season. The results obtained in this study show that in summer of southern hemisphere (January-April), the front moves southwards reaching its southernmost position (18°S) in March. In winter (May-September) it moves northwards reaching the northernmost position (14.5°S) in August. The long term average mid-position is 16.65°S (Fig.IV 45) and the seasonal shift is around 2°S south or north. These results are in good agreement with previous studies (Shannon et al., 1987; Meeuwis & Lutjerharms, 1990; Mohrholz et al., 2001; Hardman-Mountford et al., 2003 and Veitch et al., 2006)

Shannon et al., (1987) found the front around 14-18°S with an extension of 150 km offshore. According to Meeuwis & Lutjerharms (1990), the northernmost position of the front was in June-July (13°S) and the southernmost was in April (17°S) with a mid-position at 16°S. The average temperature at the ABF according to Veitch et al., 2006 is 20.7°C in summer and 18°C in winter with a seasonal variation of $\pm 2.4^\circ\text{C}$ in winter and 4.2°C in summer. In this present study, it was found 22.6°C (March) and 16.8°C (August) with a seasonal variation of $\pm 2^\circ\text{C}$ (Fig.IV 47). Hardman-Mountford et al., (2003) reported to ABF to be between 15-17°S. Hagen et al., (2005) reported the position at distance analysis between 50 and 400 km and also found the mid-position to be at 16°S with a seasonal variation of $\pm 1^\circ\text{S}$. The most recent study of the ABF (Veitch et al., 2006) found that the range of the variation was small in summer (16-16.5°S) and wide in winter (15.5-17.5°S). These results are confirmed by this present study (Fig.IV 55), where in summer (January-April), the position of the front ranges between 16.4 and 17.6°S and in winter (May-September) between 15.4-18°S. This is an observation made in whole time-series from 1987-2002. Also the standard deviation computed on SST gradient in this present study (Fig.IV 48) shows small deviation in summer (0.3-0.6) and wide in winter (0.5-0.8). The mid-position of

the ABF is between 16.65°S (Fig.IV 45) while Veitch et al., (2006) found their mean location at $\approx 16.4^\circ\text{S}$.

The previous observations were made by the use of a time-series (3-20 years) however Gammelsrød et al., (1997), Lass et al., (2000) and Mohrholz et al., (2001) based their observation on a single survey and the results obtained were related to time of the cruise (March-April).

Most of the authors (Mohrholz et al., 2001; Veitch et al., 2006; Meeuwis and Lutjeharms, 1990) consider the local windstress as a driving force for the front displacement while others consider the advection of warm water from the Equatorial current or both of them. The present study considers both factors as the driving force since it is believed that the movement of the ITCZ affects the position of the Angola-Benguela front (Shannon, 1985; Boyd et al, 1987).

This ABF was found to be a permanent feature in this present study during 16 years of observations all authors quoted above have confirmed the fact.

The ABF can also be located with chlorophyll data and is then referred to as the biological front (Mitchell-Innes et al., 2001) in contrast with the thermal front. Their observation was based on a single survey (June/July 1999) and found the biological front to be between 16.5-17°S with the concentration of chlorophyll (water column) reaching 10 mg m^{-3} . The average position of the biological front found in this study in June–July was between 16.6-16.9°S (Fig.IV 50) but the biological front anomalies (Fig.IV 56) show that in June-July 1999, the front was between 15.6 and 15.9°S respectively. The average concentration (1998-2003) of chlorophyll in June-July respectively was 2.2-1.8 mg m^{-3} (Fig.IV 52). In these months (June-July), the biological front is in its southernmost position (17°S) but the concentration of chlorophyll-a is the lowest (2.2-1.8 mg m^{-3}). Unlike the previous authors, John et al., (2004) uses the thermal front that was at 19°S in March 1999, which is a peak position in summer (see results of this study). The chlorophyll values were found between 3-10 mg m^{-3} while the corresponding SeaWiFS chlorophyll at this month was 1.4 mg m^{-3} .

5.4 COASTAL UPWELLING OFF ANGOLA

The Benguela region is among the four major eastern upwelling regions of the world (Shannon, 1985; Andrews & Hutchings, 1980) and only a portion of the Angola coast is part of this biological highly productive region. Three upwelling cells were identified in this present study: Cabinda, Ambriz and Cunene (Fig.IV 59).

Lutjeharms & Meeuwis (1987) identified the same cells (same latitudes) off Angola and referred to them as the Cabinda, Luanda and Cunene cells. The cell situated at 7°S, is off Ambriz while Luanda is situated at 9°S. This study will use “Ambriz” instead of “Luanda” as termed by Lutjeharms & Meeuwis (1987), although unknown in the world.

As discussed earlier, coastal upwelling is driven by the windstress. Only strong windstress parallel to the coast can drive Ekman transport which causes deep cold water, rich in nutrients to upwell to the surface. Among the cells found off Angola, Cunene is the major one with a latitudinal extension of about 1° (118 km) and is the only wind driven upwelling cell off Angola.

Boyd (1987), Hardman-Mountford et al. (2003), Risien et al. (2004) made a study of windstress capable of driving Ekman transport in the region. It was found that from 10-15°S, the area was dominated by light southwesterly wind stress with an average stress of about

0.03 N m⁻² but from 15-18°S, the windstress is strong and consistent reaching 0.2 N m⁻² with peaks in August (0.4 N m⁻²) and May (0.3 N m⁻²).

This stress at the Cunene (0.2-0.4 N m⁻²) is strong enough to drive upwelling, although it is weakened in summer when the South Atlantic anticyclone is further south. This stress is comparable with those observed in Cape Frio (≈0.2-0.3 N m⁻²) and in Luderitz (≈0.3-0.4 N m⁻²). Boyd (1987) found an upwelling windstress varying from 4-10 dyn cm⁻² (1 dyn cm⁻² = 0.1 N cm⁻²) in the region between 16-18°S with peaks in March and September to December. He computed an upwelling index as a gradient between onshore- and offshore windstress and found it to range between -0.10 and -0.20 dyn cm⁻² with a peak in September - December.

All three authors cited above, studied the upwelling through windstress analysis and found the same position for the Cunene cell although there is a slight difference in the seasonality of the upwelling occurrences. In this study upwelling is expressed in terms of an SST based index and the Cunene cell has the highest upwelling index from April to August with a peak in May. Risien et al., (2004) found a peak in windstress in that month while Boyd (1987) and Hardman-Mountford et al., (2003) found peaks in March and in September to December. This study considers the Cunene cell to be located between 16.5 and 17.5°S while the quoted authors have considered the cell to be between 16 and 18°S.

Shannon (1985), Lutjerharms & Meeuwis (1987) and Hardman-Mountford et al., (2003) also studied coastal upwelling off southern Africa by using both temperature and windstress and came to the conclusion that from the equator to 15°S, the windstress is too weak to drive Ekman transport. Then a question arises: what drives the upwelling in northern Angola (Cabinda and Ambriz upwelling cells)? Both cells are permanent but the upwelling index is weaker (0 to -1.5) than that of Cunene. In summer (January-April) and in spring (September-December), the upwelling index is very weak or even absent while in winter (May-August) it reaches the maximum (-1.5°C). One can believe that the cold water found along the coast of Cabinda and Ambriz are due to winter cooling however several authors (Shannon, 1985; Berrit, 1976; Picaut, 1983; Lutjerharms & Meeuwis, 1987 and Hardman-Mountford et al., 2003) refer to these cells as upwelling cells.

Now it is necessary to answer to the question raised earlier. Berrit (1976), Picaut (1983), Moore et al., (1978) suggest that the upwelling occurring in the north of 15°S to the equator is remotely forced by the winds in the vicinity of the northern coast of Brazil. An increase of the easterly wind in the western equatorial Atlantic excites an internal equatorial Kelvin wave. This wave travels along the equatorial waveguide and diverge north and south at the African coast in the form of coastal Kelvin and Rossby waves, becoming trapped by the coast. They also believe that the equatorial Kelvin wave takes at least one month (speed=1 m s⁻¹) to travel from the forcing area (coast of Brazil) to the African coast. The same authors provide further details on this subject.

Shannon (1985), Ajao & Houghton (1998), Hardman-Mountford (2000) and Hardman-Mountford et al., (2003) support the above quoted hypothesis related to the driving force of the upwelling occurring in eastern equatorial African coast.

The northern upwelling cells (Cabinda and Ambriz) are therefore not wind-driven; upwelling index is weak but the concentration of chlorophyll (Fig.IV-2) is the highest (18 mg m⁻³) and almost constant all year round in the band 10 km to 70 km offshore. Off Ambriz, it has a peak in winter 15 mg m⁻³ and a low in summer (7 mg m⁻³). But off Cunene, the chlorophyll concentration is low with a peak (10 mg m⁻³) in September-December (Fig.V-2),

period corresponding to a high in windstress. This concentration is found only at 10 km offshore. At 70 km offshore, it is reduced to 3-4 mg m⁻³.

The high concentration found in the north does not depend only on the upwelling, but as already discussed, is also enhanced by the nutrients transported by the river (Cadée, 1984; Eisma & Van Bennekom, 1978).

5.5 WARM AND COLD EVENTS IN THE BENGUELA REGION

Warm and cool periods identified during 1987-2002 in the Benguela region will be discussed under this research as well as their impacts on the Angola-Benguela front, the Congo River plume and the coastal upwelling. These events were identified in the SST anomalies of the three sub-regions obtained from the cluster procedure. The analysis of SST anomalies showed that warm or cold events occurred in the years described below:

Warm period 1987-1989 (January-December):

The SST anomalies during this period showed positive anomalies ranging between +0.5 °C and 1.2°C. This warm event lasted more than six months and the anomaly was more than +0.5°C therefore it was an El Niño event (Climate Prediction Center, 2006). Besides, Shannon, (1985), Shannon et al., (1986), Mann, (1992) found that during Benguela Niños the ITCZ is shifted further south in the gulf of Guinea while in the Benguela region, it is shifted north and there is a relaxation of local windstress leading to the warming of coastal waters therefore a non-upwelling period.

This warm event was not previously documented in the region, but Hardman-Mountford et al., (2003) consider this period as intermediate between cool and warm period. Then the same authors in their analysis consider 1987 as a cool event. Veitch et al. (2006) only consider 1988 (March-April) as a warm event in this period. Due to the impact on fisheries, this period did not attract scientists; consequently this period is not documented. However in the Pacific, the Climate Prediction Center (2006) classifies Jun-Sept (1986) to Jan-Mar (1988) as an El Niño period with a maximum anomaly of +1.6 °C: in 1987, warming lasted all year from January to December, with anomalies ranging between 1.1-1.6 °C.

In 1988, warming (+0.8 °C) was recorded only in January and February but the rest of the year was regarded as a cool period (April-June to Nov-Jan) with a maximum of -1.9 °C. The year-1989 was considered as a cool year (-0.6; -1.7). It is obvious that warming in the Pacific does not mean warming in the Benguela. Some scientists believe that there is a connection between ENSO and Benguela Niños and warming in the Pacific is advected through Kelvin waves and reach the Eastern Atlantic one year later (Philander, 1981; Binet et al., 2001; Roy & Reason, 2001; Hardman-Mountford et al., 2003, Coldberg et al., 2004).

According to Philander (1981), the connection between Pacific and Atlantic Walker atmospheric convection cells has been suggested as an explanation of the out of phase coupling of the Pacific ENSO and Atlantic Niños/Niñas alternances. Besides, Roy & Reason (2001) studied the relationship existing between the Pacific ENSO and coastal upwelling off West Africa. They came up to the conclusion that “warm events in the Pacific during fall and early winter lead, a few months later, to a relaxed state of the wind-induced upwelling on the eastern side of the Atlantic basin and to warm conditions being observed along the coast of West Africa during late winter and spring”.

However others (Shannon, 1985; Shannon et al., 1986; Mann, 1992) remain skeptical and continue to believe that Benguela Niños are driven by local relaxation of windstress causing a southward shift of the ITCZ. Mann (1992) stated that an attempt was made to link Benguela Niños with ENSOs, however it was unsuccessful since the periodicity of the former is about 10 years whereas the ENSO is just 2-3 years.

During this period, the Angola-Benguela front (Fig.IV 54) was further south (17-18°S) and non-upwelling was observed in any of three Angolan upwelling cells. In March-April (1988), Veitch et al., (2006) observed southward incursion of warm water up to 18°S.

Warm period 1994 (Oct-Dec)-1995 (Jan-May)

The observation made during this period showed SST anomalies ranging between +0.7 and +1.2°C (Figs.IV 37-40). The event started in October 1994 and ended in May 1995. In the Pacific, Climate Prediction Center (2006) observed this warm event between 1994 (Mar-May) and 1995 (Feb-Apr). It means that the abnormal conditions lasted from March to November 1994, and continued in 1995 from January to February. As most modern scientists accept the theory of tele-connection, warming reaches the Atlantic a year later.

Comparing the occurrence of the event in the Pacific and in the south Atlantic, it took just seven months and ended three months earlier.

Besides Benguela Nino'1984 (Shannon 1985, Shannon et al.,1986 Boyd et al.,1987), the anomalous thermal condition observed in 1994-1995 was the most intense and the best documented in the region (Luyeye, 1995; Gammelsrød et al., 1998; Binet et al., 2001).

The results obtained in this research study show $\Delta T = T_{95} - T_{94}$ (Fig.IV 73-78). This ΔT ranges from 1°C to 2°C from September 94 to May 1995. The difference was not large at the surface but at 20 m depth, Gammelsrød et al., (1998) found $\Delta T=8^{\circ}\text{C}$ (Fig.IV 79) and 5m depth, they found $\Delta \text{salinity}=5$ (Fig.IV 80). Salinity was low in Angola waters dropping from 35 to 30 psu in central Angola while in the Congo River plume; it dropped down to 28-29 (Fig.IV 80). This low salinity was attributed to heavy rainfalls in that period which increased the outflow of the river.

The Angola-Benguela front (Fig.IV-54) was found further south between 17.14-17.73°S in March-April 1995 while in the same months 1994, the front was at 16.33-16.17°S. Although Veitch et al., (2006) did not comment specifically on the position of the ABF in 1995, they stated that during major warm anomalies, the SST gradients weaken in the frontal zone and are significantly increased in the region to the south of it, indicating that the ABF shifts or spreads southwards by approximately 8° (≈ 900 km) during major warm anomalies. And they added "that the warm anomalies take about a month to affect the position of ABF".

Gammelsrød et al., (1998) suggest that Benguela Niños are associated with a positive subsurface salinity anomaly in Namibian waters and a negative surface salinity anomaly in Angolan waters. However, Binet et al., (2001) state that the excess of local rains cannot account for the large volume of low salinity waters in Angola but that it seems to be related to the deviation of the Congo River plume, pushed back towards the coast by the warm oceanic waters and not by increased river discharge. A negative flow anomaly of about $-1 \text{ m}^3 \text{ s}^{-1}$ was observed in the Congo River (1995) and positive anomaly in the rainfall in Pointe Noire of about +90 mm (Binet et al., 2001) and +170 mm in Luanda (Filipe, 1995).

We do not know how the Congo River affects salinity to the north of Cabinda, but what happens along the Angola Coast is well known. Salinity is affected only from the mouth

of the river to the south of Luanda and only at the upper layer (15 m). From Luanda to the Cunene, there is no salinity effect. Therefore warm water intruding along the Namibian coast has high salinity (35-36) which is normal for the Angolan waters.

In addition to the salinity anomaly, the thermocline deepened from 25 to 40 m depth in central Angola. This warm and brackish water killed most of the pelagic fish or forced them to move northwards or southwards (Gammelsrød et al., 1998; Binet et al., 2001; Luyeye, 1995).

The upwelling index anomalies (Fig.IV 62-64) computed in this present study showed that upwelling was depressed in all three Angolan upwelling cells during the 1994-1995 event. In fact the index anomaly remained at a level $> +2^{\circ}\text{C}$, the highest in the series.

Warm period 1998 -2000 (Jan-Dec)

During this period, SST anomalies ranged between $+0.9^{\circ}\text{C}$ and $+1.2^{\circ}\text{C}$. Warming lasted three years from January 1998 to December 2000 (Fig.IV 37-40). In the Pacific (climate Prediction Center, 2006), the situation was completely different. Two major events occurred during this period: 1997(Apr-June) to 1998 (Mar-May) (warm event) and 1998 (Jun-Aug) to 2000 (May-Jul) (cold event). The warm event started in April 1997 and ended in March 1998 with a maximum anomaly of about $+2.5^{\circ}\text{C}$. The cold event started in June 1998 and lasted until May 2000 with a maximum anomaly of -1.6°C .

In early 1998, the start of warming in Benguela coincided with the end of the Pacific warm 1998 event while 1999 was a cool year in the Pacific it was a warm year, with a magnitude equal to the one of 1995, in Angola.

Hardman-Mountford et al., (2003) referred to this period (1998-1999) as a warm event with high SST anomalies, higher than usual sea levels and weak southerly winds but the year 2000 was not included because the the time-series used ended in 1999. These authors consider 1999 as a Benguela Niño. Besides, that warm SST anomalies stretched as far as the Southern Benguela, equatorward winds were in low phase during this period. Veitch et al., (2006) also refer to 1999 as a warm year without including 1998 and 2000. They also found a southward movement of the ABF up to 18°S .

The results found in this present study showed that the ABF was further south ($17-17.5^{\circ}\text{S}$) in 1998-1999 but shifted northward in 2000 reaching 15°S (Fig.IV-54). During this period, the concentration of chlorophyll (Fig.V 41-44) was very low (anomaly = -0.2 mg m^{-3} , -1 mg m^{-3}), no upwelling was observed in any of the Angolan cells (Fig.IV 62-64) and the salinity went down to 30 at the Congo River mouth in March 1999 and in March 2000 (Fig.IV 66).

Cold period (1996-1997)

This period showed SST negative anomalies ranging between -0.8°C and -1.4°C starting in September 1996 until May 1997. In the Pacific, cooling occurred between August 1995 and February 1996 with SST anomalies of about -0.8°C , but as mentioned before warm occurred between April 1997 and March 1998, with an anomaly of $+2.5^{\circ}\text{C}$.

In the literature, cool events receive less attention than warm events because they do not have the dramatic adverse effect on biological production and, especially, marine living resources.

Early 1996 was reported a warm year in the region (Gammelsrød et al., 1998; Hardman-Mountford et al., 2003 and Veitch et al., 2006); but this warming was very short (Jan-March). However Hardman-Mountford et al., (2003) and Veitch et al., (2006) referred to 1997 as cool year. During the cool period, upwelling is enhanced therefore high biological productivity is recorded. The ABF (Fig.IV 54) was fluctuating between 16 and 17.5°S moving northwards (15.5°S) just for a short period (Jan-Feb 1997) then a strong upwelling was observed in the entire coast from May-Dec 95 (Fig.IV 59-60 & Figs.IV 62-64). In 1996 and 1997, a slight upwelling was observed in the three cells.

Cold period (2001-2002)

Negative SST anomalies ranging between -0.7°C and -1.4°C were observed during this period starting from August 2001 to December 2002 (Fig.IV 37-40). In the Pacific, warm and cool events were recorded (CPC, 2006):

- A cool event between (Sept-Nov) 2000 and (Jan-Mar) 2001 with a negative anomaly of about -0.7
- A warm event between (Apr-Jun) 2002 and (Feb-Apr) 2003 with a positive anomaly of about +1.5

In the Benguela, both events were observed as a single cool period. During this period the ABF was further north, fluctuating between 14.5°S and 16°S (Fig.IV 54). The chlorophyll concentration was high (anomaly=1.4 mg m⁻³) in coastal and offshore sub-regions (Fig. IV-37, 40-42). Strong upwelling (-2°C) was observed at the Cunene cell but nothing out of ordinary was found in Cabinda and Ambriz cells (Fig.IV 59-60 & Figs.IV 62-64).

CHAPTER VI CONCLUSIONS

1. Cluster analysis was used successfully to partition the Angola marine environment into three different sub-regions: northern, coastal and offshore sub-regions. The variation of SST and chlorophyll-a in the longshore and offshore directions were used as a guide in the subdivision process however the results obtained have some shortcomings: the coastal sub-region by itself has two systems, which are completely different in terms of environment (temperature, salinity, upwelling, wind) and biota (chlorophyll-a, zooplankton and fish species). South of the ABF should be a fourth sub-region, but the cluster procedure did not define that part as a single area with common properties. Instead it was defined as a large number of small sub-regions indicating an immensely very variable region.

It is recognized that the subdivision should ideally have been performed on the grounds of more comprehensive set of oceanographic parameters, notably salinity and oxygen but such data are presently not available with sufficient spatial and temporal density.
2. Several attempts were made to identify the extension of the Congo River plume by using SST, chlorophyll-a or the combination of both in the cluster procedure. It, however, turned out that only the chlorophyll concentration was partly effective for the purpose and needed to be verified through the use of CTD salinity data.

The plume can be detected with chlorophyll but there are complications in the form of the transition of freshwater plankton to saline water plankton.

Correlation carried out between salinity and chlorophyll-a concentration indicates high concentration of chlorophyll in the range of 30-33.5 (brackish water) and low chlorophyll-a concentration in both low salinity water (28-32) and in high salinities (33.5-36). This result agrees with those of Cadée (1978).

Cluster results showed an offshore extension until 370 km (offshore distance), which matched with other scientists' results (800 km). The southward extension of the plume is around 8-9°S (Ambriz-Luanda).

Low salinity (28-33) during the rainy summer (January-April) allows detecting the latitudinal extension of the plume. In winter, salinity is high everywhere (34-35).
3. The northern and southern boundaries of the ABF were found to be between 15°S and 18°S with a mid-position at 16.86°S in summer (April) and 16.49°S in winter (August) but with variation induced by warm and cold events. With the biological front, the results were not as expected. The range of the ABF variation is similar to what was obtained with SST but there is no correlation between SST and chlorophyll frontal positions. When the thermal front shifts northwards, the biological front shifts southwards in most cases.

4. Three upwelling cells off Angola were identified: Cabinda (5.02-5.5°S); Ambriz (7-8°S) and Cunene (16.5-17.33°S). The same cells were identified by Lutjeharms and Meeuwis, (1987). Cunene was found to be the only upwelling cell driven by the windstress (Shannon, 1985; Boyd, 1987 and Risien et al., 2004). However off Cabinda and Ambriz, the windstress is too weak to drive Ekman transport. Kelvin and Rossby waves are believed to drive the upwelling in the north of Angola, remotely forced from the western Atlantic (Coast of Brazil) (Berrit, 1976; Picaut, 1983; Moore et al., 1978)
5. Warm and cold events were identified with Meteosat-SST between 1987 and 2002. SST anomalies obtained from the sub-regions, position anomalies of the Angola-Benguela front and upwelling index anomalies allowed identifying all warm and cold periods:
 - a) Warm events: 1987-1989 (Jan-Dec); 1994 (Oct-Dec)-1995 (Jan-May); 1998-2000 (Jan-Dec).

These events are characterized by a positive anomaly higher than +0.5°C and lasted more than six months. Although the hypothesis on teleconnections between the Pacific ENSO and Benguela Niños is partially but not fully accepted by scientists of the region, it was observed in most cases an occurrence of a warm event in the Benguela six months or one year after it has occurred in the Pacific.

In addition, the Pacific Niños are frequent and last longer than the Benguela Niños.

Most of oceanographic features are affected by the warm events:

- High temperature and low salinity off Angola
- Salinity is mostly affected by an increase of the outflow of Congo river in the region of the plume
- Low chlorophyll concentration
- Upwelling weakens or ceases
- ABF moves southwards in its southernmost position

- b) Cold events: 1996 (Sept)-1997(Aug); 2001(Aug)-2002 (Dec)

The cold events are characterized by a negative anomaly lower than -0.5°C and lasted more than six months. The connection with the Pacific is similar to the warm events. They negatively affect oceanographic features: low temperature and high salinity, high chlorophyll concentration, strong upwelling and the ABF move northwards in its northernmost positions.

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APPENDIX

IDL PROGRAMS USED IN THIS RESEARCH PROJECT

1. EXTRACTION OF CHL-a DATA FROM 5-DAY SEAWIFS COMPOSITE IMAGES

```
;EXTRACTION OF CHLOROPHYLL_a DATA FROM SEAWIFS IMAGES
;
;EXTRACTION OF CHLOROPHYLL_a DATA FROM SEAWIFS IMAGES
;CALCULATION OF MONTHLY MEAN CHLOROPHYLL_a"
;IDL PROGRAM WRITTEN BY VIANDA L.L. FILIPE /UCT MSc STUDENT (2005/2006)"
;SUPERVISOR DR. KOBUS AGENBAG (MCM/CAPE TOWN)
;
img_dir='C:\DATA\SEAWIFS_IMAGES\'
;
img_str='*.bil'
;
out_dir='C:\IDL COURSE\PROJECT\SEAWIFS_FILES\SWATH3\'
out_file='SEAWIFS16_17SWATH3.txt'
;
;STARTING AND ENDING TIME (YEAR, MONTH & IMAGES)
start_year=1998
end_year=2004
start_month=1
end_month=12
start_img=1
end_img=6
;
;GEOGRAPHICAL COORDINATES OF THE IMAGE
start_lat=-5.00
end_lat=-40.00
start_lon=5.00
end_lon=40.00
;
;PIXEL SAMPLES (NUMBER OF COLUMNS), SCAN LINES (NUMBER OF ROWS), Xsize & Ysize
;
xdim=825
ydim=825
ysize=(start_lat-end_lat)/ydim
xsize=(end_lon-start_lon)/xdim
;
PRINT,ysize,xsize
;
;LENGTH OF THE SWATH
;
swath_width1=10 ;km (distance between the coast and the first point offshore)
swath_width2=20 ;km (distance between the first point and 2nd point offshore)
swath_width3=40
;
;
y=106 ; arbitrary value obtained from the centre of the region (inverted image),
; values obtained from RDPIX (y1=543;y=649-543=106)
x1=84 ; Value of the first pixel in the scan line y=106
x2=85 ; Value of the second pixel in the scan line y=106
;
; CONVERSION OF X1 AND X2 INTO LON1 AND LON2
;
lon1= start_lon+(xsize/2)+x1*xsize
lon2= start_lon+(xsize/2)+x2*xsize
;
Print,"lon1=",lon1,"lon2=",lon2
;
;GEOGRAPHICAL COORDINATES OF A GIVEN REGION (IN THIS CASE:ANGOLA)
;
latn=-16.5
lats=-17.5
lone=9.00
lonw=15.00
```

```

;
;CONVERSION OF GEOGRAPHICAL COORDINATES (lat,long) INTO X,Y COORDINATES
;
yn=ROUND(((start_lat-latn)/ysize)-0.5) ; y1 (for latn)
ys=ROUND(((start_lat-lats)/ysize)-0.5) ; y2 (for lats)
xe=ROUND(((lon-start_lon)/xsize)-0.5) ; x1 (for long)
xw=ROUND(((lonw-start_lon)/xsize)-0.5) ; x2 (for long)
;
Print,"yn=",yn,"ys=",ys,"xe=",xe,"xw=",xw
;
;RANGE OF THE CHOLOROPHYLL-A CONCENTRATION (Chl-C) IN ANGOLA
;
minChl_C=0.1 ;mg/cubic meter (Minimum acceptable Chlorophyll_a concentration)
maxChl_C=50 ; mg/cubic meter (Maximum acceptable chlorophyll_a concentration)
maxval=(alog10(maxChl_C)+2.0)/0.015 ; Converting minChl_C into digital count
minval=(alog10(minChl_C)+2.0)/0.015 ; Converting maxChl_C into digital count
Print,"maxval=",maxval,"minval=",minval
min_percent_good=30 ; Minimum percentage of good Chl_C required in a swath in order to
compute the mean_Ch1_C
;
;*****;*****
n=72*((end_year)-(start_year)+1)
Print,n ; number of files
arr=STRARR(n)
darr=INTARR(n)
barr=INTARR(n)
numfile=-1
MODE= 2
FOR year=start_year,end_year DO BEGIN
str_year=STRTRIM(string(year),2)
IF MODE EQ 1 THEN BEGIN
IF year GT start_year THEN BEGIN
sm=1
em=12
IF year EQ end_year THEN BEGIN
sm=1
em=end_month
ENDIF
ENDIF ELSE BEGIN
sm=start_month
em=12
ENDELSE
ENDIF ELSE BEGIN, mode 2
sm=start_month
em=end_month
ENDELSE
;
FOR month=sm,em DO BEGIN
IF month GT 9 THEN BEGIN
str_month=STRTRIM(string(month),2)
ENDIF ELSE BEGIN
str_month='0'+ STRTRIM(string(month),2)
ENDELSE
;
FOR image=start_img,end_img DO BEGIN
numfile=numfile+1
str_image=STRTRIM(string(image),2)
img_str='chl'+ str_year + str_month + 'p' + str_image + '.bil'
arr(numfile)=img_str
barr[numfile]=year
darr[numfile]=month
ENDFOR
ENDFOR
ENDFOR
Print,arr
;*****;*****
img_str=img_dir+'*.bil'

```

```

img_list=FINDFILE(img_str,count=num_img)
;
file_path=img_dir + arr(0)
OPENR,luni,file_path,/GET_LUN ; READING THE FIRST IMAGE
a=ASSOC(luni,BYTARR(xdim,ydim))
image=a(0)
CLOSE,luni & FREE_LUN,luni
;
y_start=Min([yn,ys]) ;MINIMUM VALUE OF LATITUDE
y_end= Max([yn,ys]) ;MAXIMUM VALUE OF LATITUDE
;
swath_mask=BYTARR(xdim,ydim); OPEN A 2 DIMENSIONAL ARRAY OF SWATH_MASK
;
FOR y=y_start,y_end DO BEGIN
;
; CONVERSION OF Y INTO THE CORRESPONDING LATITUDE
;
laty= start_lat-(ysize/2)-y*ysize

;COMPUTATION OF THE PIXEL SIZE USING MAP-2POINTS (LONG BEING CONSTANTS AND LAT, A ;VARIABLE)
;
xdim1=MAP_2POINTS(lon1,laty,lon2,laty,/meters)/1000; XDIM1/1000 CONVERTING M INTO KM
;
idx=where(image[*],y EQ 253,cnt) ; SEARCH FOR THE FIRST PIXEL AT THE LAND_BORDER
;
x_coast=idx(0) ; FIRST PIXEL FOUND AT THE COAST (LAND_BORDER)
x_swath_width1=ROUND(Float((swath_width1)/(xdim1))) ; NUMBER OF PIXELS BETWEEN ;THE
COAST AND THE FIRST SWATH
x_swath_width2=ROUND(Float((swath_width2)/(xdim1))) ; NUMBER OF PIXELS BETWEEN ;THE
FIRST AND THE SECOND SWATH OFFSHORE
x_swath_width3=ROUND(Float((swath_width3)/(xdim1)))
;
x11=x_coast ; X VALUE OF THE COAST
x12=(x11-1)-(x_swath_width1) ; X VALUE OF THE FIRST SWATH
x13=(x12+1)-(x_swath_width2) ; X VALUE OF THE SECOND SWATH
x14=(x13+1)-(x_swath_width3)
;
PRINT,"x11=",x11,"x12=",x12,"x13=",x13,"xdim1=",xdim1
;
swath_mask[x14:x13,y]=205 ; FILL THE MASK_SWATH WITH 205

ENDFOR
;
;*****
;*****
;idx_land=where(image EQ 253 OR image EQ 254,num_idx_land)
;image(idx_land)=swath_mask(idx_land)
;
;idx_land=WHERE(image EQ 254,num_idx_land)
;idx_border=WHERE(image EQ 253,num_idx_border)
;swath_mask_copy=swath_mask
;swath_mask_copy[idx_land]=150
;swath_mask_copy[idx_border]=200
;
;Print,"num_idx_land=",num_idx_land
;
;!ORDER=1
;wnum=ID.WINDOW+1
;WINDOW,wnum,XSIZE=xdim,YSIZE=ydim
;TVSCL,swath_mask > 100 < 255
;TV,swath_mask_copy
;*****
;*****
;
;idx_swath=WHERE(swath_mask EQ 205,num_idx_swath); CHECKING 205 ASSIGNED TO THE MASK
;
;min_pixels=ROUND((min_percent_good/100.0)*num_idx_swath)
;
;computation of the Mean Chl_C excluding cloud and bad Chl_C
;
n_images=numfile

```

```

averages=FLTARR(3,n_images+1)
;
FOR j=0,n_images DO BEGIN      ; Process all the images
  file_path=img_dir + arr(j)
  idx=where(img_list EQ file_path,count); checking the missing files
  ;
  IF count NE 0 THEN BEGIN; only if there is no missing files
    OPENR,luni,file_path,/GET_LUN
    a=ASSOC(luni,BYTARR(xdim,ydim))
    image=a(0)
    CLOSE,luni & FREE_LUN,luni
  ;
  ;COMPUTATION OF X,Y COORDINATES FROM IDX SWATH (GEOGRAPHICAL POSITION OF THE
  ;DIGITAL COUNTS CORRESPONDING TO THE Chl_C)

  subimage=INTARR(num_idx_swath)
  Chl_C=FLTARR(num_idx_swath)
  FOR i=0,num_idx_swath-1 DO BEGIN
    x=idx_swath[i]MOD 825
    y=idx_swath[i]/825
    subimage(i)=image[idx_swath(i)]
  ;
;CHECKING THE PIXELS WITHIN THE REQUIRED RANGE AND EXCLUDING CLOUDS, LAND AND ;LAND_BORDER
;
  index=WHERE (subimage LT 253 AND subimage GT minval AND subimage LE maxval,ct)
  ;
  ;CONVERSION OF DIGITAL COUNTS INTO Chl_C
  ;
  Chl_C(i)=10^(0.015*subimage(i)-2.0)
  ;
  ;Print,i,x,y,subimage(i),Chl_C(i)
ENDFOR

;
IF ct GE min_pixels THEN BEGIN ; A MINIMUM NUMBER OF GOOD PIXELS IS REQUIRED
  ; IN ORDER TO COMPUTE THE MEAN_Ch1_C
  mean_Ch1_C=MEAN(Chl_C(index))      ; COMPUTATION OF THE MEAN_Ch1_C
;EXCLUDING ALL BAD VALUES (LAND, CLOUDS, BORDER AND ALL 0.1> Chl_C > 50mg/m3 )
  averages[0,j]=barr(j)              ; First column of years
  averages[1,j]=darr(j)              ; Second column of months
  averages[2,j]=mean_Ch1_C           ; Third column of mean_Ch1_C
  ENDFIF ELSE BEGIN
    averages[0,j]=barr(j)             ;First column of years
    averages[1,j]=darr(j)            ;Second column of months
    averages[2,j]=-9999.99           ;Third column of mean_Ch1_C
  ENDELSE
;
  ENDFIF ELSE BEGIN                  ; if there is any missing file, then write -9999.99
    averages[0,j]=barr(j)            ; First column of years
    averages[1,j]=darr(j)            ; Second column of months
    averages[2,j]=-9999.99           ; Third column of mean-Chl-C
  ENDELSE
ENDFOR

;
;*****
;*****
For j=0,n_images-5,6 DO
PRINT,averages(0:1,j),averages(2,j:j+5),format='(I5,2X,I4,2X,F10.2,4X,F10.2,4X,F10.2,4X,F10.2,4X,F10.2,4X,F10.2)'
OPENW,luno,out_dir+out_file,/GET_LUN; open an ouput file
PRINTF,luno,"EXTRACTION OF CHROROPHYLL a DATA FROM SEAWIFS 5-DAYS COMPOSITE
IMAGES",format='(5X,A70,/) '
PRINTF,luno,"CALCULATION OF MONTHLY MEAN CHLOROPHYLL a USING THE SWATH",format='(5X,A70,/) '
PRINTF,luno,"IDL PROGRAM WRITTEN BY VIANDA L.L. FILIPE /UCT MSc STUDENT
(2005/2006)",format='(5X,A70,/) '
PRINTF,luno,"SUPERVISOR DR. KOBUS AGENBAG (MCM/CAPE TOWN)",format='(10X,A50,/) '
PRINTF,luno,"MEAN SEAWIFS CHLOROPHYLL a CONCENTRATION",format='(15X,A50,/) '
PRINTF,luno,start_year,start_month,start_img,format=$
'(5X,"START_YEAR=",I5,3X,"START_MONTH=",I3,3X,"START_IMAGE=",I2,5X,/) '
PRINTF,luno,end_year,end_month,end_img,format=$
'(5X,"END_YEAR=",I5,3X,"END_MONTH=",I3,3X,"END_IMAGE=",I2,5X,/) '
PRINTF,luno,latn,lone,$

```

```

format='(5X,"START_LATITUDE=",F10.4,3X,"START_LONGITUDE=",F10.4,5X/)'
PRINTF,luno,lats,lonw,$
format='(5X,"END_LATITUDE=",F10.4,5X,"END_LONGITUDE=",F10.4,5X/)'
PRINTF,luno,swath_width1,swath_width2,$
format='(5X,"SWATH_WIDTH1=",F10.4,5X,"SWATH_WIDTH2=",F10.4,5X/)'
PRINTF,luno,minChl_C,maxChl_C,$
format='(5X,"MINIMUM CHLOROPHYLL_a=",F12.4,5X,"MAXIMUM CHLOROPHYLL_a=",F12.4,5X/)'
;
;*****
;*****
; Write mean Chl_C in six according to six composites per month
;
For j=0,n_images-5,6 DO PRINTF,luno,averages(0:1,j), averages(2,j:j+5),$
format='(I5,2X,I4,2X,F10.2,4X,F10.2,4X,F10.2,4X,F10.2,4X,F10.2,4X,F10.2)'
Close,luno & FREE_LUN,luno
END

```

```

#####
#####

```

2 EXTRACTION OF SST DATA FROM METEOSAT COMPOSITES IMAGES

```

;INPUT FILES: 5 DAY METEOSAT SST IMAGES
;
;EXTRACTION OF SST DATA FROM METEOSAT IMAGES
;CALCULATION OF MONTHLY MEAN SST
;IDL PROGRAM WRITTEN BY VIANDA L.L. FILIPE /UCT MSc STUDENT (2005/2006)"
;SUPERVISOR DR. KOBUS AGENBAG (MCM/CAPE TOWN)
;
img_dir='C:\DATA\METEOSAT_IMAGES\'
img_str='*.sst'
;
out_dir='C:\Master Thesis\'
out_file='sst1_2SWATH6.txt'
;
;STARTING AND ENDING TIME (YEAR,MONTH & IMAGES)
start_year=1987
end_year=2003
start_month=1
end_month=12
start_img=1
end_img=6
;
;GEOGRAPHICAL COORDINATES OF THE IMAGE
;
start_lat=-5.00
end_lat=-40.00
start_lon=5.00
end_lon=40.00
;
;Pixel Samples (nber of columns), Scan lines (nber of rows), Xsize & Ysize
;
xdim=650
ydim=650
ysize=(start_lat-end_lat)/ydim
xsize=(end_lon-start_lon)/xdim
;
PRINT,ysize,xsize
;
;Lentgh of the swath
;
swath_width1=10 ;km (Distance between the coast and the first point offshore)
swath_width2=20 ;km (Distance between the first point and the second offshore)
swath_width3=40
;
;
y=106 ; obtained from the centre of the region,values
; obtained from RDPIX (y1=543;y=649-543=106)
x1=84 ; Value of the first pixel in the scan line y=106

```

```

x2=85          ; Value of the second pixel in the scan line y=106
;
; CONVERSION OF X1 AND X2 INTO LONGITUDE 1 AND LONGITUDE 2
;
lon1= start_lon+(xsize/2)+x1*xsize
lon2= start_lon+(xsize/2)+x2*xsize
;
Print,"lon1=",lon1,"lon2=",lon2
;
;GEOGRAPHICAL COORDINATES OF A GIVEN REGION (In this case: Angola)
;
latn=-15.74
lats=-17.68
lone=9.00
lonw=15.00
;
;CONVERSION OF GEOGRAPHICAL COORDINATES OF THE REGION (lat,long) into X,Y COORDINATES
;
yn=ROUND(((start_lat-latn)/ysize)-0.5) ; y1 (for latn)
ys=ROUND(((start_lat-lats)/ysize)-0.5) ; y2 (for lats)
xe=ROUND(((lone-start_lon)/xsize)-0.5) ; x1 (for long)
xw=ROUND(((lonw-start_lon)/xsize)-0.5) ; x2 (for long)
;
Print,"yn=",yn,"ys=",ys,"xe=",xe,"xw=",xw
;
;TEMPERATURE RANGE ACCEPTABLE IN ANGOLAN WATERS
;
minT=16          ; minimum temperature
maxT=32          ; maximum temperature
;CONVERSION OF TEMPERATURES(DECIMAL) INTO DIGITAL NUMBERS (DN)
;
minval=2*(55-maxT)
maxval=2*(55-minT)
min_percent_good=30      ; MINIMUM PERCENTAGE OF GOOD SST REQUIRED IN A SWATH
;
;*****
;*****
n=72*((end_year)-(start_year)+1) ;TOTAL NUMBER OF BINARY FILES
Print,n ; number of files
arr=STRARR(n)
darr=INTARR(n)
barr=INTARR(n)
numfile=-1
MODE= 2
; THE FOLLOWING SUBROUTINE ALLOWS TO LIST ALL BINARY FILES
FOR year=start_year,end_year DO BEGIN
    str_year=STRTRIM(string(year),2)
    IF MODE EQ 1 THEN BEGIN
        IF year GT start_year THEN BEGIN
            sm=1
            em=12
            IF year EQ end_year THEN BEGIN
                sm=1
                em=end_month
            ENDIF
        ENDIF ELSE BEGIN
            sm=start_month
            em=12
        ENDELSE
    ENDIF ELSE BEGIN; mode 2
        sm=start_month
        em=end_month
    ENDELSE
;
    FOR month=sm,em DO BEGIN
        IF month GT 9 THEN BEGIN
            str_month=STRTRIM(string(month),2)
        ENDIF ELSE BEGIN
            str_month='0'+ STRTRIM(string(month),2)
        ENDELSE
;

```

```

        FOR image=start_img,end_img DO BEGIN
            numfile=numfile+1
            str_image=STRTRIM(string(image),2)
            img_str='b'+ str_year + str_month + 'p' + str_image + '.sst'
            arr[numfile]=img_str
            barr[numfile]=year
            darr[numfile]=month
        ENDFOR
    ENDFOR

ENDFOR

Print,arr
;*****
;*****
img_str=img_dir+'.sst'
img_list=FINDFILE(img_str,count=num_img)
;
file_path=img_dir + arr(0)
OPENR,luni,file_path,/GET_LUN ; READING THE FIRST IMAGE
a=ASSOC(luni,BYTARR(xdim,ydim))
image=a(0)
CLOSE,luni & FREE_LUN,luni
;
y_start=Min([yn,ys]); COMPUTE THE MINIMUM LATITUDE AS THE STARTING LAT
y_end= Max([yn,ys]); COMPUTE THE MAXIMUM LATITUDE AS THE ENDING LAT
;
swath_mask=BYTARR(xdim,ydim); OPEN A 2 DIMENSIONAL ARRAY OF SWATH_MASK
;
FOR y=y_start,y_end DO BEGIN
;
; CONVERSION OF Y INTO THE CORRESPONDING LATITUDE
;
laty= start_lat-(ysize/2)-y*ysize
;
;COMPUTATION OF THE PIXEL SIZE USING MAP-2POINTS (LONGITUDES LON1 & LONG2 ARE ;CONSTANTS $
AND LATITUDE, A VARIABLE VARYING BETWEEN START_LAT AND END_LAT)
;
xdiml=MAP_2POINTS(lon1,laty,lon2,laty,/meters)/1000; XDIM1/1000 CONVERTING M INTO KM
;
idx=where(image[*],y EQ 29,cnt)
;
x_coast=idx(0) ; FIRST PIXEL FOUND AT THE COAST (BORDER)
x_swath_width1=ROUND(Float((swath_width1)/(xdiml))) ; NUMBER OF PIXELS BETWEEN THE
COAST AND THE FIRST SWATH
x_swath_width2=ROUND(Float((swath_width2)/(xdiml))) ; NUMBER OF PIXELS BETWEEN THE
FIRST SWATH AND THE SECOND OFFSHORE.
x_swath_width3=ROUND(Float((swath_width3)/(xdiml)))
;
x11=x_coast ; X VALUE OF THE COAST
x12=(x11-1)-(x_swath_width1) ; X VALUE OF THE FIRST SWATH
x13=(x12+1)-(x_swath_width2) ; X VALUE OF THE SECOND SWATH
;
PRINT,"x11=",x11,"x12=",x12,"x13=",x13,"xdiml=",xdiml
;
swath_mask[x12:x11,y]=255 ; FILL THE MASK_SWATH WITH 255
;
;
ENDFOR
;
;*****
;*****
;
idx_swath=WHERE(swath_mask EQ 255,num_idx_swath); CHECKING 255 ASSIGNED TO THE MASK
;
min_pixels=ROUND((min_percent_good/100.0)*num_idx_swath)
;
;computation of the Mean SST including cloud and bad SST masking
;
n_images=numfile
averages=FLTARR(3,n_images+1)

```

```

;
FOR j=0,n_images DO BEGIN ; Process all the images
  file_path=img_dir + arr(j)
  idx=where(img_list EQ file_path,count) ; checking the missing files
  ;
  IF count NE 0 THEN BEGIN ; only if there is no missing files
    OPENR,luni,file_path,/GET_LUN
    a=ASSOC(luni,BYTARR(xdim,ydim))
    image=a(0)
    CLOSE,luni & FREE_LUN,luni
  ;
  ;CALCULATION OF X,Y COORDINATES FROM IDX_SWATH (POSITION OF DIGITAL COUNTS)
;
  subimage=INTARR(num_idx_swath) ; OPEN AN INTEGER ARRAY OF SUBIMAGE
  sst=FLTARR(num_idx_swath) ; OPEN A FLOATING ARRAY OF SST
  FOR i=0,num_idx_swath-1 DO BEGIN
    x=idx_swath[i]MOD 650 ;CALCULATION OF X COORDINATES
    y=idx_swath[i]/650 ; CALCULATION OF Y COORDINATES
    subimage(i)=image[idx_swath(i)]
;CHECKING THE PIXELS WITHIN THE REQUIRED RANGE (EXCLUDING LAND,BORDER,CLOUDS AND
; ALL TEMP.LESS THAN 16 AND GREATER THAN 32C
    index=WHERE (subimage GT 30 AND subimage LE minval AND subimage LE maxval,ct)
    SST(i)=55.0-(subimage(i)/2.0) ; CONVERSION OF DIGITAL COUNTS INTO DEGREES CELSIUS
    ;Print,i,x,y,subimage(i),sst(i)
  ENDFOR
;
  IF ct GE min_pixels THEN BEGIN ; A minimum number of good pixels is REQUIRED
to compute the mean SST
    mean_SST=MEAN(SST(index))
    averages[0,j]=barr(j) ;First column of years
    averages[1,j]=darr(j) ;Second colum of months
    averages[2,j]=mean_SST ;Third column of mean SST
  ENDFIF ELSE BEGIN ;if the number of good pixels is less than the
minimum required then the file is rejected by writing -99.999
    averages[0,j]=barr(j) ;First column of years
    averages[1,j]=darr(j) ;Second colum of months
    averages[2,j]=-9999.99 ;Third column of mean SST
  ENDELSE
;
  ENDFIF ELSE BEGIN; if there is any missing file, then write -9999.99
    averages[0,j]=barr(j) ; First column of years
    averages[1,j]=darr(j) ; Second column of months
    averages[2,j]=-9999.99 ; Third column of mean SST
  ENDELSE
ENDFOR
;
;*****
;*****
;THE FOLLOWING SUBROUTINE ALLOWS TO WRITE THE OUTPUT IN A SPECIFIC OUTPUT FILE.
;
FOR j=0,n_images-5,6 DO
PRINT,averages(0:1,j),averages(2,j:j+5),format='(I5,2X,I4,2X,F10.2,4X,F10.2,4X,F10.2,4X,F10.2,4X,F10.2,4X,F10.2)'
OPENW,luno,out_dir+out_file,/GET_LUN; open an ouput file
PRINTF,luno,"EXTRACTION OF SST DATA FROM METEOSAT 5-DAYS COMPOSITE
IMAGES",format='(5X,A70,/) '
PRINTF,luno,"CALCULATION OF MONTHLY MEAN SST USING THE SWATH",format='(5X,A50,/) '
PRINTF,luno,"IDL PROGRAM WRITTEN BY VIANDA L.L. FILIPE /UCT MSc STUDENT
(2005/2006)",format='(5X,A70,/) '
PRINTF,luno,"SUPERVISOR DR. KOBUS AGENBAG (MCM/CAPE TOWN)" ,format='(10X,A50,/) '
PRINTF,luno,"MEAN METEOSAT SST_1V1",format='(15X,A50,/) '
PRINTF,luno,start_year,start_month,start_img,format=$
'(5X,"START YEAR=",I5,3X,"START MONTH=",I3,3X,"START_IMAGE=",I2,5X,/) '
PRINTF,luno,end_year,end_month,end_img,format=$
'(5X,"END YEAR=",I5,3X,"END MONTH=",I3,3X,"END_IMAGE=",I2,5X,/) '
PRINTF,luno,latn,lone,$
format='(5X,"START LATITUDE=",F10.4,3X,"START LONGITUDE=",F10.4,5X/) '
PRINTF,luno,lats,lonw,$
format='(5X,"END LATITUDE=",F10.4,5X,"END LONGITUDE=",F10.4,5X,/) '
PRINTF,luno,swath_width1,swath_width2,$

```

```

format='(5X,"SWATH_WIDTH1=",F10.4,5X,"SWATH_WIDTH2=",F10.4,5X,/) '
PRINTF,luno,minT,maxT,$
format='(5X,"MINIMUM TEMPERATURE=",I4,5X,"MAXIMUM TEMPERATURE=",I4,5X,/) '
;*****
;*****
; Write mean SST in six according to six composites per month

For j=0,n_images-5,6 DO PRINTF,luno,averages(0:1,j), averages(2,j:j+5),$; PRINT EIGHT COLUMNS
IN WHICH THE FIRST,IS THE YEAR, THE SECOND, THE MONTHS AND FROM THE THIRD TO THE EIGHTH, THE
SST ACCORDING TO THE IMAGES (6 COLUMNS)
format='(I5,2X,I4,2X,F10.2,4X,F10.2,4X,F10.2,4X,F10.2,4X,F10.2,4X,F10.2)'
Close,luno & FREE_LUN,luno
END

#####
#####

```

3 CONVERSION OF LONGITUDES AND LATITUDES INTO X,Y COORDINATES

```

;IDL PROGRAM WRITTEN BY VIANDA FILIPE
; UCT MSC STUDENT (2005-2006)
;
;*****
;*****
start_lat=-5.00
end_lat=-40.00
start_lon=5.00
end_lon=40.00
;
;Conversion of latitude and longitude into X,Y coordinates
;
xdim=825
ydim=825
ysize=(start_lat-end_lat)/ydim
xsize=(end_lon-start_lon)/xdim
;
PRINT,ysize,xsize
;
y1=8
x1=84
y2=427
x2=95
;
;*****
;*****
latn=start_lat-(ysize/2)-y1*ysize
lats=start_lat-(ysize/2)-y2*ysize
lonw=start_lon+(xsize/2)+x1*xsize
lonw=start_lon+(xsize/2)+x2*xsize
;
Print,"latn=",latn,"lats=",lats,"lonw=",lonw
;
;Conversion of geographical coordinates(lat,long) into X,Y Coordinates
;
y1=ROUND(((start_lat-lat1)/ysize)-0.5) ; y1 (for latn)
y2=ROUND(((start_lat-lat2)/ysize)-0.5) ; y2 (for lats)
x1=ROUND(((lon1-start_lon)/xsize)-0.5) ; x1 (for long)
x2=ROUND(((lon2-start_lon)/xsize)-0.5) ; x2 (for long)
;
Print,"y1=",y1,"y2=",y2,"x1=",x1,"x2=",x2
;
END

#####
#####

```

4. OUTPUT PIXELS IN A SCANLINE FOR TESTING THE ACCURACY OF THE PROGRAM (CASE 2: SEAWIFS CHLOROPHYLL SWATH-MASK)

```

;DISPLAY OF CHLOROPHYLL_a SWATH_MASK FOR TESTING THE ACCURACY OF THE PROGRAM
;IDL PROGRAM WRITTEN BY VIANDA L.L. FILIPE /UCT MSc STUDENT (2005/2006)"
;SUPERVISOR DR. KOBUS AGENBAG (MCM/CAPE TOWN)
;
img_dir='C:\DATA\SEAWIFS-1998-2004-CLIMATOLOGY\'
;
img_file='clim_1998-2004_12.bil'
;
out_dir='C:\Master Thesis\SEAWIFS_FILES\'
out_file='clim_1998-2004_120.txt'
;
;GEOGRAPHICAL COORDINATES OF THE IMAGE
start_lat=-5.00
end_lat=-40.00
start_lon=5.00
end_lon=40.00
;
;PIXEL SAMPLES (NUMBER OF COLUMNS), SCAN LINES (NUMBER OF ROWS), Xsize & Ysize
;
xdim=825
ydim=825
ysize=(start_lat-end_lat)/ydim
xsize=(end_lon-start_lon)/xdim
;
PRINT,ysize,xsize
;
;LENGTH OF THE SWATH
;
swath_width1=600 ;km (distance between the coast and the first point offshore)
;
;
y=106 ; arbitrary value obtained from the centre of the region(inverted image),
; values obtained from RDPIX (y1=543;y=649-543=106)
x1=84 ; Value of the first pixel in the scan line y=106
x2=85 ; Value of the second pixel in the scan line y=106
;
; CONVERSION OF X1 AND X2 INTO LON1 AND LON2
;
lon1= start_lon+(xsize/2)+x1*xsize
lon2= start_lon+(xsize/2)+x2*xsize
;
Print,"lon1=",lon1,"lon2=",lon2
;
;GEOGRAPHICAL COORDINATES OF A GIVEN REGION (IN THIS CASE:ANGOLA)
;
latn=-5.50
lats=-17.33
lone=9.00
lonw=15.00
;
;CONVERSION OF GEOGRAPHICAL COORDINATES (lat,long) INTO X,Y COORDINATES
;
yn=ROUND(((start_lat-latn)/ysize)-0.5) ; y1 (for latn)
ys=ROUND(((start_lat-lats)/ysize)-0.5) ; y2 (for lats)
xe=ROUND(((lone-start_lon)/xsize)-0.5) ; x1 (for long)
xw=ROUND(((lonw-start_lon)/xsize)-0.5) ; x2 (for long)
;
Print,"yn=",yn,"ys=",ys,"xe=",xe,"xw=",xw
;
;RANGE OF THE CHOLOROPHYLL-A CONCENTRATION (Chl_C) IN ANGOLA
;
minChl_C=0.1 ; mg/cubic meter (Minimum acceptable Chlorophyll_a concentration)
maxChl_C=50 ; mg/cubic meter (Maximum acceptable chlorophyll_a concentration)
maxval=(alog10(maxChl_C)+2.0)/0.015 ; Converting minChl_C into digital count
minval=(alog10(minChl_C)+2.0)/0.015 ; Converting maxChl_C into digital count
Print,"maxval=",maxval,"minval=",minval

```

```

min_percent_good=30 ; Minimum percentage of good Chl_C required in a swath in order to
compute the mean_Ch1_C
;
file_path=img_dir + img_file
OPENR,luni,file_path,/GET_LUN ; READING THE FIRST IMAGE
a=ASSOC(luni,BYTARR(xdim,ydim))
image=a(0)
CLOSE,luni & FREE_LUN,luni
;
y_start=Min([yn,ys]) ;MINIMUM VALUE OF LATITUDE
y_end= Max([yn,ys]) ;MAXIMUM VALUE OF LATITUDE
;
swath_mask=BYTARR(xdim,ydim); OPEN A 2 DIMENSIONAL ARRAY OF SWATH_MASK
;
FOR y=y_start,y_end DO BEGIN
;
; CONVERSION OF Y INTO THE CORRESPONDING LATITUDE
;
laty= start_lat-(ysize/2)-y*ysize

;COMPUTATION OF THE PIXEL SIZE USING MAP-2POINTS (LONG BEING CONSTANTS AND LAT, A VARIABLE)
;
xdim1=MAP_2POINTS(lon1,laty,lon2,laty,/meters)/1000; XDIM1/1000 CONVERTING M INTO KM
;
idx=where(image[*],y EQ 253,cnt) ; SEARCH FOR THE FIRST PIXEL AT THE LAND_BORDER
;
x_coast=idx(0) ; FIRST PIXEL FOUND AT THE COAST (LAND_BORDER)
x_swath_width1=ROUND(Float((swath_width1)/(xdim1))) ; NUMBER OF PIXELS BETWEEN THE
COAST AND THE FIRST SWATH
;
x11=x_coast ; X VALUE OF THE COAST
x12=(x11+1)-(x_swath_width1) ; X VALUE OF THE FIRST SWATH
;
PRINT,"x11=",x11,"x12=",x12,"y=",y,"xdim1=",xdim1
;
swath_mask[x12:x11,y]=125 ; FILL THE MASK_SWATH WITH 205
ENDFOR
;
;*****
*****
OPENW,luno,out_dir+out_file,/GET_LUN; open an output file
For y=11,290 DO PRINTF,luno,y,Reverse(image[x12:x11,y])
Close,luno & FREE_LUN,luno
END

#####
#####

```

5.DISPLAY OF CLIMATOLOGIES (CHOROPHYLL IMAGES)

```

;DISPLAY OF CHLOROPHYLL_a IMAGES FROM SEAWIFS
;IDL PROGRAM WRITTEN BY VIANDA L.L. FILIPE /UCT MSc STUDENT (2005/2006)"
;SUPERVISOR DR. KOBUS AGENBAG (MCM/CAPE TOWN)
;
img_dir='C:\DATA\SEAWIFS-1998-2004-CLIMATOLOGY\'
;
img_file='clim_1998-2004_12.bil'
;
out_dir='E:\PROJECT\SEAWIFS_FILES\'
out_file='clim_1998-2004_03.txt'
;
;GEOGRAPHICAL COORDINATES OF THE IMAGE
start_lat=-5.00
end_lat=-40.00
start_lon=5.00
end_lon=40.00
;
;PIXEL SAMPLES (NUMBER OF COLUMNS), SCAN LINES (NUMBER OF ROWS), Xsize & Ysize
;
xdim=825

```

```

ydim=825
ysize=(start_lat-end_lat)/ydim
xsize=(end_lon-start_lon)/xdim
;
PRINT,ysize,xsize
;
;LENGTH OF THE SWATH
;
swath_width1=300 ;km (distance between the coast and the first point offshore)
;
;
y=106 ; arbitrary value obtained from the centre of the region(inverted image),
; values obtained from RDPIX (y1=543;y=649-543=106)
x1=84 ; Value of the first pixel in the scan line y=106
x2=85 ; Value of the second pixel in the scan line y=106
;
; CONVERSION OF X1 AND X2 INTO LON1 AND LON2
;
lon1= start_lon+(xsize/2)+x1*xsize
lon2= start_lon+(xsize/2)+x2*xsize
;
Print,"lon1=",lon1,"lon2=",lon2
;
;GEOGRAPHICAL COORDINATES OF A GIVEN REGION (IN THIS CASE:ANGOLA)
;
latn=-5.50
lats=-17.33
lone=9.00
lonw=15.00
;
;CONVERSION OF GEOGRAPHICAL COORDINATES (lat,long) INTO X,Y COORDINATES
;
yn=ROUND(((start_lat-latn)/ysize)-0.5) ; y1 (for latn)
ys=ROUND(((start_lat-lats)/ysize)-0.5) ; y2 (for lats)
xe=ROUND(((lone-start_lon)/xsize)-0.5) ; x1 (for long)
xw=ROUND(((lonw-start_lon)/xsize)-0.5) ; x2 (for long)
;
Print,"yn=",yn,"ys=",ys,"xe=",xe,"xw=",xw
;
;RANGE OF THE CHOLOROPHYLL-A CONCENTRATION (Chl_C) IN ANGOLA
;
minChl_C=0.1 ; mg/cubic meter (Minimum acceptable Cholorophyll_a concentration)
maxChl_C=50 ; mg/cubic neter (Maximum acceptable chlorophyll_a concentration)
maxval=(alog10(maxChl_C)+2.0)/0.015 ; Converting minChl_C into digital count
minval=(alog10(minChl_C)+2.0)/0.015 ; Converting maxChl_C into digital count
Print,"maxval=",maxval,"minval=",minval
min_percent_good=30 ; Minimum percentage ofgood Chl_C required
; in a swath in order to compute the mean_Ch1_C
;
;*****
;*****
file_path=img_dir + img_file
OPENR,luni,file_path,/GET LUN ; READING THE FIRST IMAGE
a=ASSOC(luni,BYTARR(xdim,ydim))
image=a(0)
CLOSE,luni & FREE_LUN,luni
;
y_start=Min([yn,ys]) ;MINIMUM VALUE OF LATITUDE
y_end= Max([yn,ys]) ;MAXIMUM VALUE OF LATITUDE
;
swath_mask=BYTARR(xdim,ydim); OPEN A 2 DIMENSIONAL ARRAY OF SWATH_MASK
;
FOR y=y_start,y_end DO BEGIN
;
; CONVERSION OF Y INTO THE CORRESPONDING LATITUDE
;
laty= start_lat-(ysize/2)-y*ysize
;
;COMPUTATION OF THE PIXEL SIZE USING MAP-2POINTS (LONG BEING CONSTANTS AND LAT, A ,VARIABLE)
;
xdim1=MAP_2POINTS(lon1,laty,lon2,laty,/meters)/1000; XDIM1/1000 CONVERTING M INTO KM

```

```

;
idx=where(image[*],y EQ 253, cnt) ; SEARCH FOR THE FIRST PIXEL AT THE LAND_BORDER
;
x_coast=idx(0) ; FIRST PIXEL FOUND AT THE COAST (LAND_BORDER)
x_swath_width1=ROUND(Float((swath_width1)/(xdim1))) ; NUMBER OF PIXELS BETWEEN THE
COAST AND THE FIRST SWATH
;
x11=x_coast ; X VALUE OF THE COAST
x12=(x11-1)-(x_swath_width1) ; X VALUE OF THE FIRST SWATH
;
PRINT,"x11=",x11,"x12=",x12,"y=",y,"xdim1=",xdim1
;
swath_mask[x12:x11,y]=125 ; FILL THE MASK_SWATH WITH 205

ENDFOR
;
;*****;*****
;*****;*****
;
idx_swath=WHERE(swath_mask EQ 125,num_idx_swath); CHECKING 125 ASSIGNED TO THE MASK
;
min_pixels=ROUND((min_percent_good/100.0)*num_idx_swath)
;
OPENR,luni,file_path,/GET_LUN
a=ASSOC(luni,BYTARR(xdim,ydim))
image=a(0)
CLOSE,luni & FREE_LUN,luni
;
subimage=INTARR(num_idx_swath)
Chl_C=FLTARR(num_idx_swath)
FOR i=0,num_idx_swath-1 DO BEGIN
x=idx_swath[i]MOD 825
y=idx_swath[i]/825
subimage(i)=image[idx_swath(i)]
;
;CHECKING THE PIXELS WITHIN THE REQUIRED RANGE AND EXCLUDING CLOUDS, LAND AND LAND_BORDER
;
index=WHERE (subimage LT 253 AND subimage GT minval AND subimage LE maxval,ct)
;
;CONVERSION OF DIGITAL COUNTS INTO Chl_C
;
Chl_C(i)=10^(0.015*subimage(i)-2.0)
;
; Print,i,x,y,subimage(i),Chl_C(i)
ENDFOR
;
;*****;*****
;*****;*****
;THE FOLLOWING SUBROUTINE ALLOWS TO DISPLAY MORE THAN ONE IMAGE (QUICKLOOK) WITH THE
;RESPECTIVE HISTOGRAM
;
Wnum=!D.Window+1
!ORDER = 1
DEVICE,DECOMPOSED = 0
wnum=0
WINDOW,wnum,Xsize=xdim,Ysize=ydim,title=img_file
LOADCT,13
TV, image
PLOTS, [84,167], [824,824], COLOR=12,/DEVICE
PLOTS, [100,176], [786,786], COLOR=12,/DEVICE
PLOTS, [100,145], [786,786], COLOR=12,/DEVICE
PLOTS, [160,196], [737,737], COLOR=12,/DEVICE
PLOTS, [192,206], [670,670], COLOR=12,/DEVICE
PLOTS, [150,167], [588,588], COLOR=12,/DEVICE
PLOTS, [116,157], [568,568], COLOR=12,/DEVICE
PLOTS, [123,158], [534,534], COLOR=12,/DEVICE
;*****;*****
;*****;*****
PLOTS, [84,100], [824,787], COLOR=12,/DEVICE
PLOTS, [145,160], [786,737], COLOR=12,/DEVICE
PLOTS, [160,192], [737,670], COLOR=12,/DEVICE

```

```

PLOTS, [150,192], [588,670], COLOR=12, /DEVICE
PLOTS, [116,150], [568,588], COLOR=12, /DEVICE
PLOTS, [116,123], [568,534], COLOR=12, /DEVICE
PLOTS, [100,128], [787,670], COLOR=12, /DEVICE
PLOTS, [81,128], [534,670], COLOR=12, /DEVICE
PLOTS, [81,123], [534,534], COLOR=12, /DEVICE

;*****
*****

str1="SEAWIFS Chl_a CONCENTRATION"
XYOUTS, 420, 695, str1, DEVICE=1, CHARSIZE=2, CHARTHICK=2.0, COLOR=0, ALIGNMENT=0.5
str2="DECEMBER"
XYOUTS, 420, 665, str2, DEVICE=1, CHARSIZE=2, CHARTHICK=2.0, COLOR=0, ALIGNMENT=0.5
str3=["LUANDA", "WALVIS BAY", "CAPE COLUMBINE"]
XYOUTS, 193, 729, str3(0), DEVICE=1, CHARSIZE=1, CHARTHICK=2.0, COLOR=75, ALIGNMENT=0.0
XYOUTS, 210, 433, str3(1), DEVICE=1, CHARSIZE=1, CHARTHICK=2.0, COLOR=75, ALIGNMENT=0.0
XYOUTS, 309, 163, str3(2), DEVICE=1, CHARSIZE=1, CHARTHICK=2.0, COLOR=75, ALIGNMENT=0.0
lats=-40.0
latn=-5.0
lonw=5.0
lone=40.0
MAP_SET, LIMIT=[lats, lonw, latn, lone], POSITION=[0.0, 0.0, 1.0, 1.0], /NOERASE, /NOBORDER

MAP_GRID, LATDEL=5, LONDEL=5, /LABEL, GLINESTYLE=0, LATLAB=lonw+0.3, LONLAB=lats+0.3, CHARSIZE=1.4, C
OLOR=0
MAP_GRID, LATDEL=1, LONDEL=1, COLOR=0, GLYNESTYLE=1
;
LOADCT, 13
TVLCT, 150, 150, 50, 254

RDPIX, image
;*****
*****
;image2=TVRD(0,0,TRUE=3)
;WRITE JPEG, "C:/MASTER THESIS/ANGOLA BENGUELA FRONT_CHL_A/clim_1998-
2004_12.jpg/", image2, TRUE=3, QUALITY=100, ORDER=1
;;
END

#####
#####

6. MEAN-SST IS COMPUTED FROM EACH SCAN LINE (ABFZ)
;IDL PROGRAM USED TO COMPUTE MEAN-SST FOR THE ANGOLA BENGUELA FRONT
;IDL PROGRAM WRITTEN BY VIANDA L.L. FILIPE /UCT MSc STUDENT (2005/2006)"
;SUPERVISOR DR. KOBUS AGENBAG (MCM/CAPE TOWN)
;
img_dir='C:\DATA\METEOSAT_MONTHLY_COMPOSITES\'
img_str='*.sst'
;
out_dir='C:\Master Thesis\EL_NINO\'
out_file='METEOSAT_SST_1995.txt'
;
;STARTING AND ENDING TIME (YEAR, MONTH & IMAGES)
start_year=1995
end_year=1995
start_month=1
end_month=12
start_img=1
end_img=1
;
;GEOGRAPHICAL COORDINATES OF THE IMAGE
;
start_lat=-5.00
end_lat=-40.00
start_lon=5.00
end_lon=40.00
;
;Pixel Samples (nber of columns), Scan lines (nber of rows), Xsize & Ysize
;

```

```

xdim=650
ydim=650
ysize=(start_lat-end_lat)/ydim
xsize=(end_lon-start_lon)/xdim
;
PRINT,ysize,xsize
;
;Lentgh of the swath
;
swath_width1=60 ;km (Distance between the coast and the first point offshore)
;
;
y=106 ; obtained from the centre of the region,values
; obtained from RDPIX (y1=543;y=649-543=106)
x1=84 ; Value of the first pixel in the scan line y=106
x2=85 ; Value of the second pixel in the scan line y=106
;
; CONVERSION OF X1 AND X2 INTO LONGITUDE 1 AND LONGITUDE 2
;
lon1= start_lon+(xsize/2)+x1*xsize
lon2= start_lon+(xsize/2)+x2*xsize
;
Print,"lon1=",lon1,"lon2=",lon2
;
;GEOGRAPHICAL COORDINATES OF A GIVEN REGION (In this case: Angola)
;
latn=-10
lats=-19
;
;CONVERSION OF GEOGRAPHICAL COORDINATES OF THE REGION (lat,long) into X,Y COORDINATES
;
yn=ROUND(((start_lat-latn)/ysize)-0.5) ; y1 (for latn)
ys=ROUND(((start_lat-lats)/ysize)-0.5) ; y2 (for lats)
;
Print,"yn=",yn,"ys=",ys
;
;TEMPERATURE RANGE ACCEPTABLE IN ANGOLAN WATERS
;
minT=12 ; minimum temperature
maxT=32 ; maximum temperature
;CONVERSION OF TEMPERATURES(DECIMAL) INTO DIGITAL NUMBERS (DN)
;
minval=2*(55-maxT)
maxval=2*(55-minT)
min_percent_good=50 ; MINIMUM PERCENTAGE OF GOOD SST REQUIRED IN A SWATH
;
;*****
;*****
n=12*((end_year)-(start_year)+1) ;TOTAL NUMBER OF BINARY FILES
Print,n ; number of files
arr=STRARR(n)
darr=INTARR(n)
barr=INTARR(n)
numfile=-1
MODE= 2

; THE FOLLOWING SUBROUTINE ALLOWS TO LIST ALL BINARY FILES
FOR year=start_year,end_year DO BEGIN
  str_year=STRTRIM(string(year),2)
  IF MODE EQ 1 THEN BEGIN
    IF year GT start_year THEN BEGIN
      sm=1
      em=12
    IF year EQ end_year THEN BEGIN
      sm=1
      em=end_month
    ENDIF
  ENDIF ELSE BEGIN
    sm=start_month
    em=12
  ENDELSE

```

```

ENDIF ELSE BEGIN; mode 2
    sm=start_month
    em=end_month
ENDELSE
;
    FOR month=sm,em DO BEGIN
        numfile=numfile+1
        IF month GT 9 THEN BEGIN
            str_month=STRTRIM(string(month),2)
        ENDIF ELSE BEGIN
            str_month='0'+ STRTRIM(string(month),2)
        ENDELSE
        img_str='b'+ str_year + str_month +'.sst'
        arr[numfile]=img_str
        barr[numfile]=year
        darr[numfile]=month
    ENDFOR

ENDFOR

Print,arr
;
;*****;*****
;*****;*****
;
img_str=img_dir+'*.sst'
img_list=FINDFILE(img_str,count=num_img)
;
file_path=img_dir + arr(0)
    OPENR,luni,file_path,/GET_LUN ; READING THE FIRST IMAGE
    a=ASSOC(luni,BYTARR(xdim,ydim))
    image=a(0)
    CLOSE,luni & FREE_LUN,luni
;
y_start=Min([yn,ys]); COMPUTE THE MINIMUM LATITUDE AS THE STARTING LAT
y_end= Max([yn,ys]); COMPUTE THE MAXIMUM LATITUDE AS THE ENDING LAT
;
;
numrows=y_end-y_start+1
;
swath_arr=INTARR(3,numrows+1)
yi=-1
;
FOR y=y_start,y_end DO BEGIN
    yi=yi+1
;
; CONVERSION OF Y INTO THE CORRESPONDING LATITUDE
;
laty= start_lat-(ysize/2)-y*ysize
;
;COMPUTATION OF THE PIXEL SIZE USING MAP-2POINTS (LONGITUDES LON1 & LONG2 ARE CONSTANTS $ AND
LATITUDE, A VARIABLE VARYING BETWEEN START_LAT AND END_LAT)
;
xdim1=MAP_2POINTS(lon1,laty,lon2,laty,/meters)/1000; XDIM1/1000 CONVERTING M INTO KM
;
idx=where(image[*],y) EQ 29,cnt)
;
x_coast=idx(0) ; FIRST PIXEL FOUND AT THE COAST (BORDER)
x_swath_width1=ROUND(Float((swath_width1)/(xdim1))) ; NUMBER OF PIXELS BETWEEN THE
COAST AND THE FIRST SWATH
;
x11=x_coast-1 ; X VALUE OF THE COAST
x12=(x11+1)-(x_swath_width1) ; X VALUE OF THE FIRST SWATH
;
PRINT,y,"x11=",x11,"x12=",x12,"xdim1=",xdim1,"x_swath_width1=",x_swath_width1
;
swath_arr(*,yi)=[y,x11,x12] ;STORING ALL Y_COORD. AND THE CORRESPONDING X11 AND X12
INTO SWATH_ARR
;
ENDFOR

```

```

Print, swath_arr
;
;*****;*****
;*****;*****
;
min_pixels=ROUND((min_percent_good/100.0)* x_swath_width1)
Print,min_pixels
n_images=numfile
;
OPENW,luno,out_dir+out_file,/GET_LUN; OPEN AN OUTPUT FILE
;
;
FOR j=0,n_images DO BEGIN ; PROCESSING OF ALL IMAGES
file_path=img_dir + arr(j)
index=WHERE(img_list EQ file_path,count); CHECK ANY MISSING IMAGE
;
IF count NE 0 THEN BEGIN
;
OPENR,luni,file_path,/GET_LUN
a=ASSOC(luni,BYTARR(xdim,ydim))
image=a(0)
CLOSE,luni & FREE_LUN,luni
;
averages=FLTARR(2,numrows)
;
; HOW TO FIND THE CORRESPONDING IMAGE VALUES FROM Y AND XL1 AND XL2
FOR i=0,numrows-1 DO BEGIN
;
y=swath_arr[0,i]
xl1=swath_arr[1,i]
xl2=swath_arr[2,i]
;
SUBIMAGE=image[xl2:xl1,y]
;Print,y,subimage
idx=WHERE (SUBIMAGE GT 30 AND SUBIMAGE GT minval AND SUBIMAGE LE maxval,ct); ;EXCLUDE
ALL CLOUDS, BORDER, LAND AND ALL DN OUTSIDE THE TEMP. RANGE SPECIFIED FOR ANGOLA
SST=55.0-(SUBIMAGE/2.0)
;
;
IF ct GE min_pixels THEN BEGIN ; A minimum number of good pixels is REQUIRED to
compute the mean SST
mean_SST=MEAN(SST(idx))
averages[0,i]=swath_arr[0,i] ;First column of scan lines
averages[1,i]=mean_SST ;Second column of mean SST

ENDIF ELSE BEGIN ;if the number of good pixels is less than the minimum required
than the file is rejected by writing -99.999
averages[0,i]=swath_arr[0,i] ;First column of scan lines
averages[1,i]=-9999.99 ;Second column of mean SST

ENDELSE
;
ENDFOR

ENDIF ELSE BEGIN

ENDELSE
;THE FOLLOWING SUBROUTINE ALLOWS TO WRITE THE OUTPUT IN A SPECIFIC OUTPUT FILE.
PRINTF,luno,arr(j)
PRINTF,luno,averages
;
ENDFOR
;
;*****;*****
;*****;*****
;
Close,luno & FREE_LUN,luno
END
#####
#####

```

7 CREATE A BINARY FILE FOR CONVERSION OF INDICES(825X825) TO INDICES(625X625)

```

; IDL PRG FOR CONVERTING INDICES (825X825) TO INDICES (650X650)
; IDL PRG WRITTEN BY VIANDA FILIPE, UCT MSC STUDENT (2005-2006)
; SUPERVISOR: DR JACOBUS J. AGENBAG
dir_name='C:\CLUSTER_1\CONGO PLUME\PLUME_METEOSAT_SST\FAROFFSHORE_PLUME\'
file_name='FAROFFSHORE.BIN'
out_dir='C:\CLUSTER_1\CONGO PLUME\PLUME_METEOSAT_SST\FAROFFSHORE_PLUME\'
out_file='FAROFFSHORE_XY.txt'
;
xdim=650
ydim=650
;
func1_dir='C:\CLUSTER_1\CLUSTER_IDL_PRG\' ; Directory for 'make_WC_swath_array'
;
CD,func1_dir,CURRENT=clusterdir ;Change directory and call the function "bsort"
RESOLVE_ROUTINE,'BSORT',/IS_FUNCTION
CD,clusterdir
;
clus_arr=LONARR(825) ; 825 is the number of pixels
OPENR,luni,dir_name+file_name,/GET_LUN
READU,luni,clus_arr ; read the binary file
CLOSE,luni & FREE_LUN,luni
;
;
print,clus_arr

N_arr=clus_arr[UNIQ(clus_arr,BSORT(clus_arr))]; to avoid duplication of pixels, the function
"uniq" is used after sorted the array.

idx_swath=N_arr
num_idx_swath=N_ELEMENTS(idx_swath); number of pixels after sorting and applied "Uniq"
;
Print,idx_swath,num_idx_swath
;
OPENW,luni,out_dir+out_file,/GET_LUN
;
For i=0,num_idx_swath-1 DO BEGIN ; compute the number of pixels
x=idx_swath(i)MOD 650
y=idx_swath(i)/650
PRINTF,luni,i,x,y,idx_swath(i)
ENDFOR
CLOSE,luni & FREE_LUN,luni
END

```

```

#####
#####

```

8 CLUSTER PROGRAMME: COMPUTATION OF MEAN_CHL_A IN COASTAL SUBREGION

```

;
;EXTRACTION OF CHLOROPHYLL a DATA FROM SEAWIFS IMAGES
;CALCULATION OF MONTHLY MEAN CHLOROPHYLL_a"
;IDL PROGRAM WRITTEN BY VIANDA L.L. FILIPE /UCT MSC STUDENT (2005/2006)"
;SUPERVISOR DR. KOBUS AGENBAG (MCM/CAPE TOWN)
;
img_dir='C:\DATA\SEAWIFS_GAC_MONTHLY\'
;
img_str='*.bil'
;
out_dir='C:\CLUSTER_1\SEAWIFS_CHL\'
out_file='COASTAL_SUBREGION_MEAN.txt'
out_file1='COASTAL_SUBREGION_XY.txt'
;
;STARTING AND ENDING TIME (YEAR,MONTH & IMAGES)
start_year=1998
end_year=2004
start_month=1

```

```

end_month=12
start_img=1
end_img=1
;
;GEOGRAPHICAL COORDINATES OF THE IMAGE
start_lat=-5.00
end_lat=-40.00
start_lon=5.00
end_lon=40.00
;
;PIXEL SAMPLES (NUMBER OF COLUMNS), SCAN LINES (NUMBER OF ROWS), Xsize & Ysize
;
xdim=825
ydim=825
ysize=(start_lat-end_lat)/ydim
xsize=(end_lon-start_lon)/xdim
;
PRINT,ysize,xsize
;
;LENGTH OF THE SWATH
;
swath_width1= 70 ;km (distance between the coast and the first point offshore)
swath_width2=300 ;km (distance between the first point and 2nd point offshore)
swath_width3=103 ;km (distance between the coast and the first point offshore)
;
;
y=106 ; arbitrary value obtained from the centre of the region (inverted image),
; values obtained from RDPIX (y1=543;y=649-543=106)
x1=84 ; Value of the first pixel in the scan line y=106
x2=85 ; Value of the second pixel in the scan line y=106
;
; CONVERSION OF X1 AND X2 INTO LON1 AND LON2
;
lon1= start_lon+(xsize/2)+x1*xsize
lon2= start_lon+(xsize/2)+x2*xsize
;
Print,"lon1=",lon1,"lon2=",lon2
;
;GEOGRAPHICAL COORDINATES OF A GIVEN REGION (IN THIS CASE:ANGOLA)
;
;REGION II-A
latn=-6.76061
lats=-7.14242
;REGION II-B
latn1=-7.14242
lats1=-8.71212
;REGION II-C
latn2=-8.71212
lats2=-17.3667
lone=9.00
lonw=15.00
;
;CONVERSION OF GEOGRAPHICAL COORDINATES (lat,long) INTO X,Y COORDINATES
;
yn=ROUND(((start_lat-latn)/ysize)-0.5) ; y1 (for latn)
ys=ROUND(((start_lat-lats)/ysize)-0.5) ; y2 (for lats)
xe=ROUND(((lone-start_lon)/xsize)-0.5) ; x1 (for long)
xw=ROUND(((lonw-start_lon)/xsize)-0.5) ; x2 (for long)

yn1=ROUND(((start_lat-latn1)/ysize)-0.5) ; y3 (for latn)
ys1=ROUND(((start_lat-lats1)/ysize)-0.5) ; y4 (for lats)
;
yn2=ROUND(((start_lat-latn2)/ysize)-0.5) ; y4 (for latn)
ys2=ROUND(((start_lat-lats2)/ysize)-0.5) ; y5 (for lats)
;
Print,"yn=",yn,"ys=",ys,"xe=",xe,"xw=",xw
;
;RANGE OF THE CHOLOROPHYLL-A CONCENTRATION (chl_C) IN ANGOLA
;

```

```

minChl_C=0.1 ; mg/cubic meter (Minimum acceptable Cholorophill_a
concentration)
maxChl_C=50 ; mg/cubic neter (Maximum acceptable chlorophill_a
concentration)
maxval=(alog10(maxChl_C)+2.0)/0.015 ; Converting minChl_C into digital count
minval=(alog10(minChl_C)+2.0)/0.015 ; Converting maxChl_C into digital count
Print,"maxval=",maxval,"minval=",minval
min_percent_good=30 ; Minimum percentage ofgood Chl_C required in a swath in order to
compute the mean_Ch1_C
;
n=12*((end_year)-(start_year)+1)
Print,n ; number of files
arr=STRARR(n)
darr=INTARR(n)
barr=INTARR(n)
numfile=-1
MODE= 2
;*****
;*****
;THE FOLLOWING SUBROUTINE ALLOWS TO LIST ALL BINARY FILES
FOR year=start_year,end_year DO BEGIN
  str_year=STRTRIM(string(year),2)
  IF MODE EQ 1 THEN BEGIN
    IF year GT start_year THEN BEGIN
      sm=1
      em=12
      IF year EQ end_year THEN BEGIN
        sm=1
        em=end_month
      ENDIF
    ENDIF ELSE BEGIN
      sm=start_month
      em=12
    ENDELSE
  ENDIF ELSE BEGIN; mode 2
    sm=start_month
    em=end_month
  ENDELSE
;
  FOR month=sm,em DO BEGIN
    numfile=numfile+1
    IF month GT 9 THEN BEGIN
      str_month=STRTRIM(string(month),2)
    ENDIF ELSE BEGIN
      str_month='0'+ STRTRIM(string(month),2)
    ENDELSE
    img_str='chl'+ str_year + str_month +'.bil'
    arr[numfile]=img_str
    barr[numfile]=year
    darr[numfile]=month
  ENDFOR
ENDFOR
Print,arr
;*****
;*****
;
img_str=img_dir+'*.bil'
img_list=FINDFILE(img_str,count=num_img)
;
file_path=img_dir + arr(0)
OPENR,luni,file_path,/GET_LUN ; READING THE FIRST IMAGE
a=ASSOC(luni,BYTARR(xdim,ydim))
image=a(0)
CLOSE,luni & FREE_LUN,luni
;
y_start=Min([yn,ys]) ;MINIMUM VALUE OF LATITUDE
y_end= Max([yn,ys]) ;MAXIMUM VALUE OF LATITUDE
;
y1_start=Min([yn1,ys1]) ;MINIMUM VALUE OF LATITUDE

```

```

y1_end= Max([yn1,ys1]) ;MAXIMUM VALUE OF LATITUDE
;
y2_start=Min([yn2,ys2]) ;MINIMUM VALUE OF LATITUDE
y2_end= Max([yn2,ys2]) ;MAXIMUM VALUE OF LATITUDE
;
;FIRST LOOP FOR THE SUBREGION II_B
;
swath_2a_mask=BYTARR(xdim,ydim); OPEN A 2 DIMENSIONAL ARRAY OF SWATH_MASK
FOR y=y_start,y_end DO BEGIN
;
; CONVERSION OF Y INTO THE CORRESPONDING LATITUDE
;
laty= start_lat-(ysize/2)-y*ysize
;
;COMPUTATION OF THE PIXEL SIZE USING MAP-2POINTS (LONG BEING CONSTANTS AND LAT, A VARIABLE)
;
xdim1=MAP_2POINTS(lon1,laty,lon2,laty,/meters)/1000; XDIM1/1000 CONVERTING M INTO KM
;
idx=where(image[* ,y] EQ 253,cnt) ; SEARCH FOR THE FIRST PIXEL AT THE LAND_BORDER
;
x_coast=idx(0) ; FIRST PIXEL FOUND AT THE COAST (LAND_BORDER)
x_swath_width1=ROUND(Float((swath_width1)/(xdim1))) ; NUMBER OF PIXELS BETWEEN THE
COAST AND THE FIRST SWATH
x_swath_width2=ROUND(Float((swath_width2)/(xdim1)))
;
;
x11=x_coast ; X VALUE OF THE COAST
x12=(x11-1)-(x_swath_width1) ; X VALUE OF THE FIRST SWATH
x13=(x12+1)-(x_swath_width2)
;
PRINT,"y=",y,"x11=",x11,"x12=",x12,x11,"x13=",x13,"xdim1=",xdim1
;
swath_2a_mask[x13:x12,y]=205 ; FILL THE MASK_SWATH WITH 205
ENDFOR
;*****
;*****
;SECOND LOOP FOR THE SUBREGION II_B
;
swath_2b_mask=BYTARR(xdim,ydim); OPEN A 2 DIMENSIONAL ARRAY OF SWATH_MASK
FOR y1=y1_start,y1_end DO BEGIN
;
; CONVERSION OF Y INTO THE CORRESPONDING LATITUDE
;
laty1= start_lat-(ysize/2)-y1*ysize
;
;COMPUTATION OF THE PIXEL SIZE USING MAP-2POINTS (LONG BEING CONSTANTS AND LAT, A VARIABLE)
;
xdim2=MAP_2POINTS(lon1,laty1,lon2,laty1,/meters)/1000; XDIM1/1000 CONVERTING M INTO KM
;
idx=where(image[* ,y1] EQ 253,cnt) ; SEARCH FOR THE FIRST PIXEL AT THE LAND_BORDER
;
x_coast=idx(0) ; FIRST PIXEL FOUND AT THE COAST (LAND_BORDER)
x_swath_width1=ROUND(Float((swath_width1)/(xdim2))) ; NUMBER OF PIXELS BETWEEN THE
COAST AND THE FIRST SWATH
x_swath_width3=ROUND(Float((swath_width3)/(xdim2)))
;
;
x14=x_coast ; X VALUE OF THE COAST
x15=(x14-1)-(x_swath_width1) ; X VALUE OF THE FIRST SWATH
x16=(x15+1)-(x_swath_width3)
;
PRINT,"y1=",y1,"x14=",x14,"x15=",x15,"x16=",x16,"xdim2=",xdim2
;
swath_2b_mask[x16:x15,y1]=205 ; FILL THE MASK_SWATH WITH 205
ENDFOR
;*****
;*****
;THIRD LOOP FOR THE SUBREGION II_C

```

```

;
      swath_2c_mask=BYTARR(xdim,ydim); OPEN A 2 DIMENSIONAL ARRAY OF SWATH_MASK
;
FOR y2=y2_start,y2_end DO BEGIN
;
; CONVERSION OF Y INTO THE CORRESPONDING LATITUDE
;
laty2= start_lat-(ysize/2)-y2*ysize
;
;COMPUTATION OF THE PIXEL SIZE USING MAP-2POINTS (LONG BEING CONSTANTS AND LAT, A VARIABLE)
;
xdim3=MAP_2POINTS(lon1,laty2,lon2,laty2,/meters)/1000; XDIM1/1000 CONVERTING M INTO KM
;
idx=where(image[* ,y2] EQ 253,cnt) ; SEARCH FOR THE FIRST PIXEL AT THE LAND_BORDER
;
x_coast=idx(0) ; FIRST PIXEL FOUND AT THE COAST (LAND_BORDER)
x_swath_width3=ROUND(Float((swath_width3)/(xdim3))) ; NUMBER OF PIXELS BETWEEN THE
COAST AND THE FIRST SWATH
;
x17=x_coast ; X VALUE OF THE COAST
x18=(x17-1)-(x_swath_width3) ; X VALUE OF THE FIRST SWATH
p=x17-x18
;
;
PRINT,"y2=",y2,"x17=",x17,"x18=",x18,"p=",p,"xdim3=",xdim3
;
swath_2c_mask[x18:x17,y2]=205 ; FILL THE MASK_SWATH WITH 205

ENDFOR
;*****
;*****
;idx_land=where(image EQ 253 OR image EQ 254,num_idx_land)
;image(idx_land)=swath_mask(idx_land)
;
;
idx_land=WHERE(image EQ 254,num_idx_land)
idx_border=WHERE(image EQ 253,num_idx_border)
swath_mask=[swath_2a_mask+swath_2b_mask+swath_2c_mask]
swath_mask[idx_land]=150
swath_mask[idx_border]=200
;
Print,"num_idx_land=",num_idx_land,"num_idx_border=",num_idx_border
;
;
!ORDER=1
wnum=!D.WINDOW+1
WINDOW,wnum,XSIZE=xdim,YSIZE=ydim
TVSCL,swath_mask > 100 < 255
TV,swath_mask
;
;*****
;*****
;
idx_swath1=WHERE(swath_2a_mask EQ 205,num_idx_swath1); CHECKING 205 ASSIGNED TO THE MASK
idx_swath2=WHERE(swath_2b_mask EQ 205,num_idx_swath2); CHECKING 205 ASSIGNED TO THE MASK
idx_swath3=WHERE(swath_2c_mask EQ 205,num_idx_swath3); CHECKING 205 ASSIGNED TO THE MASK
idx_swath=[idx_swath1,idx_swath2,idx_swath3]
num_idx_swath=N_ELEMENTS(idx_swath)
;idx_swath=WHERE(swath_mask_copy EQ 205,num_idx_swath)
;
Print,num_idx_swath1,num_idx_swath2,num_idx_swath3,num_idx_swath
;Print,num_idx_swath
;
min_pixels=ROUND((min_percent_good/100.0)*num_idx_swath)
Print,min_pixels
;
;computation of the Mean Chl_C excluding cloud and bad Chl_C
;
;
n_images=numfile
averages=FLTARR(3,n_images+1)
;
FOR j=0,n_images DO BEGIN ; Process all the images
file_path=img_dir + arr(j)

```

```

idx=where(img_list EQ file_path,count); checking the missing files
)
IF count NE 0 THEN BEGIN; only if there is no missing files
OPENR,luni,file_path,/GET_LUN
a=ASSOC(luni,BYTARR(xdim,ydim))
image=a(0)
CLOSE,luni & FREE_LUN,luni
)
;COMPUTATION OF X,Y COORDINATES FROM IDX_SWATH (GEOGRAPHICAL POSITION OF THE
;DIGITAL COUNTS CORRESPONDING TO THE Chl_C)
OPENW,luno,out_dir+out_file1,/GET_LUN;
subimage=INTARR(num_idx_swath)
Chl_C=FLTARR(num_idx_swath)
FOR i=0,num_idx_swath-1 DO BEGIN
x=idx_swath[i]MOD 825
y=idx_swath[i]/825
subimage(i)=image[idx_swath(i)]
)
;CHECKING THE PIXELS WITHIN THE REQUIRED RANGE AND EXCLUDING CLOUDS, LAND AND
LAND_BORDER
)
index=WHERE (subimage LT 253 AND subimage GT minval AND subimage LE maxval,ct)
)
;CONVERSION OF DIGITAL COUNTS INTO Chl_C
)
Chl_C(i)=10^(0.015*subimage(i)-2.0)
)
PRINTF,luno,i,x,y,subimage(i),Chl_C(i)
ENDFOR
Close,luno & FREE_LUN,luno
)
IF ct GE min_pixels THEN BEGIN ; A MINIMUM NUMBER OF GOOD PIXELS IS
REQUIRED IN ORDER TO COMPUTE THE MEAN_Ch1_C
mean_Ch1_C=MEAN(Chl_C(index)) ; COMPUTATION OF THE MEAN_Ch1_C
EXCLUDING ALL BAD VALUES (LAND, CLOUDS, BORDER AND ALL 0.1> Chl_C > 50mg/m3 )
averages[0,j]=barr(j) ; First column of years
averages[1,j]=darr(j) ; Second column of months
averages[2,j]=mean_Ch1_C ; Third column of mean_Ch1_C
ENDIF ELSE BEGIN
averages[0,j]=barr(j) ;First column of years
averages[1,j]=darr(j) ;Second column of months
averages[2,j]=-9999.99 ;Third column of mean_Ch1_C
ENDELSE
)
ENDIF ELSE BEGIN ; if there is any missing file, then write -9999.99
averages[0,j]=barr(j) ; First column of years
averages[1,j]=darr(j) ; Second column of months
averages[2,j]=-9999.99 ; Third column of mean_Ch1_C
ENDELSE
ENDFOR
)
;*****
;*****
)
For j=0,n_images DO PRINT,averages(0:1,j),averages(2,j),format='(I5,2X,I4,2X,F10.2)'
OPENW,luno,out_dir+out_file,/GET_LUN; open an output file
PRINTF,luno,"EXTRACTION OF CHLOROPHYLL_a DATA FROM SEAWIFS MONTHLY COMPOSITE
IMAGES",format='(5X,A70,/) '
PRINTF,luno,"CALCULATION OF MONTHLY MEAN CHLOROPHYLL-A USING A SWATH",format='(5X,A70,/) '
PRINTF,luno,"IDL PROGRAM WRITTEN BY VIANDA L.L. FILIPE /UCT MSc STUDENT
(2005/2006)",format='(5X,A70,/) '
PRINTF,luno,"SUPERVISOR DR. KOBUS AGENBAG (MCM/CAPE TOWN)",format='(10X,A50,/) '
PRINTF,luno,"MEAN SEAWIFS CHLOROPHYLL_a CONCENTRATION",format='(15X,A50,/) '
PRINTF,luno,start_year,start_month,start_img,format=$
'(5X,"START_YEAR=",I5,3X,"START_MONTH=",I3,3X,"START_IMAGE=",I2,5X,/) '
PRINTF,luno,end_year,end_month,end_img,format=$
'(5X,"END_YEAR=",I5,3X,"END_MONTH=",I3,3X,"END_IMAGE=",I2,5X,/) '
PRINTF,luno,latn,lone,$
format='(5X,"START_LATITUDE=",F10.4,3X,"START_LONGITUDE=",F10.4,5X,/) '
PRINTF,luno,lats,lonw,$
format='(5X,"END_LATITUDE=",F10.4,5X,"END_LONGITUDE=",F10.4,5X,/) '

```

```

PRINTF, luno, swath_width1, $
format='(5X,"SWATH_WIDTH1=",F10.4,/) '
PRINTF, luno, minChl_C, maxChl_C, $
format='(5X,"MINIMUM CHLOROPHYLL_a=",F12.4,5X,"MAXIMUM CHLOROPHYLL_a=",F12.4,5X,/) '
;
; Write mean Chl_C in six according to six composites per month
;
For j=0,n_images DO PRINTF,luno,averages(0:1,j), averages(2,j),$
format='(I5,2X,I4,2X,F10.2,4X,F10.2) '
Close,luno & FREE_LUN,luno
END

```

```

#####
#####

```

9 BINARY FILE (1-D FROM CLUSTER PROGRAM)

```

; IDL PRG FOR READING THE INDICES RESULTED FROM CLUSTER IMAGES
; IDL PRG WRITTEN BY VIANDA FILIPE, UCT MSC STUDENT (2005-2006)
img_dir='C:\cluster_1\'
img_file='clus12.bin'
out_dir='C:\cluster_1\'
out_file='clus10.txt'
xdim=825
ydim=825
;
;It is a LONARR( 36, 23280) array where:
;There are 3 columns for each of 12 clusters: 1-D, x- and y-coordinates
;The number of data values vary from cluster to cluster.
;
clus_arr=LONARR(36,23280)
OPENR,luni,img_dir+img_file,/GET_LUN
READU,luni,clus_arr
CLOSE,luni & FREE_LUN,luni
clus12_arr=clus_arr[33:35,*]
clus11_arr=clus_arr[30:32,*]
clus10_arr=clus_arr[27:29,*]
;
OPENW,luno,out_dir+out_file,/GET_LUN
;
For i=0,3118 DO BEGIN
x=clus10_arr(1,i)
y=clus10_arr(2,i)
;
; x=clus10_arr(0,i)MOD 825
; y=clus10_arr(0,i)/825
;
PRINTF,luno,i,x,y
ENDFOR
CLOSE,luno & FREE_LUN,luno
END

```

```

#####
#####

```

10 Display the CLUSTER image in different colours (RGB)

```

; IDL PGR FOR COLOUR TESTS
; IDL PGR WRITTEN BY Vianda Filipe, UCT MSC STUDENT (2005-2006)
img_dir='C:\CLUSTER_1\CONGO PLUME\'
png_file='clus12_CONGO_PLUME.png'
out_dir='C:\CLUSTER_1\'
out_file='CLUS12SST.txt'
xdim=825
ydim=825
img_path=img_dir+png_file
Read_png,img_path,cluster_img

;Create a window

Wnum=!D.Window+1

```

```

!ORDER=0
DEVICE,DECOMPOSED=0
Wnum=0
WINDOW,Wnum,Xsize=xdim,Ysize=ydim,title=img_path
;Display a monochrome image using different colours (RGB)
;
TV,cluster_img(0,*,*)
WAIT,5
TV,cluster_img(1,*,*)
WAIT,5
TV,cluster_img(2,*,*)
WAIT,5
;
;Display the image in different colours(RGB)
;
ERASE
TV,cluster_img(0,*,*),channel=1
WAIT,5
TV,cluster_img(2,*,*),channel=3
WAIT,5
ERASE
TV,cluster_img(1,*,*),channel=2
WAIT,5
;
; REFORM changes the dimension of an array without changing the total number of elements
;
imgred=REFORM(cluster_img(0,*,*))
imggrn=REFORM(cluster_img(1,*,*))
imgble=REFORM(cluster_img(2,*,*))
;
;RDPIX,imgred
;RDPIX,imggrn
;RDPIX,imgble
idx_clus02=WHERE(imgred EQ 20 AND imggrn EQ 20 AND imgble EQ 255,CNT_clus02)
idx_clus07=WHERE(imgred EQ 0 AND imggrn EQ 186 AND imgble EQ 74,CNT_clus07)
idx_clus11=WHERE(imgred EQ 252 AND imggrn EQ 107 AND imgble EQ 0,CNT_clus11)
idx_clus12=WHERE(imgred EQ 252 AND imggrn EQ 43 AND imgble EQ 255,CNT_clus12)
Print,CNT_clus02
Print,CNT_clus07
Print,CNT_clus11
Print,CNT_clus12
;tred=imgred
;
END

#####
#####

```

11 COMPUTATION OF THE CLUSTER INDICES

```

;EXTRACTION OF SST DATA FROM METEOSAT IMAGES
;THE PROGRAM EXTRACTS INDICES FROM CLUSTERS AND COMPUTES
;THE MONTHLY MEAN SST FOR EACH SUB_REGION
;IDL PROGRAM WRITTEN BY VIANDA L.L. FILIPE /UCT MSc STUDENT (2005/2006)"
;SUPERVISOR DR. KOBUS AGENBAG (MCM/CAPE TOWN)
;
img_dir='C:\DATA\METEOSAT_MONTHLY_COMPOSITES\'
;
img_str='*.SST'
;
out_dir='C:\CLUSTER_1\CONGO_PLUME\PLUME_METEOSAT_SST\FAROFFSHORE_PLUME\'
out_file='FAROFFSHORE_MEAN_SST.TXT'
;
out_file1='FAROFFSHORE_SST_XY.TXT'
;
;STARTING AND ENDING TIME (YEAR,MONTH & IMAGES)
start_year=1987
end_year=2003
start_month=1
end_month=12

```

```

start_img=1
end_img=1
;
;GEOGRAPHICAL COORDINATES OF THE IMAGE
start_lat=-5.00
end_lat=-40.00
start_lon=5.00
end_lon=40.00
;
;PIXEL SAMPLES (NUMBER OF COLUMNS), SCAN LINES (NUMBER OF ROWS), Xsize & Ysize
;
xdim=650
ydim=650
ysize=(start_lat-end_lat)/ydim
xsize=(end_lon-start_lon)/xdim
;
PRINT,ysize,xsize
;
;LENGTH OF THE SWATH
;
swath_width1=370 ;km (distance between the coast and the first point offshore)
;
y=106 ; arbitrary value obtained from the centre of the region(inverted image),
; values obtained from RDPIX (y1=543;y=649-543=106)
x1=84 ; Value of the first pixel in the scan line y=106
x2=85 ; Value of the second pixel in the scan line y=106
;
; CONVERSION OF X1 AND X2 INTO LON1 AND LON2
;
lon1= start_lon+(xsize/2)+x1*xsize
lon2= start_lon+(xsize/2)+x2*xsize
;
Print,"lon1=",lon1,"lon2=",lon2
;
;GEOGRAPHICAL COORDINATES OF A GIVEN REGION (IN THIS CASE:ANGOLA)
;
latn=-5.02
lats=-17.33
lone=9.00
lonw=15.00
;
;CONVERSION OF GEOGRAPHICAL COORDINATES (lat,long) INTO X,Y COORDINATES
;
yn=ROUND(((start_lat-latn)/ysize)-0.5) ; y1 (for latn)
ys=ROUND(((start_lat-lats)/ysize)-0.5) ; y2 (for lats)
xe=ROUND(((lone-start_lon)/xsize)-0.5) ; x1 (for long)
xw=ROUND(((lonw-start_lon)/xsize)-0.5) ; x2 (for long)
;
Print,"yn=",yn,"ys=",ys,"xe=",xe,"xw=",xw
;
;TEMPERATURE RANGE ACCEPTABLE IN ANGOLAN WATERS
;
minT=12 ; minimum temperature
maxT=32 ; maximum temperature
;CONVERSION OF TEMPERATURES(DECIMAL) INTO DIGITAL NUMBERS (DN)
;
minval=2*(55-maxT)
maxval=2*(55-minT)
min_percent_good=30 ; MINIMUM PERCENTAGE OF GOOD SST REQUIRED IN A SWATH
;
n=12*((end_year)-(start_year)+1)
Print,n ; number of files
arr=STRARR(n)
darr=INTARR(n)
barr=INTARR(n)
numfile=-1
MODE= 2
;*****
;*****
FOR year=start_year,end_year DO BEGIN

```

```

str_year=STRTRIM(string(year),2)
IF MODE EQ 1 THEN BEGIN
  IF year GT start_year THEN BEGIN
    sm=1
    em=12
    IF year EQ end_year THEN BEGIN
      sm=1
      em=end_month
    ENDIF
  ENDIF ELSE BEGIN
    sm=start_month
    em=12
  ENDELSE
ENDIF ELSE BEGIN; mode 2
  sm=start_month
  em=end_month
ENDELSE
;
FOR month=sm,em DO BEGIN
  numfile=numfile+1
  IF month GT 9 THEN BEGIN
    str_month=STRTRIM(string(month),2)
  ENDIF ELSE BEGIN
    str_month='0'+ STRTRIM(string(month),2)
  ENDELSE
  img_str='b'+ str_year + str_month +'.sst'
  arr[numfile]=img_str
  barr[numfile]=year
  darr[numfile]=month
ENDFOR

ENDFOR
Print,arr
;*****
;*****
;
img_str=img_dir+'.sst'
img_list=FINDFILE(img_str,count=num_img)
;
;*****
;*****
; SUBPROGRAM ALLOWING TO EXTRACT X AND Y COORDINATES INCLUDING 1-D FROM THE BINARY ;FILE
"CLUS12.BIN"
; GENERATED BY THE IDL CLUSTER PROGRAM "MAKE CLUSTERS"
;
dir_name='C:\CLUSTER_1\CONGO PLUME\PLUME_METEOSAT_SST\FAROFFSHORE_PLUME\'
file_name='FAROFFSHORE.BIN'
;
;
func1_dir='C:\CLUSTER_1\CLUSTER_IDL_PRG\' ; Directory for 'make_WC_swath_array'
;
CD,func1_dir,CURRENT=clusterdir
RESOLVE_ROUTINE,'BSORT',/IS_FUNCTION
CD,clusterdir
;
outarr=LONARR(825)
OPENR,luni,dir_name+file_name,/GET_LUN
  READU,luni,outarr
  CLOSE,luni & FREE_LUN,luni
;
Clus_arr=outarr[UNIQ(outarr,BSORT(outarr))]
;
idx_swath=Clus_arr
num_idx_swath=N_ELEMENTS(idx_swath)
;
Print,num_idx_swath
;
;*****
;*****
min_pixels=ROUND((min_percent_good/100.0)* num_idx_swath)

```

```

;
;computation of the Mean_sst excluding cloud and bad SST
;
n_images=numfile
averages=FLTARR(3,n_images+1)
;
FOR j=0,n_images DO BEGIN      ; Process all the images
  file_path=img_dir + arr(j)
  idx=where(img_list EQ file_path,count); checking the missing files
  ;
  IF count NE 0 THEN BEGIN; only if there is no missing files
    OPENR,luni,file_path,/GET_LUN
    a=ASSOC(luni,BYTARR(xdim,ydim))
    image=a(0)
    CLOSE,luni & FREE_LUN,luni
;*****
;*****
;COMPUTATION OF X,Y COORDINATES FROM IDX_SWATH (GEOGRAPHICAL POSITION OF THE DIGITAL COUNTS
CORRESPONDING TO THE SST)
;
  OPENW,luno,out_dir+out_file1,/GET_LUN;

    subimage=INTARR(num_idx_swath)
    SST=FLTARR(num_idx_swath)
    ;
    FOR i=0,num_idx_swath-1 DO BEGIN

      x=idx_swath(i)MOD 650      ;CALCULATION OF X COORDINATES
      y=idx_swath (i)/650      ; CALCULATION OF Y COORDINATES
      subimage(i)=image[idx_swath(i)]

;CHECKING THE PIXELS WITHIN THE REQUIRED RANGE (EXCLUDING LAND,BORDER,CLOUDS AND ALL ;SST
OUTSIDE THE RANGE)
;
      index=WHERE (subimage GT 30 AND subimage GT minval AND subimage LE maxval,ct)
      SST(i)=55.0-(subimage(i)/2.0) ; CONVERSION OF DIGITAL COUNTS INTO DEGREE CELSIUS
      ;
      PRINTF,luno,i,x,y,subimage(i),sst(i)
    ENDFOR
    Close,luno & FREE_LUN,luno
    ;
    IF ct GE min_pixels THEN BEGIN; A minimum number of good pixels is REQUIRED to
compute the mean SST
      mean_SST=MEAN(SST(index))
      averages[0,j]=barr(j)      ;First column of years
      averages[1,j]=darr(j)      ;Second colum of months
      averages[2,j]=mean_SST     ;Third column of mean SST
      ENDFIF ELSE BEGIN          ;if the number of good pixels is less than the
minimum required than the file is rejected by writing -99.999
      averages[0,j]=barr(j)      ;First column of years
      averages[1,j]=darr(j)      ;Second colum of months
      averages[2,j]=-9999.99     ;Third column of mean SST
      ENDELSE
      ;
      ENDFIF ELSE BEGIN; if there is any missing file, then write -9999.99
      averages[0,j]=barr(j)      ; First column of years
      averages[1,j]=darr(j)      ; Second column of months
      averages[2,j]=-9999.99     ; Third column of mean SST
      ENDELSE
    ENDFOR
;*****
;*****
;
For j=0,n_images DO PRINT,averages(0:1,j),averages(2,j),format='(I5,2X,I4,2X,F10.2)'
;
OPENW,luno,out_dir+out_file,/GET_LUN; open an ouput file
;
PRINTF,luno, "EXTRACTION OF MEAN_SST DATA FROM METEOSAT MONTHLY COMPOSITE
IMAGES",format='(5X,A70,/)'
PRINTF,luno,"CALCULATION OF MONTHLY SST USING THE SWATH",format='(5X,A70,/)'

```

```

PRINTF,luno,"IDL PROGRAM WRITTEN BY VIANDA L.L. FILIPE /UCT MSc STUDENT
(2005/2006)",format='(5X,A70,/) '
PRINTF,luno,"SUPERVISOR DR. KOBUS AGENBAG (MCM/CAPE TOWN)",format='(10X,A50,/) '
PRINTF,luno,"MEAN_SST",format='(15X,A50,/) '
PRINTF,luno,start_year,start_month,start_img,format=$
'(5X,"START_YEAR=",I5,3X,"START_MONTH=",I3,3X,"START_IMAGE=",I2,5X,/) '
PRINTF,luno,end_year,end_month,end_img,format=$
'(5X,"END_YEAR=",I5,3X,"END_MONTH=",I3,3X,"END_IMAGE=",I2,5X,/) '
PRINTF,luno,latn,lone,$
format='(5X,"START_LATITUDE=",F10.4,3X,"START_LONGITUDE=",F10.4,5X,/) '
PRINTF,luno,lats,lonw,$
format='(5X,"END_LATITUDE=",F10.4,5X,"END_LONGITUDE=",F10.4,5X,/) '
PRINTF,luno,swath_widthl,$
format='(5X,"SWATH_WIDTH1=",F10.4,/) '
PRINTF,luno,minval,maxval,$
format='(5X,"MAXVAL=",F12.4,5X,"MINVAL=",F12.4,5X,/) '
;
; Write monthly mean SST
For j=0,n_images DO PRINTF,luno,averages(0:1,j), averages(2,j),
format='(I5,2X,I4,2X,F10.2,4X,F10.2) '

Close,luno & FREE_LUN,luno
END

```

```

#####
#####

```

12 COMPUTATION OF MEAN-CHL USING CLUSTER INDICES

```

;EXTRACTION OF CHL DATA FROM SEAWIFS IMAGES
;IDL PROGRAM WRITTEN BY VIANDA L.L. FILIPE /UCT MSc STUDENT (2005/2006)
;SUPERVISOR DR. KOBUS AGENBAG (MCM/CAPE TOWN)
;
img_dir='C:\DATA\SEAWIFS_GAC_MONTHLY\'
img_str='*.bil'
;
out_dir='C:\CLUSTER_1\'
out_file='CLUS10_Ch1_C.txt'
;
;STARTING AND ENDING TIME (YEAR,MONTH & IMAGES)
start_year=1998
end_year=1998
start_month=1
end_month=1
start_img=1
end_img=1
;
;GEOGRAPHICAL COORDINATES OF THE IMAGE
;
start_lat=-5.00
end_lat=-40.00
start_lon=5.00
end_lon=40.00
;
;Pixel Samples (nber of columns), Scan lines (nber of rows), Xsize & Ysize
;
xdim=825
ydim=825
ysize=(start_lat-end_lat)/ydim
xsize=(end_lon-start_lon)/xdim
;
PRINT,ysize,xsize
;
;Lentgh of the swath
;
swath_widthl=370 ;km (Distance between the coast and the first point offshore)
;
;
y=106 ; obtained from the centre of the region,values
; obtained from RDPIX (y1=543;y=649-543=106)
x1=84 ; Value of the first pixel in the scan line y=106
x2=85 ; Value of the second pixel in the scan line y=106

```

```

;
; CONVERSION OF X1 AND X2 INTO LONGITUDE 1 AND LONGITUDE 2
;
lon1= start_lon+(xsize/2)+x1*xsize
lon2= start_lon+(xsize/2)+x2*xsize
;
Print,"lon1=",lon1,"lon2=",lon2
;
;GEOGRAPHICAL COORDINATES OF A GIVEN REGION (In this case: Angola)
;
latn=-5.50
lats=-17.33
lone=9.00
lonw=15.00
;
;CONVERSION OF GEOGRAPHICAL COORDINATES OF THE REGION (lat,long) into X,Y COORDINATES
;
yn=ROUND(((start_lat-latn)/ysize)-0.5) ; y1 (for latn)
ys=ROUND(((start_lat-lats)/ysize)-0.5) ; y2 (for lats)
xe=ROUND(((lone-start_lon)/xsize)-0.5) ; x1 (for long)
xw=ROUND(((lonw-start_lon)/xsize)-0.5) ; x2 (for long)
;
Print,"yn=",yn,"ys=",ys,"xe=",xe,"xw=",xw
;
;Chl_C RANGE ACCEPTABLE IN ANGOLAN WATERS
;
minchl_C=0.1 ; minimum temperature
maxchl_C=50 ; maximum temperature
;CONVERSION OF Chl_C(DECIMAL) INTO DIGITAL NUMBERS (DN)
;
minval=(alog10(minchl_C)+2.0)/0.015
maxval=(alog10(maxchl_C)+2.0)/0.015
min_percent_good=30 ; MINIMUM PERCENTAGE OF GOOD Chl_C REQUIRED IN A SWATH
;
;
Print,minchl_C,maxchl_C
n=12*((end_year)-(start_year)+1) ;TOTAL NUMBER OF BINARY FILES
Print,n ; number of files
arr=STRARR(n)
darr=INTARR(n)
barr=INTARR(n)
numfile=-1
MODE= 2
; THE FOLLOWING SUBROUTINE ALLOWS TO LIST ALL BINARY FILES
FOR year=start_year,end_year DO BEGIN
  str_year=STRTRIM(string(year),2)
  IF MODE EQ 1 THEN BEGIN
    IF year GT start_year THEN BEGIN
      sm=1
      em=12
      IF year EQ end_year THEN BEGIN
        sm=1
        em=end_month
      ENDIF
    ENDIF ELSE BEGIN
      sm=start_month
      em=12
    ENDELSE
  ENDIF ELSE BEGIN; mode 2
    sm=start_month
    em=end_month
  ENDELSE
;
  FOR month=sm,em DO BEGIN
    numfile=numfile+1
    IF month GT 9 THEN BEGIN
      str_month=STRTRIM(string(month),2)
    ENDIF ELSE BEGIN
      str_month='0'+ STRTRIM(string(month),2)
    ENDELSE
    img_str='chl'+ str_year + str_month +'.bil'
  
```

```

arr(numfile)=img_str
barr[numfile]=year
darr[numfile]=month

ENDFOR

ENDFOR
Print,arr
;*****
;*****
img_str=img_dir+'.bil'
img_list=FINDFILE(img_str,count=num_img)
;*****
;*****
;
image_dir='C:\cluster_1\'
image_file='clus12.bin'
;out_dir='C:\cluster_1\'
;out_file='clus10.txt'
xdim1=825
ydim1=825
;
;*****
;*****
;It is a LONARR( 36, 23280) array where:
;There are 3 columns for each of 12 clusters: 1-D, x- and y-coordinates
;The number of data values vary from cluster to cluster.
;
clus_arr=LONARR(36,23280)
OPENR,luni,image_dir+image_file,/GET_LUN
READU,luni,clus_arr
CLOSE,luni & FREE_LUN,luni
clus12_arr=clus_arr[33:35,*]
clus11_arr=clus_arr[30:32,*]
clus10_arr=clus_arr[27:29,*]
;
;OPENW,luno,out_dir+out_file,/GET_LUN
;
;For i=0,3118 DO BEGIN
; x=clus10_arr(1,i)
; y=clus10_arr(2,i)
;
; x=clus10_arr(0,i)MOD 825
; y=clus10_arr(0,i)/825
;
;PRINTF,luno,i,x,y
;ENDFOR
;CLOSE,luno & FREE_LUN,luno
;*****
;*****
n_images=numfile
;
OPENW,luno,out_dir+out_file,/GET_LUN; OPEN AN OUTPUT FILE
;
FOR j=0,n_images DO BEGIN ; Process all the images
file_path=img_dir + arr(j)

OPENR,luni,file_path,/GET_LUN
a=ASSOC(luni,BYTARR(xdim,ydim))
image=a(0)
CLOSE,luni & FREE_LUN,luni
;
;COMPUTATION OF X,Y COORDINATES FROM IDX SWATH (GEOGRAPHICAL POSITION OF THE
;DIGITAL COUNTS CORRESPONDING TO THE Chl_C)
;
subimage=INTARR(3119)
Chl_C=FLTARR(3119)
FOR i=0,3118 DO BEGIN
x=clus10_arr(0,i)MOD 825
y=clus10_arr(0,i)/825
subimage(i)=image[clus10_arr(0,i)]
;

```

```

;CHECKING THE PIXELS WITHIN THE REQUIRED RANGE AND EXCLUDING CLOUDS, LAND AND LAND_BORDER
;
; index=WHERE (subimage LT 253 AND subimage GT minval AND subimage LE maxval,ct)
;
; CONVERSION OF DIGITAL COUNTS INTO Chl_C
;
; Chl_C(i)=10^(0.015*subimage(i)-2.0)
;
; Printf,luno,i,x,y,subimage(i),Chl_C(i)
ENDFOR
;
; mean_Ch1_C=MEAN(Chl_C(index)) ; COMPUTATION OF THE MEAN_Ch1_C EXCLUDING ALL BAD
VALUES (LAND, CLOUDS, BORDER AND ALL 0.1> Chl_C > 50mg/m3 )
;
; averages[0,j]=barr(j) ; First column of years
;
; averages[1,j]=darr(j) ; Second colun of months
;
; averages[2,j]=mean_Ch1_C ; Third column of mean_Ch1_C
;
; Printf,luno,mean_Ch1_C
ENDFOR
;
;
; *****
; *****
;
; Close,luno & FREE_LUN,luno
END

```

```

#####
#####

```

13 CREATE A BINARY FILE FROM A CSV FILE

```

; IDL PRG FOR CREATING A BINARY FILE FROM A CSV FORMAT FILE
; IDL PRG WRITTEN BY VIANDA FILIPE, UCT MSC STUDENT (2005-2006)
;
;
; arr=LONARR(850)
;
; dir_name='C:\CLUSTER_1\CONGO PLUME\PLUME METEOSAT_SST\FAROFFSHORE_PLUME\'
; file_name='FAROFFSHORE.CSV'
;
; out_dir='C:\CLUSTER_1\CONGO PLUME\PLUME METEOSAT_SST\FAROFFSHORE_PLUME\'
; out_file='FAROFFSHORE.BIN'
;
; file_path=dir_name+file_name
; rec=-1
; OPENR,luni,file_path,/GET_LUN
; str=''
; WHILE EOF(luni) NE 1 DO BEGIN
;   READF,luni,str
;   len=STRLEN(str)
;   sarr=STRARR(len)
;   FOR i=0,len-1 DO sarr[i]=STRMID(str,i,1)
;   idx=WHERE(sarr EQ ',',cnt)
;   ;
;   a=LONARR(1)
;   ;
;   substr=STRMID(str,0,len-idx[0]-1)
;   READS,substr,c & a[0]=LONG(c)
;   ;Print,a
;   ;
;   rec=rec+1
;   arr(rec)=a
; ENDWHILE
;
; Print,"rec=",rec
; *****
; *****
; arr=arr[0:rec]
; CLOSE,luni & FREE_LUN,luni
; Print,arr
; PRINT,'All done'
; OPENW,luni,out_dir+out_file,/GET_LUN
; *****
; *****
; outarr=LONARR(rec+1)

```

```

outarr[*]=arr
WRITEU,luni,outarr
PRINT,'Number of records in output array =',rec
CLOSE,luni & FREE_LUN,luni
PRINT,OUTARR
END
*****
#####
#####

```

**14 USE OF CTD GEOGRAPHICAL COORDINATES FOR THE CORRESPONDING
CHL PIXELS FROM SEAWIFS IMAGES**

```

; BUILD PENTADE FROM CTD SALINITY DATA WITH IDL PRG
; IDL PRG WRITTEN BY VIANDA FILIPE, UCT MSC STUDENT (2005-2006)
img_dir="C:/DATA/METEOSAT_IMAGES_5DAYS_COMPOSITES/"
img_str=".sst"
;*****
;*****
dir_name='C:\CLUSTER 1\CONGO PLUME\CTD SALINITY\CTD_RESULTS\'
file_name='CTD_3_2003_SURVEY.bin'
out_dir='C:\CLUSTER 1\CONGO PLUME\CTD SALINITY\CTD_RESULTS\'
out_file='CTD_3_2003_SURVEY.txt'

;*****
;*****
start_lat=-5.00
end_lat=-40.00
start_lon=5.00
end_lon=40.00
;
;Conversion of latitude and longitude into X,Y coordinates
;
xdim=650
ydim=650
ysize=(start_lat-end_lat)/ydim
xsize=(end_lon-start_lon)/xdim
;
;*****
;*****
ctd95_arr=FLTARR(9,261)
OPENR,luni,dir_name+file_name,/GET_LUN
READU,luni,ctd95_arr
CLOSE,luni & FREE_LUN,luni
print,ctd95_arr
year=FIX(ctd95_arr[1,*])
month=FIX(ctd95_arr[2,*])
day=FIX(ctd95_arr[3,*])
lat=ctd95_arr[4,*]
lon=ctd95_arr[5,*]
sal=ctd95_arr[7,*]
;
;*****
;*****
IDX_ARR=LONARR(194)
SSTFILE_ARR=STRARR(194)
PENTADE=INTARR(2,6)
PENTADE[*,*]=[1,5,6,10,11,15,16,20,21,25,26,31]
FOR i=0,193 DO BEGIN
year=FIX(ctd95_arr[1,i])
month=FIX(ctd95_arr[2,i])
day=FIX(ctd95_arr[3,i])
;
pent=0
FOR j=0,5 DO BEGIN
IF day GE PENTADE[0,j] AND day LE PENTADE[1,j] THEN pent=j+1
;PRINT,pent
ENDFOR
ystr=STRTRIM(string(year),2)
IF MONTH GT 9 THEN BEGIN

```

```

        mstr=STRTRIM(string(month),2)
    ENDIF ELSE BEGIN
        mstr='0'+STRTRIM(string(month),2)
    ENDELSE
    pstr=STRTRIM(string(pent),2)
    ; chfile="chl"+ystr+mstr+"p"+pstr+".bil"
    sstfile="b"+ystr+mstr+"p"+pstr+".sst"
;
y=ROUND(((start_lat-lat(i))/ysize)-0.5) ; y1 (for latn)

x=ROUND(((lon(i)-start_lon)/xsize)-0.5) ; x1 (for long)
;
idx=(y*ydim)+x
idx_arr[*,*]=idx
sstfile_arr[*,*]=sstfile
PRINT,i,x,y,sstfile_arr(i)
ENDFOR
;STOP
Print,sstfile_arr[0:10]
;*****
;*****
subimage=INTARR(194)
sst=FLTARR(194)
OPENW,luno,out_dir+out_file,/GET_LUN
FOR k=0,193 DO BEGIN
    File_path=img_dir+sstfile_arr(k)
    OPENR,luni,file_path,/GET_LUN
    a=ASSOC(luni,BYTARR(xdim,ydim))
    image=a(0)
    CLOSE,luni & FREE_LUN,luni
;
    x=idx_arr(k)MOD xdim
    y=idx_arr(k)/ydim
    subimage(k)=image[idx_arr(k)]
    sst(k)=55.0-(subimage(k)/2.0)
;
    Printf,luno,x,y,sstfile_arr(k),sal(k),sst(k)
ENDFOR
CLOSE,luno & FREE_LUN,luno
END

#####
#####

```

15 READ CTD-BINARY FILE WITH 8 PARAMETERS (EIGHT COLUMNS)

```

; IDL PRG FOR READING A CTD-BINARY FILE WITH 8 PARAMETERS
; IDL PRG WRITTEN BY Vianda Filipe, UCT STUDENT (2005-2006)
arr=FLTARR(9,400)
dir_name='C:\CLUSTER 1\CONGO PLUME\CTD_SALINITY\CTD_RESULTS\'
file_name='CTD_8_2003_SURVEYS.CSV'
out_dir='C:\CLUSTER 1\CONGO PLUME\CTD_SALINITY\CTD_RESULTS\'
out_file='CTD_8_2003_SURVEY.bin'
file_path=dir_name+file_name
rec=-1
OPENR,luni,file_path,/GET_LUN
str=''
WHILE EOF(luni) NE 1 DO BEGIN
    READF,luni,str
    len=STRLEN(str)
    sarr=STRARR(len)
    FOR i=0,len-1 DO sarr[i]=STRMID(str,i,1)
    idx=WHERE(sarr EQ ',',cnt)
    a=FLTARR(9)
;
    substr=STRMID(str,0,idx[0])
    READS,substr,c & a[0]=FIX(c)
;
    substr=STRMID(str,idx[0]+1,idx[1]-idx[0]-1)
    READS,substr,c & a[1]=FIX(c)

```

```

;
substr=STRMID(str,idx[1]+1,idx[2]-idx[1]-1)
READS,substr,c & a[2]=FIX(c)
;
substr=STRMID(str,idx[2]+1,idx[3]-idx[2]-1)
READS,substr,c & a[3]=FIX(c)
;
substr=STRMID(str,idx[3]+1,idx[4]-idx[3]-1)
READS,substr,c & a[4]=FLOAT(c)
;
substr=STRMID(str,idx[4]+1,idx[5]-idx[4]-1)
READS,substr,c & a[5]=FLOAT(c)

substr=STRMID(str,idx[5]+1,idx[6]-idx[5]-1)
READS,substr,c & a[6]=FLOAT(c)

substr=STRMID(str,idx[6]+1,idx[7]-idx[6]-1)
READS,substr,c & a[7]=FLOAT(c)
;
substr=STRMID(str,idx[7]+1,len-idx[7]-1)
READS,substr,c & a[8]=FLOAT(c)
;
PRINT,a[4]

rec=rec+1
arr(*,rec)=a

ENDWHILE
Print,"rec=",rec
;
;*****
;*****
arr=arr[*,0:rec]
CLOSE,luni & FREE_LUN,luni
Print,arr
PRINT,'All done'
OPENW,luni,out_dir+out_file,/GET_LUN
arr1=arr[0:8,*]
;*****
;*****
outarr=FLTARR(9,rec+1)
outarr[0:8,*]=arr
WRITEU,luni,outarr
PRINT,outarr
PRINT,'Number of records in output array =',rec
CLOSE,luni & FREE_LUN,luni
;*****
;*****
ctd_arr=FLTARR(9,rec+1)
OPENR,luni,out_dir+out_file,/GET_LUN
READU,luni,ctd_arr
CLOSE,luni & FREE_LUN,luni
PRINT,ctd_arr
END

```

```

#####
#####

```

CLUSTER PROGRAMS

16 Function 'fill_blanks_2'

```

;
; This version differ from 'fill_blanks_1' in that a more sophisticated calculation
; scheme is used in so far as that the blanks are filled in a sequence such that
; the pixels with the highest probability for a good estimate (more neighbours) are
; filled first. In 'fill_blanks_1' the sequence is purely according to the 1-D index
; of blank pixels obtained from a WHERE.
;
; This function is intended to fill small numbers of 'no data' pixels
; in a 2-D array by linear interpolation from neighbouring pixels.
;

```

```

; Input required:
;   image0   the 2-D array which must be filled. It may be type
;             BYTE, INTEGER or FLOATING POINT. All interpolation
;             calculations are performed as floating point but
;             the result is returned as the same type as the input
;             image.
;   bval     The pixel value of those pixels to be filled in
;   nodata   Pixels with this value will not be filled or used in the
;             interpolation/extrapolation process. It is typically meant for
;             situations where 'image' contains a land mask.
;
; Output     A 2-D array of the same dimensions and type as the input
;
; Principle of operation:
; Each pixel with value = bval is considered to be at the centre of a 5x5 kernel
; (Using the notation the pixels in the first 'ring' around the central pixel are
; named: N1, NE1, E1, etc and those in the second 'ring' are named N2, NE2, E2 etc)
; A value for the central pixel is then computed from the following pairs of pixels
; where (1) the calculation is only performed if both pixels in the pair are not
; equal to bval and (2) each such calculation produce a result which is weighted
; by a weight inversely proportional to the mean distance from the central pixel to
; the pair being used for the interpolation
;
; Pixel#1 Pixel#2   weight
;   N1     S1       1/1
;   W1     E1       1/1
;   NW1    SE1     1/1.414   (=1/SQRT(2))
;   NE1    SW1     1/1.414
;   N2     N1       1/1.5
;   E2     E1       1/1.5
;   S2     S1       1/1.5
;   W2     W1       1/1.5
;   NW2    NW1     1/2.1213   (=1(average of SQRT(2) and SQRT(8))
;   NE2    NE1     1/2.1213
;   SE2    SE1     1/2.1213
;   SW2    SW1     1/2.1213
;
; The procedure performs one to three passes through the array. Each pass consists of ;two
cycles. On the first cycle the procedure works sequentially through the blank ;pixels but do
not compute averages. Only a record of the mean weight of the ;components which may
potentially be used to compute an average is compiled. On the ;second cycle the averages are
computed in order of these mean weights - starting ;with the highest weight. Note that an
average is only computed if at least 3 ;('min_comp') of the potential 12 components can be
derived. If after the first pass ;there are still unfilled pixels a second pass is performed
using exactly the same ;procedure as in the first pass. If after the second pass there are
still unfilled ;pixels the requirement for 3 ('min-comp') components is relaxed to one or
more ;components and a third and final pass performed.
;
; Written by J.J.Agenbag MCM Nov 2005
;
;   FUNCTION fill_blanks_2, image0,bval,nodata
;   image=image0
;   min_comp=3      ; Minimum number of components required for average calculation
;                   ; during the first two passes
;   passnumber=0    ; Perform up to three passes to fill blanks. Set up for the 1st
;
;
;   offsets=INTARR(4,12) ; An interpolation/extrapolation for pixel (x,y) is performed
;                           ; between two pixels (x+dx1,y+dy1) and (x+dx2,y+dy2). The
;                           ; array 'offsets' holds dx1,dy1,dx2 and dy2
;   offsets[*,0:5]=[0,-1,0,1, -1,0,1,0, -1,-1,1,1, 1,-1,-1,1, 0,-2,0,-1, 2,0,1,0]
;   offsets[*,6:11]=[0,2,0,1, -2,0,-1,0, -2,-2,-1,-1, 2,-2,1,-1, 2,2,1,1, -2,2,-1,1]
;
;   weights=FLTARR(12)   ; Store here the weights of the 12 interpolations/extrapolations
;   w1=1.0
;   w2=1.0/SQRT(2.0)
;   w3=1.0/1.5
;   w4=1.0/((SQRT(2.0)+SQRT(8.0))/2.0)
;   weights[*]=[w1,w1,w2,w2,w3,w3,w3,w3,w4,w4,w4,w4]
;

```

```

;
asize=SIZE(image)
xdim=asize[1] ; x dimension of the image
ydim=asize[2] ; y dimension
type=asize[3] ; Data type. 1=BYTE, 2=INTEGER, 3=LONG, 4=FLOATING POINT
;
image=FLOAT(image) ; All calculations performed in FP
bval=FLOAT(bval)
nodata=FLOAT(nodata)
;
;
idxbl=WHERE(image EQ bval,numblank) ; The index of blank pixels
;
;
-----
FOR pass=1,3 DO BEGIN ; Perform up to 3 passes through the image
  meanweights=FLTARR(numblank) ; In this array keep record of the mean
  ; weights of components which may
  PRINT,pass,numblank,$
  FORMAT= ("Performing pass no.",I2," There are",I5," blanks to fill")'
  ; potentially be used to compute an average
  FOR cycle=1,2 DO BEGIN ; For each pass first determine the sequence (ie get
  ; 'meanweights' then do the actual averages
  PRINT,cycle,FORMAT= (" Doing cycle",I2)'
  ;
  xycoord=ARRAY_INDICES(image,idxbl)
  xcoord=xycoord[0,*]
  ycoord=xycoord[1,*]
  ;
  ; In order that the interpolations/extrapolations can be performed on all
; pixels in the input image a working image is created so that
  ; there is a border of two pixels round the actual data area.
  imagew=FLTARR(xdim+4,ydim+4) ; The working image
  imagew[*,*]=bval
  imagew[2:xdim+1,2:ydim+1]=image
  ;
  ;
  FOR j=0,numblank-1 DO BEGIN ; Fill the blanks
  x=xcoord[j]+2 ; Adjust the coordinates for 'imagew'
  y=ycoord[j]+2
  sum1=0.0
  sum2=0.0
  numestimate=0 ; Keep record of number of 'good' estimates
  ;
  FOR i=0,11 DO BEGIN ; Do the 12 interpolations/extrapolations
  sgn=1.0
  IF i LE 3 THEN sgn=-1.0
  dx1=offsets[0,i]
  dy1=offsets[1,i]
  dx2=offsets[2,i]
  dy2=offsets[3,i]
  ;
  x1=x+dx1 ; The coordinates of the two pixels used to do the interpolation
  y1=y+dy1
  x2=x+dx2
  y2=y+dy2
  ;
  v1=imagew[x1,y1]
  v2=imagew[x2,y2]
  ;
  ;
  IF v1 EQ bval OR v1 EQ nodata OR $
  v2 EQ bval OR v2 EQ nodata THEN BEGIN ; One of the pixels blank or nodata.
  ; Can't do estimate
  ENDIF ELSE BEGIN
  u=SQRT(FLOAT(dx1)^2 + FLOAT(dy1)^2) ; The distance from the central
pixel
  u1=u*sgn
  u2=SQRT(FLOAT(dx2)^2 + FLOAT(dy2)^2)
  ;

```

```

; The interpolated estimate is computed from  $v = au + b$  where  $u=0$ 
a=(v2-v1)/(u2-u1)
b=v1 - a*u1
sum1=sum1+b*weights[i]
sum2=sum2+weights[i]
numestimate=numestimate+1
ENDELSE
;
;
ENDFOR ; End of FOR i=0,11 DO BEGIN ; Do the 12 estimates
;
IF cycle EQ 1 THEN BEGIN ; First cycle. Do not compute averages
IF numestimate NE 0 THEN BEGIN
meanweights[j]=sum2/FLOAT(numestimate); Store the mean weight
ENDIF
;
ENDIF ELSE BEGIN ; Second cycle. Compute averages
;
IF numestimate GE min_comp THEN BEGIN ; If there are enough than
compute
imagew[x,y]=sum1/sum2
ENDIF
ENDELSE
;
ENDFOR ; End of FOR j=0,numblank-1 DO BEGIN
;
IF cycle EQ 1 THEN BEGIN ; End of first cycle. Set up for
indexmw=REVERSE(SORT(meanweights)) ; calculation of averages
idxbl=idxbl[indexmw] ; This is the index of blank pixels in descending
; order of mean weight
ENDIF ELSE BEGIN ; End of second cycle. Set up to do
; next pass if necessary
image=imagew[2:xdim+1,2:ydim+1]
idxbl=WHERE(image EQ bval,numblank)
IF numblank EQ 0 THEN GOTO, all_done
IF pass EQ 2 THEN min_comp=1
ENDELSE
;
ENDFOR ; End of FOR cycle=1,2 DO BEGIN
;
ENDFOR ; End of FOR pass=1,3 DO BEGIN
;
all_done:
; Convert 'image' back to original type
IF type EQ 1 THEN image = BYTE(ROUND(image))
IF type EQ 2 OR type EQ 3 THEN image = ROUND(image)
;
PRINT,numblank,FORMAT='(/,"Done. There are",I5," blanks not filled")'
RETURN,image
;
END

```

```

#####
#####

```

17 'Fix_msat_clim-825x825.pro'

```

;
; After the meteosat 650x650 climatology images had been transformed
; with ENVI (see 'Meteosat_climatology_readme.doc') it was found that:
;
; 1. The new images were the correct (825x825) size and the coastline
; fitted that of the seawifs 825x825 images very well
;
; 2. The last two lines (823 and 824) and the first column (0) are blank
;
; 3. The transformed SST images are upside down relative to the seawifs
; images ( Fix with sst_img = REVERSE(sst_img,2) )
;
;
; This program fixes these problems as follows
;
; 1. The SST images are reversed
;
; 2. A Delaunay triangulation (TRIANGULATE and TRIGRID) was first used to try to
; fill in the blank lines but this was not successful. The procedure now uses
; function 'fill_blanks_2'
;
; 3. The land boundary and land (253 and 254) from the seawifs images

```

```

;       are then written on the SST image as 29 and 30 (the normal values).
;
; Written by J.J.Agenbag MCM November 2005
;
func_dir='D:\IDL_work'
CD,func_dir,CURRENT=workdir
RESOLVE ROUTINE, 'fill_blanks_2',/IS_FUNCTION
CD,workdir
;
chl_dir='G:\SeaWiFS\SeaWiFS-1998-2004-climatology\'
chl_file='clim_1998-2004_01.b110'
;
sst_dir='G:\METEOSAT_images\METEOSAT-1987-2002-climatology\'
;
sstname1='clim_1987-2002_'
sstname2=['01','02','03','04','05','06','07','08','09','10','11','12']
sstname3='_825x825.sst'
sstname3_out='_825x825.sst0'
;
xdim=825 & ydim=825
;
OPENR,luni,chl_dir+chl_file,/GET_LUN
a=ASSOC(luni,BYTARR(xdim,ydim))
chl_img=a[0]
CLOSE,luni & FREE_LUN,luni
;
;
idx_chl_lndb=WHERE(chl_img EQ 253, num_chl_lndb)
idx_chl_lnd=WHERE(chl_img EQ 254, num_chl_lnd)
;
wnum=ID.WINDOW+1
WINDOW,wnum,XSIZE=xdim,YSIZE=ydim
!ORDER=1
DEVICE,DECOMPOSED=0
;
;
FOR i=0,11 DO BEGIN      ; Do all 12 the SST images
PRINT,i+1,FORMAT=('%Fixing SST image for month',I3)
sst_file_name = sstname1 + sstname2[i] + sstname3
sst_file_name_out = sstname1 + sstname2[i] + sstname3_out
OPENR,luni,sst_dir + sst_file_name,/GET_LUN
a=ASSOC(luni,BYTARR(xdim,ydim))
sst_img=a[0]
CLOSE,luni & FREE_LUN,luni
;
;
sst_img=REVERSE(sst_img,2)      ; Flip image
;
sst_img[idx_chl_lndb]=255 ; Apply the land border from the chl image
                        ; and mask with 255
sst_img[idx_chl_lnd]=255 ; Apply the land mask from the chl image
                        ; and mask with 255
idx=WHERE(sst_img EQ 29 OR sst_img EQ 30, cnt) ; Get index of all remaining
                        ; SST land and land border pixels
IF cnt GT 0 THEN sst_img[idx]=0 ; Mask these with 0 (zero) so that they will
                        ; be filled by 'fill_blanks_2'
;
sst_img2=fill_blanks_2(sst_img,0,255) ; Use 'fill_blanks_2' to fill in the
                        ; missing pixels (those with count=0)
;
sst_img=sst_img2
sst_img[idx_chl_lndb]=29      ; Re-apply the land border as obtained from the
                        ; chl image
sst_img[idx_chl_lnd]=30      ; Re-apply the land mask as obtained from the
                        ; chl image
;
OPENW,luni,sst_dir + sst_file_name_out,/GET_LUN
WRITEU,luni,sst_img
CLOSE,luni & FREE_LUN,luni
;
TVSCL,sst_img >20 <60

```

```

        STOP
    ENDFOR
    ;
    PRINT, 'All done'
    END

```

```

#####
#####

```

18. Function 'coordinates_of_swath_pixels_v1.pro'

```

;
; This function is intended to return the x-, y- and 1D coordinates
; of all pixels in a swath parallel to the coast ie the region of
; interest is not a rectangle or square.
;
; Inputs required are:
; . The x dimensions of the image for which the coordinates are to be
;   determined.
; . A 2-D integer array with three columns where the first column contains
;   the line number (y-coordinate) and the other two columns the start and
;   end pixel numbers (x-coordinates) defining the swath width for that
;   line. Note: The two x-coordinates may be in any order of size.
;   NOTE: This array may be created with function 'make_WC_swath_array'
;
; The output will be a 2-D LONG array listing all the pixels in the swath. It
; consists of three columns: 1= the 1-D index, 2= the x-coordinate and
;                          3= y-coordinate.
;
; Written by J.J.Agenbag MCM November 2005
;

```

```

FUNCTION coordinates_of_swath_pixels, xdim, swath_coords
;
; asize=SIZE(swath_coords,/DIMENSIONS)
; numy=asize[1] ; Number of scan lines in the swath
;
; Check that there is actually data in all 'numy' records.
; At the same time re-arrange the two x-coordinates so that the smallest
; is in swath_coords[1,]
; num_data_rec=0
; maxwidth=0 ; Find the maximum swath width
FOR i=0,numy-1 DO BEGIN
    IF swath_coords[1,i] EQ 0 AND swath_coords[2,i] EQ 0 THEN GOTO,end_check
    num_data_rec=num_data_rec+1
    minx=MIN(swath_coords[1:2,i],MAX=maxx)
    swath_coords[1:2,i]=[minx,maxx]
    IF (maxx-minx+1) GT maxwidth THEN maxwidth=(maxx-minx+1)
ENDFOR
end_check:
;
; outarr=LONARR(3,num_data_rec*maxwidth) ; Create output array
; j=-1L
FOR i=0,num_data_rec-1 DO BEGIN
    FOR ix=swath_coords[1,i],swath_coords[2,i] DO BEGIN
        j=j+1L
        outarr[0,j]=ix + LONG(xdim)*swath_coords[0,i]
        outarr[1,j]=swath_coords[0,i]
        outarr[2,j]=ix
    ENDFOR
ENDFOR
;
; outarr=outarr[*;0:j] ; Chop off the unused part (if any) of 'outarr'
;
RETURN,outarr
END

```

```

#####
#####

```

19 Program 'make_clusters_v1.pro'

```

;

```

```

; This program was produced to investigate partitioning of the oceanic belt off Angola into
; zones/regions of uniform properties using IDL's CLUSTER and CLUSTER_WTS procedures.
; It was further envisaged that Meteosat SST- and SeaWiFS GAC [chl-a] monthly climatologies
; will be used to define the clusters and that two or more months' data (eg. mid-summer and
; mid-winter) be employed. In order to do so the Meteosat 650x650 SST climatologies were
; registered and transformed to fit the SeaWiFS [chl-a] 825x825 images.
;
; Principles of operation of this program:
; 1. The user must specify the number of variables - that is number of SST and [chl-a]
; files/images - to use. The maximum provided for is 24.
; 2. The user must supply the file and directory names where the images are located. NOTE:
; While the program was written with the 825x825 images in mind this is not a requirement. All
; files specified must however be co-registered.
; 3. The user must specify the number of clusters to be defined.
; 4. The user must specify the area to be used. This must be specified ito :
;     a. northern boundary
;     b. southern boundary
;     c. swath width (km)
;     d. start position of the swath (km from the coast)
;
; 5. The user must specify whether the data are to be normalised or not. If the variables
; values differ in size (the pixel counts in the chl images are for example about twice the
; size of the Meteosat SST images) then the clustering procedure will be dominated by the
; larger values. For this reason normalisation of the variables are usually performed. In this
; program normalisation of a particular variable is done by
; subtracting the mean and dividing by the standard deviation (the IDL 'STANDARDIZE').
;
; 6. The user must specify the file/image name to be used as background when the clusters
; are displayed. NOTE: The program will display the background in monochrome with the clusters
; in colour (the land and land boundary may also be displayed in colour). For this purpose 23
; colours are defined which will use counts 255, 254, 253, etc. It is important that the
; background image does not utilise the count range allocated to the colours, hence if the
; maximum count in the specified background image exceed overlaps the count range of the
; colours then the image will be byte scaled so as to remove the overlap. NOTE: The user may
; also specify 'land-only' as background in which case a blank image with only the land/land
; boundary mask will be used as background.
;
; 7. The program will display the background image with clusters and then engage the user
; in dialogue on eg. whether smoothing is desired, the smoothing kernel size, whether to save
; displays and data, etc.
;
; 8. Smoothing is performed using boxcar smoothing (IDL's 'SMOOTH' function). The user may
; select to smooth a particular cluster or all clusters. irrespective of the selection each
; cluster is smoothed completely independantly by writing the cluster as value 1.0 on a
; background of 0.0. This means that the spatial extent of the cluster will be extended with a
; fringe of decimal values  $0.0 < v < 1.0$  and the user must indicate the cut-off level (all values
; greater or equal to the cut-off will be taken to be part of the smoothed cluster, smaller
; values will be discarded.
; NOTE THAT THE ORDER IN WHICH CLUSTERS ARE SMOOTHED IS IMPORTANT because if cluster 1
; is smoothed first and then cluster 2 then the smoothed cluster 2 may partly overwrite
; smoothed cluster 1. Therefore if the user selects to smooth all clusters then the smoothing
; is carried out in sequence of cluster size starting with the smallest
;
; 9. When smoothing is performed with option 2 ('Smooth one or more clusters') then the
; smoothing process is cumulative in the sense that a smoothing action is performed
; on the result of the previous smoothing step. However, there is no carry over from
; smoothing performed with option 1 ('Smooth all clusters') to option 2. The array
; being smoothed is reset to the unsmoothed state whenever either option 1 or 2 is
; exited.
;
; 10. NOTE: Option 4 which saves the unsmoothed and smoothed data arrays to disk also
; creates header (.hdr) files. The .hdr for the smoothed array is of particular interest since
; it records the centres of the clusters ie. the characteristic 'signatures' or properties of
; the clusters. Also, in this header is a record of smoothing actions performed to generate the
; smoothed_clusters image and smoothed clusters data array (saved in options 3 and 4
; respectively)
;
; NOTE: This program makes use three functions:
; 'make_WCswatharray' in 'make_WC_swath_array_v1.pro'

```

```

;      'swathpixels_xy'          in 'coordinates_of_swath_pixels_v1.pro'
;      'make_colorkey01'       in 'make_colorkey01.pro'
;
;
;   Written by J.J.Agenbag   MCM   November 2005
;*****
;*****
;
;   Resolve the required functions
func1_dir='C:\CLUSTER_1\CLUSTER_IDL_PRG\'; Directory for 'make_WC_swath_array'
func2_dir='C:\CLUSTER_1\CLUSTER_IDL_PRG\'; Directory for coordinates_of_swath
pixels'
func3_dir='C:\CLUSTER_1\CLUSTER_IDL_PRG\'; Directory for 'make_colorkey01'
CD,func1_dir,CURRENT=clusterdir
RESOLVE_ROUTINE,'make_WCswatharray',/IS_FUNCTION
CD,func2_dir
RESOLVE_ROUTINE,'swathpixel_xy',/IS_FUNCTION
CD,func3_dir
RESOLVE_ROUTINE,'make_colorkey01',/IS_FUNCTION
CD,clusterdir
;
;*****
;*****
;   Specify the variables/image/files to be used for cluster definition
;
;   numvar=8          ; This is the number of images/files to be used
;
;   normalise='yes'   ; If 'yes' then the data will be normalised before application
; of the cluster analysis. If 'no' then normalisation will not
; be done. NOTE: Saved cluster data is always the non-normalised values
;
;   filenames=STRARR(numvar) ; These are the files names for the images to be used
;                               ; as variables
;   filedirs=STRARR(numvar)  ; These are the directories in which the files are located
;
;filenames[0:1]=['clim_1987-2002_01_825x825.sst0','clim_1987-2002_03_825x825.sst0']
;filenames[2:3]=['clim_1987-2002_07_825x825.sst0','clim_1987-2002_08_825x825.sst0']
;
;   filenames[0:1]=['clim_1998-2004_01.bil','clim_1998-2004_03.bil']
;   filenames[2:3]=['clim_1998-2004_06.bil','clim_1998-2004_08.bil']
;
;   filedirs[0]='C:\CLUSTER_1\REVERSED CLIMATOLOGIES\'
;   filedirs[1:3]=filedirs[0]
;   filedirs[0]='C:\DATA\SeaWiFS-1998-2004-climatology\'
;   filedirs[1:3]=filedirs[0]
;
;   data_ranges=INTARR(2,numvar) ; Specify the minimum and maximum 'good' counts for
;                               ; the images to be used as variables. Data outside
;                               ; these ranges will not be used
;
;   data_ranges[0,0:3]=31      ; 31 = minimum for Msat SST images
;   data_ranges[1,0:3]=255     ; maximum for msat SST images
;   data_ranges[0,0:3]=0       ; minimum for SeaWiFS [chl-a] images
;   data_ranges[1,0:3]=252     ; maximum for SeaWiFS [chl-a] images
;*****
;*****
;   mask file name: The land and land boundary masks will be derived from this file
;
;   landmask_file=filenames[0]
;   landmask_dir=filedirs[0]
;   landv =254          ; Land mask pixel count
;   landbv=253         ; The land border count
;
;*****
;*****
;   Specify the image/file to be used as back ground for the display of the clusters
;   If 'land_only' is specified in the place of a file name then the display will be
;   against a blank image with only the coast line and land mask
background_file=filenames[0]
background_dir=filedirs[0]
;

```

```

;*****;*****
;*****;*****
; Specify image and swath dimensions etc
;
; xdim=825
; ydim=825
; -----
; latn=-5.02121212 ; The latitude limits of the images (latitude at the centres
; lats=-39.97878788 ; of the first and last scan lines (in °N ie. southern lats
; must be negative
; lonw=5.02121212 ; The longitude limits (longitudes at the centres of the first
; lone=39.97878788 ; and last columns of pixels
; -----
; nblat=-5.02121212 ; The northern and southern latitude limits of the data swath
; sblat=-9.00 ; These must follow the same rules as 'latn' and 'lats'
; sdist=0.0 ; The distance from the coast to the first pixel in the swath.
; ; The distance will be taken as the distance between the seaward
; ; edge of the land boundary pixel and the landward edge of the
; ; first pixel in the swath.
; width=370.0 ; The swath width (km). Note: The width will be taken to be the
; ; distance from the shoreward edge of the first pixel to the
; ; off-shore edge of the last pixel.
;
;*****;*****
;*****;*****
; Specify number of clusters and colours for display purposes
;
; PRINT,"Sorting out the colour table"
; numclus=12 ; The number of clusters to be defined
; white_disp_count=255 ; A count reserved for eg. annotation
; black_disp_count=254 ; , , , , , ,
; land_disp_count=253 ; Land will be masked with this count in the display
; landb_disp_count=252 ; Land border will be masked with this count
; clus_disp_count=BYTARR(numclus) ; Clusters will be masked with these counts
; FOR i=0,numclus-1 DO clus_disp_count[i]=251-i
;
;
; The following are 20 colors plus black, grey and white which may be used to
; display the clusters as well as the land and land boundary
; NOTE THAT THESE COLOR COMPONENTS ARE IN PERCENTAGES AND NOT IN THE NORMAL 0-255
; colors=BYTARR(3,23)
; colors[* ,0]=[0,0,0] ; 0 Black
; colors[* ,1]=[50,50,50] ; 1 Grey
; colors[* ,2]=[100,100,100] ; 2 White
; colors[* ,3]=[73,55,40] ; 3 Light brown
; colors[* ,4]=[35,28,0] ; 4 Dark brown
; colors[* ,5]=[77,69,100] ; 5 Light purple
; colors[* ,6]=[57,44,100] ; 6 Medium purple
; colors[* ,7]=[8,8,100] ; 7 Light blue
; colors[* ,8]=[27,100,99] ; 8 Medium blue
; colors[* ,9]=[31,76,100] ; 9 Dark blue
; colors[* ,10]=[0,70,74] ; 10 Very dark blue
; colors[* ,11]=[49,100,46] ; 11 Light green
; colors[* ,12]=[0,73,29] ; 12 Dark green
; colors[* ,13]=[79,100,37] ; 13 Yellow green
; colors[* ,14]=[99,100,60] ; 14 Light yellow
; colors[* ,15]=[100,100,101] ; 15 Medium yellow
; colors[* ,16]=[99,88,58] ; 16 light orange
; colors[* ,17]=[100,76,7] ; 17 Orange
; colors[* ,18]=[99,42,0] ; 18 Dark orange
; colors[* ,19]=[100,11,8] ; 19 Red
; colors[* ,20]=[100,69,98] ; 20 Light pink
; colors[* ,21]=[99,17,100] ; 21 Dark pink
; colors[* ,22]=[82,0,78] ; 22 Dark purplish pink
;
; Convert colors from percentages to 0-255 values
; FOR i=0,22 DO BEGIN
; FOR j= 0,2 DO colors[j,i]=ROUND((FLOAT(colors[j,i])*255.0)/100.0)
; ENDFOR
;

```

```

white_color=colors[* ,2] ; Color for 'white' count
black_color=colors[* ,0] ; Color for 'black' count
land_color=colors[* ,3] ; Mask land as color 3 (light brown)
landb_color=colors[* ,4] ; Land boundary as color 4 (dark brown)
clus_color=BYTARR(numclus)
;clus_color[*]=[5,7,8,9,10,11,12,15,16,17,18,21] ;12 CLUSTERS
;clus_color[*]=[5,7,8,9,10,11,12,15,16,17] ;10 CLUSTERS
;clus_color[*]=[5,7,8,9,10,11,12,15] ; 8 CLUSTERS
;clus_color[*]=[5,7,8,9,10,11] ; 6 CLUSTERS
;clus_color[*]=[5,7,8,9] ; 4 CLUSTERS
;
wnum_unsmoothed=ID.WINDOW+1
;
;*****
;*****
; Get the land- and land boundary masks
;
PRINT,landmask_file,FORMAT=("Getting the land mask from ",A)
OPENR,luni,landmask_dir + '\' + landmask_file,/GET_LUN
a=ASSOC(luni,BYTARR(xdim,ydim))
img=a[0]
CLOSE,luni & FREE_LUN,luni
;
idxland=WHERE(img EQ landv, num_land) ; Index of land mask
idxlandb=WHERE(img EQ landbv, num_landb) ; Index of land border mask
idxocean=WHERE(img NE landv AND img NE landbv, numocean) ; Index of ocean pixels
;
;*****
;*****
; Get the image to be used as background for the display
;
PRINT,background_file,FORMAT=("Getting the background image from ",A)
IF background_file EQ 'land_only' THEN BEGIN ; Use blank image with land mask
bg_image=BYTARR(xdim,ydim)
ENDIF ELSE BEGIN
OPENR,luni,background_dir + '\' + background_file,/GET_LUN
a=ASSOC(luni,BYTARR(xdim,ydim))
bg_image=a[0]
CLOSE,luni & FREE_LUN,luni
;
minbg=MIN(bg_image[idxocean], MAX=maxbg) ; Get minimum and maximum ocean pix value
bg_image = BYTSCL(bg_image,MAX=maxbg,MIN=minbg, TOP=ID.TABLE_SIZE-(numclus+5))
ENDELSE
first_bg_image=bg_image ; Keep a copy of the 'raw' background image
bg_image[idxland]=land_disp_count ; Apply land mask
bg_image[idxlandb]=landb_disp_count ; Apply land border mask
bg_image_with_land=bg_image
;
; NOTE: Throughout the program the following will prevail as far as background
; images are concerned:
; 'first_bg_image'= the byte scaled background image without land
; 'bg_image_with_land' = the same as 'first_bg_image' but with land and land
; boundary
; 'bg_image' = as 'bg_image_with_land' and at a later stage the clusters will
; also be written on 'copy_bg_image'= as 'bg_image' but also with colour key for
; display.
;
;*****
;*****
; Get the index of pixels in the swath. The 1-D index of pixels in the swath will; be in
; swath_index[0,*], [1,*] and [2,*] are the x- and y-coordinates
;
PRINT,"make_WCswatharray",FORMAT=("Call ",A," to define the data swath")
;
corners=[latn,lats,lonw,lone]

swath_coords=make_WCswatharray(bg_image,corners,nblat,sblat,sdist,swidth,landb_disp_count)
;
PRINT,"swathpixel_xy",FORMAT=("Call ",A," to get swath pixel coordinates")
swath_index=swathpixel_xy(xdim,swath_coords)
a=SIZE(swath_index)

```

```

numpix=a[2] ; The number of pixels in the swath
;
PRINT,"Get the index of the background minus the swath"
; Get an index of bg_image excluding the swath area (At this stage 'bg_image' is just
the byte scaled background with land and land boundary)
ting=bg_image ; A temporary image
ting[swath_index]=255
bg_minus_swath_idx=WHERE(ting NE 255,cnt)
ting=0
;
;*****;*****
;*****;*****
Construct the array for computing the clusters
;
PRINT,"Constructing the data array"
clus_arr=LONARR((3+numvar+1),numpix) ; The first 3 columns are the 1-D index of pixels
in the swath and their x and y coordinates. The next numvar columns will contain the
corresponding pixel counts from the images used as variables to define the clusters and the
last column will contain the cluster number to which that pixel belongs
clus_arr[0:2,*]=swath_index
;
;
FOR i=0,numvar-1 DO BEGIN ; Read all the images and get the swath pixel values
PRINT,filenames[i],FORMAT="Read data from file ",A)
OPENR,luni,filedirs[i] + '\' + filenames[i],/GET_LUN
a=ASSOC(luni,BYTARR(xdim,ydim))
img=a[0]
clus_arr[3+i,*]=img[clus_arr[0,*]] ; Transfer the pixel counts
CLOSE,luni & FREE_LUN,luni
ENDFOR
;
;
; Check the pixel counts and keep only those pixels where all the counts are within
; the specified range
PRINT,"Checking the counts in the data array and keeping only the 'good' pixels"
FOR i=0,numpix-1 DO BEGIN
a=0
FOR j=0,numvar-1 DO BEGIN
IF clus_arr[3+j,i] GE data_ranges[0,j] AND $
clus_arr[3+j,i] LE data_ranges[1,j] THEN a=a+1
ENDFOR
;
IF a LT numvar THEN clus_arr[0,i]=-1 ; Not all counts are good
ENDFOR
;
idx=WHERE(clus_arr[0,*] NE -1, numdata) ; numdata = the number of data points from which
the clusters are to be derived
IF numdata GE 1 THEN BEGIN
clus_arr[* ,0:numdata-1]=clus_arr[* ,idx]
clus_arr=clus_arr[* ,0:numdata-1]
ENDIF
;
; If required normalise the data (in "clus_arr") and store in "norm_arr"
;
norm_arr=FLOAT(clus_arr[3:(2+numvar),*])
IF normalise EQ 'yes' THEN BEGIN
PRINT,"Normalising the data array"
norm_data=FLTARR(2,numvar) ; norm_data[0,*] = the mean
; [1,*] = the standard deviation
FOR i=0,numvar-1 DO BEGIN
a=MOMENT(norm_arr[i,*])
norm_data[* ,i]=[a[0],SQRT(a[1])]
norm_arr[i,*]=STANDARDIZE(norm_arr[i,*])
ENDFOR
ENDIF
;
;
;*****;*****
;*****;*****
; Compute the clusters from the data in norm_arr and apply to the background image
;

```

```

PRINT,numclus,numdata,FORMAT='("Compute the",I3," clusters from",I6," data points")'
PRINT,FORMAT='("and write the clusters on the background image for display",/)'
;
wts = CLUST_WTS(norm_arr, N_CLUSTERS=numclus, /DOUBLE, N_ITERATIONS=30) ; Compute the
cluster centres
clus = CLUSTER(norm_arr,wts, N_CLUSTERS=numclus) ; Do the clustering
clus_arr[(3+numvar),*]=clus
norm_arr=0
;
clus_idx=LONARR(numclus,numdata) ; Create an array for storing the 1-D indices
; of the individual clusters
clus_numdata=INTARR(numclus) ; Store here the number of points in each cluster
;
; Before displaying the clusters, smoothing or saving them first sort them in sequence of
size (number of points) with the smallest first.
max_numdata=0
FOR i=0,numclus-1 DO BEGIN ; Write the clusters on
idx=WHERE(clus_arr[(3+numvar),*] EQ i,cnt)
clus_numdata[i]=cnt
IF cnt GT max_numdata then max_numdata=cnt ; Find out the largest number of data
; points in an individual cluster
IF cnt GT 0 THEN clus_idx[i,0:cnt-1]=clus_arr[0,idx]
ENDFOR
;
clus_idx=clus_idx[0:numclus-1,0:max_numdata-1] ; Trim 'clus_idx' to remove unused part
;
idx=SORT(clus_numdata); Sort the clusters ie idx[0] is the column in 'clus_numdata'
; with smallest number of element and idx[numclus-1] is the one with the largest ;number of
elements but the column numbers are also the cluster numbers
; Rearrange clus_arr - simply change the cluster numbers so that 0 is the
; smallest and numclus-1 the largest
;
FOR i= 0, numclus-1 DO BEGIN
IF clus_numdata[i] GT 0 THEN BEGIN
a=clus_idx[idx[i],0:clus_numdata[i]-1]
clus_arr[(3+numvar),a]=i
ENDIF
ENDFOR
;
clus_numdata=clus_numdata[idx] ; Rearrange clus_numdata
clus_idx=clus_idx[idx,*] ; Rearrange also clus_idx
;
FOR i=0,numclus-1 DO BEGIN ; Write the clusters on the background image
PRINT i,clus_numdata[i],clus_disp_count[i],FORMAT=$
('Cluster",I3,"; Number of pixels=",I6," Apply as count",I4)'
IF clus_numdata[i] GT 0 THEN BEGIN
bg_image[clus_idx[i,0:clus_numdata[i]-1]]=clus_disp_count[i]
ENDIF
ENDFOR
;
;*****
;*****
; Make a colour key for the clusters and insert in a copy of bg_image
;*****
;*****
numkey=numclus
keylabel=STRARR(numkey)
maxlen=0
FOR i=1,numkey DO BEGIN
str=STRTRIM(STRING(i),2)
len=STRLEN(str)
IF len GT maxlen THEN maxlen=len
keylabel[i-1]=str
ENDFOR
;
FOR i=0,numkey-1 DO BEGIN
len=STRLEN(keylabel[i])
lendif=maxlen-len
IF lendif GT 0 THEN BEGIN

```

```

        FOR j=0,lendif-1 DO keylabel[i]=' ' + keylabel[i]
    ENDIF
ENDFOR
ckey=make_colorkey01(black_disp_count,white_disp_count,numclus,[10,15],clus_disp_count,$
keylabel)
;
asize=SIZE(ckey) ; Get the dimensions of the key image
key_xdim=asize[1]
key_ydim=asize[2]
Print,"key_xdim=",key_xdim,"key_ydim=",key_ydim
;
copy_bg_image=bg_image ; Make a copy of bg_image and insert the key in the copy
; Insert in bottom left corner
keyx1=3 & keyx2=keyx1+(key_xdim-1) ; x position for inserting the key. Leave
; a border of 3 pixels
keyy1=(ydim-1)-3-(key_ydim-1) ; y position for inserting the key. Leave a border of two
lines
keyy2=keyy1+(key_ydim-1)
copy_bg_image[keyx1:keyx2,keyy1:keyy2]=ckey

;*****
;*****
; Display the background image with the clusters
; First verify that the number of cluster pixels is correct
PRINT,"Verifying that the number of cluster pixels on the background image is correct"
FOR i=0,numclus-1 DO BEGIN
    idx=WHERE(bg_image EQ clus_disp_count[i],cnt)
    PRINT,i,cnt,FORMAT="("Cluster",I3," Number of pixels on image =",I6)'
ENDFOR
;
!ORDER=1
DEVICE,DECOMPOSED=0
LOADCT,0,NCOLORS=!D.TABLE_SIZE-(numclus+4) ; Load monochrome color table
;
TVLCT,white_color[0],white_color[1],white_color[2],white_disp_count
TVLCT,black_color[0],black_color[1],black_color[2],black_disp_count
TVLCT,land_color[0],land_color[1],land_color[2],land_disp_count
TVLCT,landb_color[0],landb_color[1],landb_color[2],landb_disp_count
;
FOR i=0,numclus-1 DO BEGIN ; Load cluster colors into the color table
    red = colors[0,clus_color[i]]
    green=colors[1,clus_color[i]]
    blue=colors[2,clus_color[i]]
    TVLCT,red,green,blue,clus_disp_count[i]
ENDFOR
WINDOW,wnum_unsmoothed,XSIZE=xdim,YSIZE=ydim,TITLE='Unsmoothed clusters
TV,copy_bg_image

;*****
;*****
;*****; Perform
boxcar smoothing of the clusters
;
wnum_smoothed=!D.WINDOW+1 ; The window for displaying the smoothed clusters
;
smoothed_arr=LONARR(numclus*3,numpix) ; Create an array in which to store the 1-D array
index, x-coordinate and y-coordinate of pixels in the ;smoothed clusters
; smoothed_arr[0,*] = all the 1-D indices for cluster 1
; [1,*] = all the corresponding x-coordinates for cluster 1
; [2,*] = all the corresponding y-coordinates for cluster 1
; [3,*] = all the 1-D indices for cluster 2
; etc
smoothed_clus_numdata=INTARR(numclus) ; Record here the number of elements in the
; smoothed clusters
;
;
selection=['0','1','2','3','4','5','6','7','8','9']
;
mainmenu_start:
ON_IOERROR,bad_mainmenu ; Declare a label for dealing with incorrect
; user input
inpstr=''

```

```

PRINT,"Please select one of the following:"
PRINT," 1. Smooth all clusters"
PRINT," 2. Smooth one or more clusters"
PRINT,"    In this operation smoothing is additive in the sense"
PRINT,"    that successive smoothings are performed on the results"
PRINT,"    of previous smoothing actions BUT NOTE: The array of"
PRINT,"    smoothed clusters is reset to the initial (unsmoothed)"
PRINT,"    data each time this function (#2) is initiated"
PRINT," 3. Save display(s) as .png files"
PRINT," 4. Save cluster and/or smoothed cluster"
PRINT,"    data as unformatted binary arrays"
PRINT," 5. STOP program for user action"
PRINT," 6. Exit program"
PRINT,FORMAT='(//,"Please enter selection (1-6):",)$'
READ,menu
menu=FIX(menu)
IF menu LT 1 OR menu GT 6 THEN BEGIN
    bad_mainmenu:
    PRINT,FORMAT=$
    '(//,"Incorrect entry. Must be an integer in the range 1 to 6",//)'
    GOTO,mainmenu_start
ENDIF
;
CASE 1 OF
;
;***** 1. Smooth all clusters *****
(menu EQ 1): BEGIN
;
menul_start:
;
smoothed_arr[*,*]=0 ; Zero the array used for storing the smoothed cluster data
bg_smoothedclusters=first_bg_image ; Create a new image to show the smoothed clusters
;
OPENW,lunj,clusterdir + '\ ' + 'make_clusters_journal.txt',/GET_LUN ; In this file record
information on smoothing actions
;
ON_IOERROR,bad_menula ; Declare a label for dealing with incorrect
; user input
PRINT,FORMAT='(//," Enter kernel size (3,5,7,9) or 0 (to return):",)$'
READ,kernel
kernel=FIX(kernel)
IF kernel EQ 0 THEN GOTO,mainmenu_start
IF (kernel MOD 2) EQ 0 OR kernel LT 3 OR kernel GT 9 THEN BEGIN
    bad_menula:
    PRINT,FORMAT=$
    '(//,"Incorrect entry.The kernel must be odd and in the range 3 to 9")'
    PRINT,"or you may enter 0 to return to the main menu"
    PRINT,FORMAT='("Please re-enter",//)'
    GOTO,menul_start
ENDIF
;
PRINTF,lunj,"Smooth all clusters"
PRINTF,lunj,kernel,FORMAT='("kernel size =",I2)'
;
;
menulb_start:
ON_IOERROR,bad_menulb ; Declare a label for dealing with incorrect
; user input
PRINT,FORMAT='(//,"Enter cut-off (0.0 - 1.0) for inclusion in cluster:",)$'
READ,cutoff
IF cutoff LE 0.0 OR cutoff GT 1.0 THEN BEGIN
    bad_menulb:
    PRINT,FORMAT=$
    '(//,"Incorrect entry. The cut-off determines which pixel values will be")'
    PRINT,"included in the smoothed cluster and should be a decimal number"
    PRINT,FORMAT='("greater than 0.0 and less or equal to 1.0",//)'
    GOTO,menulb_start
ENDIF
;
PRINTF,lunj,cutoff,FORMAT='("cutoff =",F6.3)'
;

```

```

CLOSE,lunj & FREE_LUN,lunj
PRINT," "
;
FOR i=0,numclus-1 DO BEGIN ; Do all the clusters
PRINT,i+1,FORMAT=('"Smoothing cluster number",I3)'
n=clus_numdata[i] ; the number of points in this cluster
index=clus_idx[i,0:n-1] ; the 1-D indices for the points
xycoords=ARRAY_INDICES(bg_image,index) ; The x- and y- coordinates corresponding to
'index'
minx=MIN(xycoords[0,*],MAX-maxx)
miny=MIN(xycoords[1,*],MAX-maxy)
smooth_img=FLTARR((maxx-minx+1)+2*kernel,(maxy-miny+1)+2*kernel) ; Create a small
'image' in which to perform the smoothing
FOR p=0,n-1 DO BEGIN ; Write the cluster as 1.0
x=(xycoords[0,p]-minx)+kernel ; Convert the cluster coordinates to those
y=(xycoords[1,p]-miny)+kernel ; of 'smooth_img'
smooth_img[x,y]=1.0
ENDFOR
;
idx_smoothed=WHERE(SMOOTH(smooth_img,kernel) GE cutoff,num_smoothed)
IF num_smoothed GT 0 THEN BEGIN
xycoords=ARRAY_INDICES(smooth_img,idx_smoothed) ; The x- and y- coordinates
; corresponding to 'idx_smoothed'
;
FOR p=0,num_smoothed-1 DO BEGIN ; Write the smoothed cluster
x=(xycoords[0,p]+minx)-kernel ; Convert the smoothed cluster coordinates to
those of of 'bg_smoothedclusters'
y=(xycoords[1,p]+miny)-kernel ;
IF x GE 0 AND x LE xdim-1 AND y GE 0 AND y LE ydim-1 then $
bg_smoothedclusters[x,y]=clus_disp_count[i]
ENDFOR
ENDIF
;
ENDFOR
;
; bg_smoothedclusters[bg_minus_swath_idx]=bg_image_with_land[bg_minus_swath_idx] ; ;This
step applies the background data and land masks and trims off cluster data
;which extend beyond the swath boundaries as a result of the smoothing.
;
; Record the coordinates of the smoothed clusters
FOR i=0,numclus-1 DO BEGIN
idx=WHERE(bg_smoothedclusters EQ clus_disp_count[i],cnt)
IF cnt NE 0 THEN BEGIN
xycoords=ARRAY_INDICES(bg_smoothedclusters,idx)
smoothed_clus_numdata[i]=cnt ; Store the number of elements
smoothed_arr[i*3,0:cnt-1]=idx ; Store the 1-D index for cluster i
smoothed_arr[i*3+1,0:cnt-1]=xycoords[0] ; Store the x-coordinates
smoothed_arr[i*3+2,0:cnt-1]=xycoords[1] ; Store the y-coordinates
ENDIF
ENDFOR
;
bg_smoothedclusters[keyx1:keyx2,keyy1:keyy2]=ckey ; Insert the color key in the image
with smoothed clusters

IF !D.WINDOW LT wnum_smoothed THEN BEGIN ; If the window does not yet exist
; then create it
WINDOW,wnum_smoothed,XSIZE=XDIM,YSIZE=ydim, TITLE='Smoothed clusters'
ENDIF
WSET,wnum_smoothed
;
TV,bg_smoothedclusters
;
GOTO,mainmenu_start
;
END ; End of '(menu EQ 1)' ; Smooth all clusters
;
;
; *****2. Smooth one or more clusters*****menu EQ 2): BEGIN
;

```

```

; When this function is entered smoothed_arr is initialised to the unsmoothed
; cluster data in clus_idx. Subsequent smoothing operations performed within the
; function are performed on smoothed_arr which is updated after each smoothing
; operation. The effect of smoothing operations are thus additive in nature.
; However, when the function is exited and re-entered smoothed_arr is reset to
; the unsmoothed data ie there is no further cumulative effect.
;
;
smoothed_arr[*,*]=0L
smoothed_clus_numdata=clus_numdata
FOR i=0,numclus-1 DO BEGIN
  cnt=clus_numdata[i]
  IF cnt GT 0 THEN BEGIN
    idx=clus_idx[i,0:cnt-1]
    xycoords=ARRAY_INDICES(bg_image,idx)
    smoothed_arr[i*3,0:cnt-1]=idx          ; Store the 1-D index for cluster i
    smoothed_arr[i*3+1,0:cnt-1]=xycoords[0,*] ; Store the x-coordinates
    smoothed_arr[i*3+2,0:cnt-1]=xycoords[1,*] ; Store the y-coordinates
  ENDIF
ENDFOR
;
IF !D.WINDOW LT wnum_smoothed THEN BEGIN          ; If the window does not yet exist
                                                    ; then create it
  WINDOW,wnum_smoothed,XSIZE=XDIM,YSIZE=ydim, TITLE='Smoothed clusters'
ENDIF
WSET,wnum_smoothed
;
bg_smoothedclusters=bg_image                    ; Initialise to the image with
                                                    ; unsmoothed clusters and no color key
copy_bg_smoothedclusters=copy_bg_image         ; Initialise to image with unsmoothed
                                                    ; clusters but WITH COLOR KEY
TV,copy_bg_smoothedclusters
;
OPENW,lunj,clusterdir + '\ ' + 'make_clusters_journal.txt',/GET_LUN
PRINTF,lunj,"Smooth one or more clusters"
;
menu2_start:
;
ON_IOERROR,bad_menu2a      ; Declare a label for dealing with incorrect
                           ; user input
PRINT,numclus,FORMAT=$
'(/," Enter number of cluster to smooth (1 -",I3,") or 0 to return to menu:",$)'
READ,cnumber
cnumber=FIX(cnumber)
IF cnumber EQ 0 THEN BEGIN
  CLOSE,lunj & FREE LUN,lunj
  GOTO,mainmenu_start
ENDIF
;
IF cnumber LT 1 OR cnumber GT numclus THEN BEGIN
  bad_menu2a:
  PRINT,numclus,FORMAT=$
  '(/,"Incorrect entry.The number must be in the range 1 to",I3)"'
  PRINT, "or you may enter 0 to return to the main menu"
  PRINT,FORMAT='("Please re-enter",/)'
  GOTO,menu2_start
ENDIF
;
PRINTF,lunj,cnumber,FORMAT='(/,"Smooth cluster no.",I3)'
;
menu2b_start:
ON_IOERROR,bad_menu2b      ; Declare a label for dealing with incorrect
                           ; user input
PRINT,FORMAT='(/," Enter kernel size (3,5,7,9):",$)'
READ,kernel
kernel=FIX(kernel)
IF (kernel MOD 2) EQ 0 OR kernel LT 3 OR kernel GT 9 THEN BEGIN
  bad_menu2b:
  PRINT,FORMAT=$
  '(/,"Incorrect entry.The kernel must be odd and in the range 3 to 9")'
  PRINT,FORMAT='("Please re-enter",/)'

```

```

        GOTO,menu2b_start
    ENDIF
;
PRINTF,lunj,kernel,FORMAT='("      kernel size =",I2)'
;
menu2c_start:
ON_IOERROR,bad_menu2c      ; Declare a label for dealing with incorrect
                          ; user input
PRINT,FORMAT='(/,"Enter cut-off (0.0 - 1.0) for inclusion in cluster:",$)'
READ,cutoff
IF cutoff LE 0.0 OR cutoff GT 1.0 THEN BEGIN
    bad_menu2c:
    PRINT,FORMAT=$
    '(/,"Incorrect entry. The cut-off determines which pixel values will be")'
    PRINT,"included in the smoothed cluster and should be a decimal number"
    PRINT,FORMAT='("greater than 0.0 and less or equal to 1.0",/)'
    GOTO,menu2c_start
ENDIF
;
PRINTF,lunj,cutoff,FORMAT='("      cutoff =",F6.3)'
;
PRINT,cnumber,FORMAT='(/,"Smoothing cluster number",I3,/)'
j=cnumber-1
xcol=(j*3)+1
ycol=xcol+1
n=smoothed_clus_numdata[j]          ; the number of points in this cluster
xycoords=smoothed_arr[xcol:ycol,0:n-1] ; The x- and y- coordinates
;
minx=MIN(xycoords[0,*],MAX=maxx)
miny=MIN(xycoords[1,*],MAX=maxy)
smooth_img=FLTARR((maxx-minx+1)+2*kernel,(maxy-miny+1)+2*kernel) ; Create a small
                          ; 'image' in which to perform the smoothing
FOR p=0,n-1 DO BEGIN                ; Write the cluster as 1.0
    x=(xycoords[0,p]-minx)+kernel    ; Convert the cluster coordinates to those
    y=(xycoords[1,p]-miny)+kernel    ; of 'smooth_img'
    smooth_img[x,y]=1.0
ENDFOR
;
smooth_img=SMOOTH(smooth_img,kernel)
idx_smoothed=WHERE(smooth_img GE cutoff,num_smoothed)
IF num_smoothed EQ 0 THEN BEGIN
    PRINT,FORMAT='(/,"No pixels in the cluster after smoothing.Cancel operation")'
    PRINTF,lunj,FORMAT='(/,"No pixels in the cluster after smoothing.Cancel operation")'
    GOTO,menu2d_start
ENDIF ELSE BEGIN
    xycoords=ARRAY_INDICES(smooth_img,idx_smoothed) ; The x- and y- coordinates
                                                ; corresponding to 'idx_smoothed'
;
    FOR p=0,num_smoothed-1 DO BEGIN          ; Write the smoothed cluster
        x=(xycoords[0,p]+minx)-kernel      ; Convert the smoothed cluster coordinates
                                                ; to those of of 'bg_smoothed clusters'
        y=(xycoords[1,p]+miny)-kernel
        IF x GE 0 AND x LE xdim-1 AND y GE 0 AND y LE ydim-1 then $
            bg_smoothedclusters[x,y]=clus_disp_count[j]
    ENDFOR
;
    bg_smoothedclusters[bg_minus_swath_idx]=bg_image with_land[bg_minus_swath_idx]
This step applies the background data and land masks and trims off cluster data which extend
beyond the swath boundaries as a result of the smoothing.Record the coordinates of the
smoothed clusters. NOTE: It is necessary to do ;so for all clusters because the smoothing of
one cluser my result in overwriting other clusters
;
FOR i=0,numclus-1 DO BEGIN
    idx=WHERE(bg_smoothedclusters EQ clus_disp_count[i],cnt)
    IF cnt NE 0 THEN BEGIN
        xycoords=ARRAY_INDICES(bg_smoothedclusters,idx)
        smoothed_clus_numdata[i]=cnt          ; Store the number of elements
        smoothed_arr[i*3,0:cnt-1]=idx        ; Store the 1-D index for cluster i
        smoothed_arr[i*3+1,0:cnt-1]=xycoords[0,*] ; Store the x-coordinates
        smoothed_arr[i*3+2,0:cnt-1]=xycoords[1,*] ; Store the y-coordinates
    ENDIF
ENDIF

```

```

        ENDFOR
        ;
        copy_bg_smoothedclusters=bg_smoothedclusters
        copy_bg_smoothedclusters[keyx1:keyx2,keyy1:keyy2]=ckey ; Insert the color key in a
copy of the image with smoothed clusters
        ;
        TV,copy_bg_smoothedclusters
        ;
    ENDELSE
    ;
    menu2d_start:
    ;
    inpstr=''
    PRINT,FORMAT='(/,"Smooth another cluster? (y/n):",,$)'
    READ,inpstr
    inpstr=STRLOWCASE(inpstr)
    ;
    IF inpstr NE 'y' AND inpstr NE 'n' THEN BEGIN
        PRINT,FORMAT=$
        '(/,"Incorrect entry.Please enter y or n (or r to return to the menu"),/)'
        GOTO,menu2d_start
    ENDIF
    ;
    IF inpstr EQ 'y' THEN GOTO,menu2_start
    ;
    CLOSE,lunj & FREE_LUN,lunj
    ;
    GOTO,mainmenu_start
    ;
    END ; End of '(menu EQ 2)' ; Smooth one particular cluster
    ;
    ; ***** 3. Save display(s) as .png files *****
    (menu EQ 3): BEGIN
    ;
    menu3a_start:
    ;
    inpstr=''
    PRINT,FORMAT='(/,"Save unsmoothed cluster image? (y/n or r to return to main menu):",,$)'
    READ,inpstr
    inpstr=STRLOWCASE(inpstr)
    IF inpstr EQ 'r' THEN GOTO,mainmenu_start
    IF inpstr NE 'y' AND inpstr NE 'n' THEN BEGIN
        PRINT,FORMAT=$
        '(/,"Incorrect entry.Please enter y or n (or r to return to the menu"),/)'
        GOTO,menu3a_start
    ENDIF
    ;
    IF inpstr EQ 'y' THEN BEGIN
        inpstr=''
        PRINT,"'.png'",FORMAT=$
        '("Enter the output file name (Note: a ".A," will be automatically added")'
        PRINT,FORMAT=$
        '("Also note that if the file already exist it will be overwritten :",,$)'
        READ,inpstr
        WSET,wnum_unsmoothed
        a=TVRD(0,0,TRUE=3)
        sizea=SIZE(a)
        b=BYTARR(sizea[3],sizea[1],sizea[2])
        b[0,*]=a[**,0]
        b[1,*]=a[**,1]
        b[2,*]=a[**,2]
        ;WRITE_JPEG,inpstr + '.jpg',a,TRUE=3,QUALITY=100,ORDER=1
        WRITE_PNG,inpstr + '.png',b,ORDER=1
    ENDIF
    ;
    wset,-1 ; Re-locate latest window number
    ;
    IF !D.WINDOW GT wnum_unsmoothed THEN BEGIN ; A smoothed cluster image exist
        menu3b_start:
        inpstr=''
        PRINT,FORMAT='(/,"Save smoothed cluster image? (y/n or r to return to main menu):",,$)'

```

```

READ,inpstr
inpstr=STRLOWCASE(inpstr)
IF inpstr EQ 'r' THEN GOTO,mainmenu_start
IF inpstr NE 'y' AND inpstr NE 'n' THEN BEGIN
PRINT,FORMAT=$
'(/\,"Incorrect entry.Please enter y or n (or r to return to the menu",/)'
GOTO,menu3b_start
ENDIF
;
;
IF inpstr EQ 'y' THEN BEGIN
inpstr=''
PRINT,FORMAT=$
'("Enter the output file name (Note: a ".A," will be automatically added")'
PRINT,FORMAT=$
'("Also note that if the file already exist it will be overwritten :",$)'
READ,inpstr
WSET,wnum smoothed
a=TVRD(0,0,TRUE=3)
sizea=SIZE(a)
b=BYTARR(sizea[3],sizea[1],sizea[2])
b[0,*,*]=a[*,*,0]
b[1,*,*]=a[*,*,1]
b[2,*,*]=a[*,*,2]
WRITE JPEG,inpstr + '.jpg',a,TRUE=3,QUALITY=100,ORDER=1
WRITE_PNG,inpstr + '.png',b,ORDER=1
ENDIF
;
ENDIF
;
GOTO,mainmenu_start

END ; End of '(menu EQ 3):' ; Save display(s) as .png files
;
; ----- 4. Save cluster data and/or smoothed cluster -----
; data as unformatted binary arrays
;
(menu EQ 4): BEGIN
;
menu4a_start:
;
inpstr=''
PRINT,FORMAT='(/\,"Save unsmoothed cluster data? (y/n or r to return to main menu):",$)'
READ,inpstr
inpstr=STRLOWCASE(inpstr)
IF inpstr EQ 'r' THEN GOTO,mainmenu_start
IF inpstr NE 'y' AND inpstr NE 'n' THEN BEGIN
PRINT,FORMAT=$
'(/\,"Incorrect entry.Please enter y or n (or r to return to the menu",/)'
GOTO,menu4a_start
ENDIF
;
;
IF inpstr EQ 'y' THEN BEGIN
inpstr=''
PRINT,FORMAT=$
'("Enter the output file name Note that if the file already")'
PRINT,FORMAT='("exist it will be overwritten :",$)'
READ,inpstr
data_fn=clusterdir + '\ ' + inpstr
;
; Structure a header file name
inplen=STRLEN(inpstr)
IF inplen EQ 0 THEN GOTO,menu4a_start
inparr=STRARR(inplen)
FOR i=0,inplen-1 DO inparr[i]=STRMID(inpstr,i,1)
idx=WHERE(inparr EQ '.',cnt) ; check for an extention
;
IF cnt EQ 0 THEN BEGIN ; If no extention then just add '.hdr'
hdr_fn=data_fn + '.hdr'
ENDIF ELSE BEGIN ; If name includes an extention then first remove it
hdr_fn=STRMID(inpstr,0,idx[0]) + '.hdr'

```

```

ENDELSE
hdr_fn=clusterdir + '\' + hdr_fn
;
; Save the data and write a header file
OPENW,luni,data_fn,/GET_LUN
WRITEU,luni,clus_arr
CLOSE,luni & FREE_LUN,luni
;
OPENW,luni,'C:\CLUSTER_1\hdr_fn\',/GET_LUN
PRINTF,luni,'"clus_arr"', '"make_clusters_v1.pro"', SYSTIME(), FORMAT=$
'"Header file for ",A," generated by ",A," on ",A)'
PRINTF,luni,data_fn,FORMAT='("and saved in file ",A)'
;
PRINTF,luni,3+numvar+1,numdata,FORMAT=$
'(/,"It is a LONARR(",I3," ",I6,") array   where:")'
PRINTF,luni,FORMAT=$
'" The first 3 columns contain the 1-D index, x-coordinate and y-coordinate"'
PRINTF,luni,numvar,FORMAT=$
'" The next",I3," column are the variable data"'
PRINTF,luni,numclus-1,FORMAT=$
'" and the last column contains the cluster numbers (0-",I3,")"'
;
PRINTF,luni,numclus,numvar,FORMAT=$
'(/,"The",I4," clusters were generated from",I3," images:")'
FOR i=0,numvar-1 DO PRINTF,luni,filenames[i],FORMAT='(4X,A)'
;
PRINTF,luni,nblat,sblat,FORMAT=$
'"for a swath between",F7.2,"°N and",F7.2,"°N"'
PRINTF,luni,sdist,swidth,FORMAT=$
'"starting",I4,"km from the coast and",I4,"km wide"'
;
PRINTF,luni,'"wts"',FORMAT='(/,"The cluster centres returned by CLUS_WIS as array
",A)'
PRINTF,luni,numvar,numclus,FORMAT='("It is an ",I3," column by",I3," row array)'
PRINTF,luni,FORMAT='("that is a column for each variable (image) and a row for each
cluster:",/)'
;
IF normalise NE 'yes' THEN BEGIN ; The data was not normalised
PRINTF,luni, "NOTE: The data set was not normalised before cluster analysis"
fmt_str='(' + STRTRIM(STRING(numvar-1),2) + '(F8.2, ", " ),F8.2)'
FOR i=0,numclus-1 DO PRINTF,luni,wts[*],FORMAT=fmt_str
ENDIF ELSE BEGIN ; The data was normalised
PRINTF,luni, "NOTE: The data set was normalised before cluster analysis. The
following"
PRINTF,luni, "are (1) the means and standard deviations used for the normalisation"
PRINTF,luni, " (2) the cluster centres in normalised units and"
PRINTF,luni, " (3) the cluster centres in non-normalised units.
;
fmt_str='(' + STRTRIM(STRING(numvar-1),2) + '(F10.4, ", " ),F10.4)'
PRINTF,luni,FORMAT='(/,"(1) Means (1st row) and standard deviations (2nd row):"'
PRINTF,luni,norm_data[0,*],FORMAT=fmt_str
PRINTF,luni,norm_data[1,*],FORMAT=fmt_str
;
fmt_str='(' + STRTRIM(STRING(numvar-1),2) + '(F8.4, ", " ),F8.4)'
PRINTF,luni,FORMAT='(/,"(2) Cluster centres in normalised units"'
FOR i=0,numclus-1 DO PRINTF,luni,wts[*],FORMAT=fmt_str
;
fmt_str='(' + STRTRIM(STRING(numvar-1),2) + '(F8.2, ", " ),F8.2)'
PRINTF,luni,FORMAT='(/,"(3) Cluster centres in non-normalised units"'
FOR i=0,numclus-1 DO BEGIN
a=FLTARR(numvar)
FOR j=0,numvar-1 DO BEGIN
a[j]=(wts[j,i]*norm_data[1,j]) + norm_data[0,j]
ENDFOR
PRINTF,luni,a[*],FORMAT=fmt_str
;
ENDFOR
ENDELSE
;

```

```

*****
*****
;
CLOSE,luni & FREE_LUN,luni
ENDIF
;
IF !D.WINDOW GT wnum_unsmoothed THEN BEGIN ; A smoothed cluster image exist and
; thus also a data array

menu4b_start:
inpstr=''
PRINT,FORMAT='(/,"Save smoothed cluster data? (y/n or r to return to main menu):",)$)'
READ,inpstr
inpstr=STRLOWCASE(inpstr)
IF inpstr EQ 'r' THEN GOTO,mainmenu_start
IF inpstr NE 'y' AND inpstr NE 'n' THEN BEGIN
PRINT,FORMAT=$
'(/,"Incorrect entry.Please enter y or n (or r to return to the menu",/)'
GOTO,menu4b_start
ENDIF
;
IF inpstr EQ 'y' THEN BEGIN
inpstr=''
PRINT,FORMAT=$
'("Enter the output file name. Note that if the file already exist")'
PRINT,FORMAT='("it will be overwritten :",$)'
READ,inpstr
data_fn=clusterdir + '\' + inpstr
; Structure a header file name
inplen=STRLEN(inpstr)
IF inplen EQ 0 THEN GOTO,menu4a_start
inparr=STRARR(inplen)
FOR i=0,inplen-1 DO inparr[i]=STRMID(inpstr,i,1)
idx=WHERE(inparr EQ '.',cnt) ; check for an extention
;
IF cnt EQ 0 THEN BEGIN ; If no extention then just add '.hdr'
hdr_fn=data_fn + '.hdr'
ENDIF ELSE BEGIN ; If name includes an extention then first remove it
hdr_fn=STRMID(inpstr,0,idx[0]) + '.hdr'
ENDELSE
hdr_fn=clusterdir + '\' + hdr_fn
;
; Save the data and write a header file
OPENW,luni,data_fn,/GET_LUN
WRITEU,luni,smoothed_arr
CLOSE,luni & FREE_LUN,luni
;
OPENW,luni,'C:\CLUSTER_1\CLUSTER_IDL_PRG\hdr_fn',/GET_LUN
PRINTF,luni,'smoothed arr', 'make_clusters_v1.pro',SYSTEMTIME(),FORMAT=$
'("Header file for ",A," generated by ",A," on ",A)'
PRINTF,luni,data_fn,FORMAT='("and saved in file ",A)'
;
PRINTF,luni,numclus*3,numpix,FORMAT=$
'(/,"It is a LONARR(",I3,",",I6,") array where:")'
PRINTF,luni,numclus,FORMAT=$
'(" There are 3 columns for each of",I3," clusters: 1-D, x- and y-coordinates")'
PRINTF,luni,FORMAT=$
'(" The number of data values vary from cluster to cluster as follows:")'
FOR i=0,numclus-1 DO PRINTF,luni,i+1,smoothed_clus_numdata[i],$
FORMAT='(" Cluster",I3," number of points =",I5)'
;
PRINTF,luni,numclus,numvar,FORMAT=$
'(/,"The",I4," clusters were generated from",I3," images:")'
FOR i=0,numvar-1 DO PRINTF,luni,filenames[i],FORMAT='(4X,A)'
;
PRINTF,luni,nblat,sblat,FORMAT=$
'("for a swath between",F7.2,"°N and",F7.2,"°N")'
PRINTF,luni,sdist,swidth,FORMAT=$
'("starting",I4,"km from the coast and",I4,"km wide")'
;
PRINTF,luni,'wts',FORMAT='(/,"The cluster centres returned by CLUS_WTS as array ",A)'

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```

PRINTF,luni,numvar,numclus,FORMAT='("It is an ",I3," column by",I3," row array")'
PRINTF,luni,FORMAT='("that is a column for each variable (image) and a row for each
cluster:",//)
;
IF normalise NE 'yes' THEN BEGIN ; The data was not normalised
PRINTF,luni, "NOTE: The data set was not normalised before cluster analysis"
fmt_str='(' + STRTRIM(STRING(numvar-1),2) + '(F8.2, ", " ),F8.2)'
FOR i=0,numclus-1 DO PRINTF,luni,wts[*],i,FORMAT=fmt_str
ENDIF ELSE BEGIN ; The data was normalised
PRINTF,luni, "NOTE: The data set was normalised before cluster analysis. The
following"
PRINTF,luni, "are (1) the means and standard deviations used for the
normalisation"
PRINTF,luni, " (2) the cluster centres in normalised units and"
PRINTF,luni, " (3) the cluster centres in non-normalised units.
;
fmt_str='(' + STRTRIM(STRING(numvar-1),2) + '(F10.4, ", " ),F10.4)'
PRINTF,luni,FORMAT='(/,"(1) Means (1st row) and standard deviations (2nd row):")'
PRINTF,luni,norm_data[0,*],FORMAT=fmt_str
PRINTF,luni,norm_data[1,*],FORMAT=fmt_str
;
fmt_str='(' + STRTRIM(STRING(numvar-1),2) + '(F8.4, ", " ),F8.4)'
PRINTF,luni,FORMAT='(/,"(2) Cluster centres in normalised units")'
FOR i=0,numclus-1 DO PRINTF,luni,wts[*],i,FORMAT=fmt_str
;
fmt_str='(' + STRTRIM(STRING(numvar-1),2) + '(F8.2, ", " ),F8.2)'
PRINTF,luni,FORMAT='(/,"(3) Cluster centres in non-normalised units")'
FOR i=0,numclus-1 DO BEGIN
a=FLTARR(numvar)
FOR j=0,numvar-1 DO BEGIN
a[j]=(wts[j],i*norm_data[1,j]) + norm_data[0,j]
ENDFOR
PRINTF,luni,a[*],FORMAT=fmt_str
;
ENDFOR
ENDELSE
;
PRINTF,luni,FORMAT='(/,"Smoothing consisted of:")'
OPENR,lunj,clusterdir + '\ ' + 'make_clusters_journal.txt',/GET_LUN
inpstr=''
WHILE NOT EOF(lunj) DO BEGIN
READF,lunj,inpstr
PRINTF,luni,inpstr
ENDWHILE
;
CLOSE,lunj & FREE_LUN,lunj
;
CLOSE,luni & FREE_LUN,luni
ENDIF
;
ENDIF
;
GOTO,mainmenu_start

END ; End of '(menu EQ 4):' ; Save data

;*****
*****
***** 5. Temporarily stop the program *****
(menu EQ 5): BEGIN
PRINT,FORMAT='(//,"The program will stop now. Enter .cont to carry on",//)'
STOP
GOTO,mainmenu_start
;
END ; End of '(menu EQ 5):' ; Temporarily stop the program
;
;*****
*****
***** 6. Exit *****
(menu EQ 6): BEGIN

```

```

;
menu6_start:
inpstr=''
PRINT,FORMAT='(//,"Do you want to exit the program? (y/n):",)$)'
READ,inpstr
inpstr=STRLOWCASE(inpstr)
;
IF inpstr NE 'y' AND inpstr NE 'n' THEN BEGIN
PRINT,FORMAT=$
' (//,"Incorrect entry.Please enter y or n",//)'
GOTO,menu6_start
ENDIF
;
IF inpstr EQ 'y' THEN BEGIN
PRINT,FORMAT='(//,"Exiting",//)'
GOTO,exit_label
ENDIF ELSE BEGIN
GOTO,mainmenu_start
ENDELSE
;
END ; End of '(menu EQ 6):' ; Exit
;
;
ENDCASE
;
exit_label:
jfn=clusterdir + '\ ' + 'make_clusters_journal.txt'
FILE_DELETE,jfn,/QUIET
;
END
#####
#####
20 PENTADE

YEAR=2000
MONTH=12
day=25
PENTADE=INTARR(2,6)
PENTADE[*,*]=[1,5,6,10,11,15,16,20,21,25,26,31]
pent=0
FOR i=0,5 DO BEGIN
IF day GE PENTADE[0,i] AND day LE PENTADE[1,i] THEN pent=i+1
PRINT,pent
ENDFOR
ystr=STRTRIM(string(year),2)
IF MONTH GT 9 THEN BEGIN
mstr=STRTRIM(string(month),2)
ENDIF ELSE BEGIN
mstr='0'+ STRTRIM(string(month),2)
ENDELSE
pstr=STRTRIM(string(pent),2)
chlfile="chl"+ystr+mstr+"p"+pstr+".bil"
SSTfile="b"+ystr+mstr+"p"+pstr+".sst"
PRINT,chlfile
PRINT,SSTfile
END
#####
#####

```

21 Read_Angola_CTD_data_v1.pro

A test procedure to read Filipe Vianda's CTD data files.
This procedure reads and stores the following:
NOTE: 'sdepth' is the depth to be sampled. Depth is decoded
(Depth = 2 characters: Characters 29 to 30)
but not stored
Station number = 4 characters: Characters 4 to 7
Latitude = 4 characters: Characters 8 to 11. Decimal degrees S. Two decimals

```

Longitude      = 5 characters: Characters 12 to 16. Decimal degrees E. Two decimals
Year           = 4 characters: Characters 17 to 20.
Month          = 2 characters: Characters 21 to 22
Day            = 2 characters: Characters 23 to 24
sdepth Temperature = 4 characters: Characters 31 to 34. Decimal °C. Two decimals.
sdepth Salinity   = 5 characters: Characters 35 to 39. Decimal ppt. Three decimals
sdepth Oxygen     = 4 characters: Characters 56 to 59. Decimal ml oxygen per liter. Two
decimals
;
;
; Written by J.J.Agenbag MCM 12 Sep 2006
;
outputdir='C:\CLUSTER_1\CONGO PLUME\CTD_SALINITY\'
outfile='CTD_5_1997-2000_SURVEYS'
;
CD,outputdir,CURRENT=workdir0
outputpath=outputdir + '\' + outfile
OPENW,luno,outputpath,/GET_LUN
PRINT,outputpath,FORMAT='(/,"Open output file ",A,/)\'
CD,workdir0
;
;
datadir='C:\DATA\CTD_DATA_ICES_FORMAT\'
CD,datadir,CURRENT=workdir0
;
num_inputdirs = 6      ; Number of input directories
input_dir=STRARR(num_inputdirs)
input_dir[0:1]='1994_2003_ICES\QUERY-2001402-X-X-X-X-X','1994_2003_ICES\QUERY-2001406-X-
X-X-X-X'
input_dir[2:3]='1994_2003_ICES\QUERY-2002403-X-X-X-X-X','1994_2003_ICES\QUERY-2002408-X-
X-X-X-X'
input_dir[4:5]='1994_2003_ICES\QUERY-2003404-X-X-X-X-X','1994_2003_ICES\QUERY-2003408-X-
X-X-X-X'
;input_dir[6:7]='1994_2003_ICES\QUERY-2000403-X-X-X-X-X','1994_2003_ICES\QUERY-2000408-
X-X-X-X-X'
;
;
sdepth=5      ; The depth for which temperature, salinity and oxygen data are
; extracted
num_vars=9      ; Number of variables to read
var_chars=INTARR(3,num_vars) ; The start and end characters in the input string plus
number of decimals
var_chars[*,*]=[4,7,0, 8,11,2, 12,16,2, 17,20,0, 21,22,0, 23,24,0, 31,34,2, 35,39,3,
56,59,2]
;
varnames=STRARR(num_vars)
varnames[0:5]='Station no.','Year','Month','Day','Latitude','Longitude'
varnames[6:num_vars-1]='20m Temperature','20m Salinity','20m Oxygen'
;
num_rec_skip=1      ; Skip this number of records before starting to read data
;
stv=[0,3,4,5]
vars_st=INTARR(4,20000) ; Store here the standard (integer) output components ie.
Station number, year, month and day. The number of records is unknown at this stage.
nonstv=[1,2,6,7,8]
vars_nonst=FLTARR(5,20000) ; The non-standard output variables eg. latitude,longitude,
; temperature, salinity and oxygen
;
irec=-1      ; Row index for 'vars_st' and 'vars_nonst'
FOR i=0,num_inputdirs-1 DO BEGIN
CD,input_dir[i],CURRENT=workdir1
file_list=FINDFILE('*.dos',COUNT=num_files)
;
FOR j=0,num_files-1 DO BEGIN
file_name=file_list[j]
pathname=datadir + '\' + input_dir[i] + '\' + file_name
PRINT,pathname,FORMAT='("Reading file ",A)\'
OPENR,luni,file_name,/GET_LUN
str=''
IF num_rec_skip GT 0 THEN BEGIN
FOR k=0,num_rec_skip-1 DO READF,luni,str ; Read and discard the first record(s)

```

```

ENDIF
;
WHILE EOF(luni) NE 1 DO BEGIN           ; Read all other records
  READF,luni,str
  ;
  substr=STRMID(str,29,2)               ; Get the depth
  depth=0
  READS,substr,depth
  IF depth LT sdepth THEN BEGIN       ; Check for correct depth
    GOTO, label_read_next_record
  ENDIF ELSE BEGIN
    IF depth GT sdepth THEN BEGIN
      PRINT,sdepth,FORMAT='("No",I3,"m data in this file")'
      PRINTF,luno,sdepth,file name,FORMAT='("No",I3,"m data in file ",A)'
      GOTO, label_read_next_file
    ENDIF
  ENDELSE
;
; This is the record for the specified depth. Extract the data
irec=irec+1
;
FOR k=0,num_vars-1 DO BEGIN           ; Decode all the variables
  c1=var_chars[0,k]
  c2=var_chars[1,k]
  ndec=var_chars[2,k]
  nc=c2-c1+1
  substr=STRMID(str,c1,nc)
  var=0L
  READS,substr,var
  idx=WHERE(stv EQ k,cnt)
  ;
  IF cnt NE 0 THEN BEGIN
    vars_st[idx,irec]=var
  ENDIF ELSE BEGIN
    idx_nonst=WHERE(nonstv EQ k,cnt_nonst)
    var=FLOAT(var)/(10.0^ndec)
    vars_nonst[idx_nonst,irec]=var
  ENDELSE
;
ENDFOR                                ; End of 'FOR k=0,num_vars-1 DO BEGIN'
GOTO,label_read_next_file             ; Data for the specified depth has been
;                                     ; extracted. Go do next file.
;
label_read_next_record:
ENDWHILE                               ; End of 'WHILE EOF(luni) NE 1 DO BEGIN'
;
label_read_next_file:
CLOSE,luni & FREE_LUN,luni
ENDFOR                                  ; End of 'FOR j=0,num_files-1 DO BEGIN'
;
CD,workdir1 ; Go up to previous directory level
ENDFOR                                  ; End of 'FOR i=0,num_inputdirs-1 DO BEGIN'
;
; Output
;
PRINT,outputpath,FORMAT='(//,"Outputting data to ",A)'
;
; Print column headers
FOR i=0,num_vars-2 DO BEGIN
  PRINTF,luno,varnames[i],FORMAT='(A,"",,$)'
ENDFOR
PRINTF,luno,varnames[num_vars-1],FORMAT='(A)'
;
; Print the data
FOR i=0,irec DO BEGIN
  FOR j=0,3 DO PRINTF,luno,vars_st[j,i],FORMAT='(I,"",,$)'
  FOR j=0,3 DO PRINTF,luno,vars_nonst[j,i],FORMAT='(F,"",,$)'
  PRINTF,luno,vars_nonst[4,i],FORMAT='(F)'
ENDFOR
;

```

```

CLOSE,luno & FREE_LUN,luni
;
PRINT,FORMAT='(/,"All done")'
;
END

```

```

#####
#####

```

23 FUNCTION 'make_WC_swatharray'

```

; This function is intended to create an array defining a swath parallel to
; the southern African west coast - an array such as needed by function
; 'swathpixel_xy'.
; NOTE: This function ONLY work on the west coast !!
;
; It returns a 2-D integer array of three columns where
;     the first column contains the line number (y-coordinate)
;     and the other two columns the start and end pixel numbers
;     (x-coordinates) defining the swath width for that line.
;     Note: The first x-coordinate will be that of the pixel nearest the
;           and inside the swath. The second x-coordinate will be the one
;           furthest from the coast and the last pixel still in the swath.
;
; Inputs required:
;   image           The image (2-D byte array) for which the swath is to be
;                   defined. It MUST contain a land mask
;   latn and lats   The latitudes at the centres of the first and last lines
;                   in 'image'. Must be decimal degrees and in °N (ie southern
;                   hemisphere latitudes are negative)
;   lonw and lone   Longitudes at the centres of the first and last pixels. Must
;                   be decimal degrees and °E (ie western hemisphere longitudes
;                   are negative)
;   nblat and sblat The northern and southern latitude boundaries for the swath
;                   These must follow the same rules as nlat and slat
;   sdist           The distance (km) from the coast to the first pixel in the
;                   swath (ie the one nearest the coast). The distance will be
;                   taken as the distance between the seaward edge of the land
;                   boundary pixel and the landward edge of the first pixel in
;                   the swath.
;   swidth          the swath width (km). Note: The width will be taken to be the
;                   distance from the shoreward edge of the first pixel to the
;                   off-shore edge of the last pixel.
;   landb_mask      The land border or land mask pixel count. Note this count will
;                   be used to find the location of the coast and the coast will
;                   be taken to be the west-most land_mask value found in a
;                   particular scan line.
;
; Written by J.J.Agenbag MCM November 2005
;
FUNCTION make_WCswatharray,image,latn,lats,lonw,lone,nblat,sblat,sdist,swidth,$
        landb_mask
;
asize=SIZE(image,/DIMENSIONS)
xdim=asize[0] ; x dimension of the image
ydim=asize[1] ; y dimension
;
x_pixel_size = DOUBLE(ABS(lonw-lone))/DOUBLE(xdim-1.0) ; pixel x-dimension (degrees)
y_pixel_size = DOUBLE(ABS(latn-lats))/DOUBLE(ydim-1.0) ; pixel y-dimension (degrees)
;
; The x/y to lat long conversions are given by:
; latitude = nlat - y * y_pixel_size
; longitude = wlon + x * x_pixel_size
; y         = ROUND((nlat - latitude)/y_pixel_size)
; x         = ROUND((longitude - wlon)/x_pixel_size)
;
;
nline=ROUND(DOUBLE(latn - nblat)/y_pixel_size) ; The northern-most line in the swath
IF nline LT 0 THEN nline = 0

```

```

    IF nline GT ydim-1 THEN nline = ydim-1
    sline=ROUND(DOUBLE(latn - sblat)/y_pixel_size) ; The southern-most line in the swath
    IF sline LT 0 THEN sline = 0
    IF sline GT ydim-1 THEN sline = ydim-1
    fline=MIN([nline,sline],MAX=lline) ; The first and last scan lines in the swath
    numlines=lline-fline+1
  ;
  ; Determine the x-dimension of a pixel in kilometer at a position half way between
  ; nlat and slat
  ;
  clat=(nblat+sblat)/2.0
  lon1=lonw + 1.0* x_pixel_size ; The longitudes of two adjacent pixels
  lon2=lonw + 2.0* x_pixel_size
  a=MAP_2POINTS(lon1,clat,lon2,clat,/METERS)
  pix_xsize=a[0]/1000.0 ; The x-dimension of the pixel in kilometers
  PRINT,pix_xsize
  ;
  ; Convert 'sdist' and 'swidth' from kilometer to number of pixels
  sdist_pix=ROUND(FLOAT(sdist)/pix_xsize) ; sdist in number of pixels
  swidth_pix=ROUND(FLOAT(swidth)/pix_xsize) ; swidth in number of pixels
  ;
  outarr=INTARR(3,numlines) ; The output array
  ;
  i=-1
  FOR j=fline,lline DO BEGIN ; DO all the lines
    i=i+1
    idx=WHERE(image[*],j) EQ landb_mask,cnt)
    x_landb=idx[0] ; The westernmost land mask pixel
    fpix=x_landb - sdist_pix-1 ; The x-coordinate of the first
    ; pixel in the swath
    lpix=fpix - swidth_pix +1 ; The last pixel in the swath
    outarr[*],i]=[j,fpix,lpix]
  ENDFOR
  ;
  RETURN,outarr
END
#####
#####

```

23 COMPUTATION OF UPWELLING INDICES FROM METEOSAT SST IMAGES

```

;PROGRAM TO COMPUTE MEAN SST FOR UPWELLING PURPOSE
;MEAN SST IS COMPUTED FROM EACH SCAN LINE
;IDL PROGRAM WRITTEN BY VIANDA L.L. FILIPE /UCT MSc STUDENT (2005/2006)"
;SUPERVISOR DR. KOBUS AGENBAG (MCM/CAPE TOWN)
;
img_dir='C:\DATA\METEOSAT_MONTHLY_COMPOSITES\'
img_str='*.sst'
;
out_dir='C:\UPWELLING\'
out_file='UPWELLING_ONSHORE_SST.txt'
;
;STARTING AND ENDING TIME (YEAR,MONTH & IMAGES)
start_year=1987
end_year=2002
start_month=1
end_month=12
start_img=1
end_img=1
;
;GEOGRAPHICAL COORDINATES OF THE IMAGE
;
start_lat=-5.00
end_lat=-40.00
start_lon=5.00
end_lon=40.00
;
;Pixel Samples (nber of columns), Scan lines (nber of rows), Xsize & Ysize
;
xdim=650
ydim=650
ysize=(start_lat-end_lat)/ydim

```

```

xsize=(end_lon-start_lon)/xdim
;
PRINT,ysize,xsize
;
;Lentgh of the swath
;
swath_width1=12 ;km (Distance between the coast and the first point offshore)
swath_width2=24 ;km
;
;
y=106 ; obtained from the centre of the region,values
; obtained from RDPIX (y1=543,y=649-543=106)
x1=84 ; Value of the first pixel in the scan line y=106
x2=85 ; Value of the second pixel in the scan line y=106
;
; CONVERSION OF X1 AND X2 INTO LONGITUDE 1 AND LONGITUDE 2
;
lon1= start_lon+(xsize/2)+x1*xsize
lon2= start_lon+(xsize/2)+x2*xsize
;
Print,"lon1=",lon1,"lon2=",lon2
;
;GEOGRAPHICAL COORDINATES OF A GIVEN REGION (In this case: Angola)
;
latn=-5.0212
lats=-17.33
;
;CONVERSION OF GEOGRAPHICAL COORDINATES OF THE REGION (lat,long) into X,Y COORDINATES
;
yn=ROUND(((start_lat-latn)/ysize)-0.5) ; y1 (for latn)
ys=ROUND(((start_lat-lats)/ysize)-0.5) ; y2 (for lats)
;
Print,"yn=",yn,"ys=",ys
;
;TEMPERATURE RANGE ACCEPTABLE IN ANGOLAN WATERS
;
minT=12 ; minimum temperature
maxT=32 ; maximum temperature
;CONVERSION OF TEMPERATURES(DECIMAL) INTO DIGITAL NUMBERS (DN)
;
minval=2*(55-maxT)
maxval=2*(55-minT)
min_percent_good=30 ; MINIMUM PERCENTAGE OF GOOD SST REQUIRED IN A SWATH
;
;
n=12*((end_year)-(start_year)+1) ;TOTAL NUMBER OF BINARY FILES
Print,n ; number of files
arr=STRARR(n)
darr=INTARR(n)
barr=INTARR(n)
numfile=-1
MODE= 2
; THE FOLLOWING SUBROUTINE ALLOWS TO LIST ALL BINARY FILES
FOR year=start_year,end_year DO BEGIN
str_year=STRTRIM(string(year),2)
IF MODE EQ 1 THEN BEGIN
IF year GT start_year THEN BEGIN
sm=1
em=12
IF year EQ end_year THEN BEGIN
sm=1
em=end_month
ENDIF
ENDIF ELSE BEGIN
sm=start_month
em=12
ENDELSE
ENDIF ELSE BEGIN; mode 2
sm=start_month
em=end_month
ENDELSE

```

```

      FOR month=sm,em DO BEGIN
        numfile=numfile+1
          IF month GT 9 THEN BEGIN
            str_month=STRTRIM(string(month),2)
          ENDIF ELSE BEGIN
            str_month='0'+ STRTRIM(string(month),2)
          ENDELSE
            img_str='b'+ str_year + str_month +'.sst'
            arr[numfile]=img_str
            barr[numfile]=year
            darr[numfile]=month
          ENDFOR
        ENDFOR
      Print,arr
    ;
    ;*****
    ;*****
    ;
    img_str=img_dir+'*.sst'
    img_list=FINDFILE(img_str,count=num_img)
    ;
    file_path=img_dir + arr(0)
    OPENR,luni,file_path,/GET LUN ; READING THE FIRST IMAGE
    a=ASSOC(luni,BYTARR(xdim,ydim))
    image=a(0)
    CLOSE,luni & FREE_LUN,luni
    ;
    y_start=Min([yn,ys]); COMPUTE THE MINIMUM LATITUDE AS THE STARTING LAT
    y_end= Max([yn,ys]); COMPUTE THE MAXIMUM LATITUDE AS THE ENDING LAT
    ;
    numRows=y_end-y_start+1
    ;
    ;*****
    ;*****
    swath_mask=BYTARR(xdim,ydim)
    swath_arr=INTARR(3,numRows+1)
    yi=-1
    ;
    FOR y=y_start,y_end DO BEGIN
      yi=yi+1
      ;
      ; CONVERSION OF Y INTO THE CORRESPONDING LATITUDE
      ;
      laty= start_lat-(ysize/2)-y*ysize
      ;
      ;COMPUTATION OF THE PIXEL SIZE USING MAP-2POINTS (LONGITUDES LON1 & LONG2 ARE ;CONSTANTS $
      AND LATITUDE, A VARIABLE VARYING BETWEEN START_LAT AND END_LAT)
      ;
      xdim1=MAP_2POINTS(lon1,laty,lon2,laty,/meters)/1000; XDIM1/1000 CONVERTING M INTO KM
      ;
      idx=where(image[*],y) EQ 29,cnt)
      ;
      x_coast=idx(0) ; FIRST PIXEL FOUND AT THE COAST (BORDER)
      x_swath_width1=ROUND(Float((swath_width1)/(xdim1))) ; NUMBER OF PIXELS BETWEEN THE
      COAST AND THE FIRST SWATH
      x_swath_width2=ROUND(Float((swath_width2)/(xdim1)))
      ;
      x11=x_coast ; X VALUE OF THE COAST
      x12=(x11-1)-(x_swath_width1) ; X VALUE OF THE FIRST SWATH
      x13=(x12+1)-(x_swath_width2)
      ;
      PRINT,y,"x11=",x11,"x12=",x12,"x13=",x13,"xdim1=",xdim1,"x_swath_width1=",
      x_swath_width1,"x_swath_width2=", x_swath_width2
      ;
      swath_arr(*,yi)=[y,x12,x13] ;STORING ALL Y_COORD. AND THE CORRESPONDING X11 AND X12
      INTO SWATH_ARR
      ;
      swath_mask(x13:x12,y)=255
    ENDFOR
    Print,swath_arr
  
```

```

;
;*****
;*****
idx_land=WHERE(image EQ 30,num_idx_land)
idx_border=WHERE(image EQ 29,num_idx_border)
swath_mask[idx_land]=120
swath_mask[idx_border]=200
;
Print,"num_idx_land=",num_idx_land,"num_idx_border=",num_idx_border
;
!ORDER=1
wnum=!D.WINDOW+1
WINDOW,wnum,XSIZE=xdim,YSIZE=ydim
TVSCL,swath_mask > 100 < 255
TV,swath_mask
;print,swath_mask[66:139,158]
;*****
;*****
min_pixels=ROUND((min_percent_good/100.0)* x_swath_width2)
Print,min_pixels
n_images=numfile
;
OPENW,luno,out_dir+out_file,/GET_LUN; OPEN AN OUTPUT FILE
;
FOR j=0,n_images DO BEGIN ; PROCESSING OF ALL IMAGES
    file_path=img_dir + arr(j)
    index=WHERE(img_list EQ file_path,count); CHECK ANY MISSING IMAGE
;
    IF count NE 0 THEN BEGIN
;
        OPENR,luni,file_path,/GET_LUN
        a=ASSOC(luni,BYTARR(xdim,ydim))
        image=a(0)
        CLOSE,luni & FREE_LUN,luni
;
;
        averages=FLTARR(2,numrows)
;*****
;*****
; HOW TO FIND THE CORRESPONDING IMAGE VALUES FROM Y AND XL1 AND XL2

        FOR i=0,numrows-1 DO BEGIN
;
            y=swath_arr[0,i]
            xl2=swath_arr[1,i]
            xl3=swath_arr[2,i]
;
            SUBIMAGE=image[xl3:xl2,y]
;
            idx=WHERE (SUBIMAGE GT 30 AND SUBIMAGE GT minval AND SUBIMAGE LE maxval,ct)
; EXCLUDE ALL CLOUDS,BORDER, LAND AND ALL DN OUTSIDE
; THE
TEMP. RANGE SPECIFIED FOR ANGOLA
        SST=55.0-(SUBIMAGE/2.0)
;
        IF ct GE min_pixels THEN BEGIN ; A minimum number of good pixels is REQUIRED to
compute the mean SST
            mean_SST=MEAN(SST(idx))
            averages[0,i]=swath_arr[0,i] ;First column of scan lines
            averages[1,i]=mean_SST ;Second column of mean SST

        ENDIF ELSE BEGIN ;if the number of good pixels is less than the minimum required
than the file is rejected by writing -99.999
            averages[0,i]=swath_arr[0,i] ;First column of scan lines
            averages[1,i]=-9999.99 ;Second column of mean SST

        ENDELSE
;
    ENDFOR

ENDIF ELSE BEGIN

```

```
ENDELSE
;THE FOLLOWING SUBROUTINE ALLOWS TO WRITE THE OUTPUT IN A SPECIFIC OUTPUT FILE.
PRINTF,luno,arr(j)
PRINTF,luno,averages
;
ENDFOR
;
Close,luno & FREE_LUN,luno
;
END
```

```
##### END #####
```

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