Spatial Dynamics of the Coastal Upwelling off Côte-d'Ivoire

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Abstract

Coastal SST measurements and images derived from Meteosat Satellit TIR channel are used to study the spatio-temporal evolution of the minor upwelling off Côte-d'Ivoire. The TIR images derived from Meteosat provide a comprehensive view of the spatial dynamics of the upwelling off Côte-d'Ivoire. The cooling water was detected by Meteosat sensors because there is generally a clear sky situation and a sufficient spatial extension of the upwelling each time it takes place. The use of the Meteosat data seems to be sufficient to localize the surface cooling off Côte-d'Ivoire. The minor upwelling appears to be more persistent in the western side than in the eastern side off Côte-d'Ivoire. In spite of its local aspect, the use of the coastal SST measurements can be considered as a good tool to detect the presence of the coastal upwelling.

Résumé

Les mesures de SST côtières et les images dérivées du canal IR du satellite Météosat sont utilisées pour étudier l'évolution spatio-temporelle du petit upwelling devant la Côte-d'Ivoire. Les images TIR dérivées de Météosat donnent une image interprétable des dynamiques spatiales des upwellings devant la Côte-d'Ivoire. Les refroidissements sont détectés par les capteurs de Météosat parce qu'en général un ciel clair et une extension suffisante au large se produit. L'utilisation de Météosat apparaît satisfaisante pour localiser les zones de refroidissement devant la Côte-d'Ivoire. Le petit upwelling apparaît plus persistant dans la partie ouest que dans la partie est de la Côte-d'Ivoire. En dépit de son aspect local, l'utilisation des mesures de SST côtières peuvent être considérées comme un bon moyen pour détecter la présence de l'upwelling côtier.

INTRODUCTION

The temperature of the uppermost layer of the ocean determines the heat content and affects biological activity. Observed large-scale and persistent anomalies in sea surface temperature are of great interest in the context of global climate change monitoring (McClain *et al.*, 1985; Bakun, 1990). Sea surface temperature (SST) is also known to affect the spatial distribution of marine species (Brown and Winn, 1989). Thus, knowledge of the spatio-temporal evolution of SST can be related to annual indices of the abundance of fishes and to the impact of climate changes on the spatial distribution of pelagic fishes (Mendelssohn and Cury, 1989; Pezennec and Koranteng, this vol.).

Coastal SST measurements have shown that, twice a year, there is a moderate, then a great decrease of the SST between January and March (minor upwelling) and between July and September (major upwelling) along the coasts of Côte-d'Ivoire and Ghana. Upwellings-induced plankton production maintain large stocks of pelagic fishes. Indeed, there has been an increase of catches of *Sardinella aurita* in Côte-d'ivoire and Ghana during the last decade and a new spatial and seasonal distribution of the stock (Binet and Servain, 1993; Pezennec and Bard, 1992).

Generally, the large-scale behaviour of coastal upwelling can be better observed from geostationary satellites imagery than by coastal SST measurements. Satellite data provide uniform and continuous coverage of the SST when there is a clear sky situation. The Meteosat data derived from the Thermal Infra Red (TIR) channel have been shown to be appropriate for these studies because they provide the kind of spatial and temporal coverage required for fisheries related investigations.

Since 1991, the Meteosat high resolution transmission can be received by a Primary Data User Station (PDUS) installed at the University of Abidjan (Côte-d'Ivoire). This ensures that we receive regular half hourly Visible, Water Vapor and Thermal Infrared images data with a spatial resolution of 5km for the TIR channel, only a few minutes after they have been scanned.

In its initial form, the PDUS system has been installed to satellite estimation of rainfall over Côte-d'Ivoire. However, images data derived from TIR channel have been archived for the purpose of sea surface temperature monitoring.

In the present paper, coastal SST measurements and TIR images from Meteosat are used to study the spatio-temporal evolution of the SST off Côte-d'Ivoire. This preliminary study is focused on the minor upwelling of the year 1993.

1. DESCRIPTION OF THE STUDY AREA

1.1. General climatology along the coastline of Côte-d'Ivoire

A knowledge of the Ivoirian and Ghanaian coastal upwelling mechanism requires to study the climatology of the Gulf of Guinea and to pay attention to the local climate of Cape Palmas and Cape Three Points, because it is recognized that surface cooling is strongest on the eastern sides of these two capes (Ingham, 1970).

The climate of South Côte-d'Ivoire and Ghana is characterized by four seasons:
a) The long dry season, which begins in December and ends in March;
b) The long rainy season, which starts in May and lasts three months, with rain storm events from April to May;
c) August and September, which correspond to the short dry season;
d) October and November, which correspond to the short rainy season.

According to Cautenet (1979), the precipitations are more important at Axim (1969 mm) than at Takoradi (1068 mm) and at Accra (659 mm), whatever the season. Axim and Takoradi are 56 km faraway and are symmetrical in relation to Cape Three Points (Fig. 1). The same trend is also observed at Tabou near Cape Palmas. The effective level of rainfall records at Tabou is about 2100 mm/year. The levels of rainfall recorded at San Pedro and Fresco are less important than the levels of rainfall at Tabou.

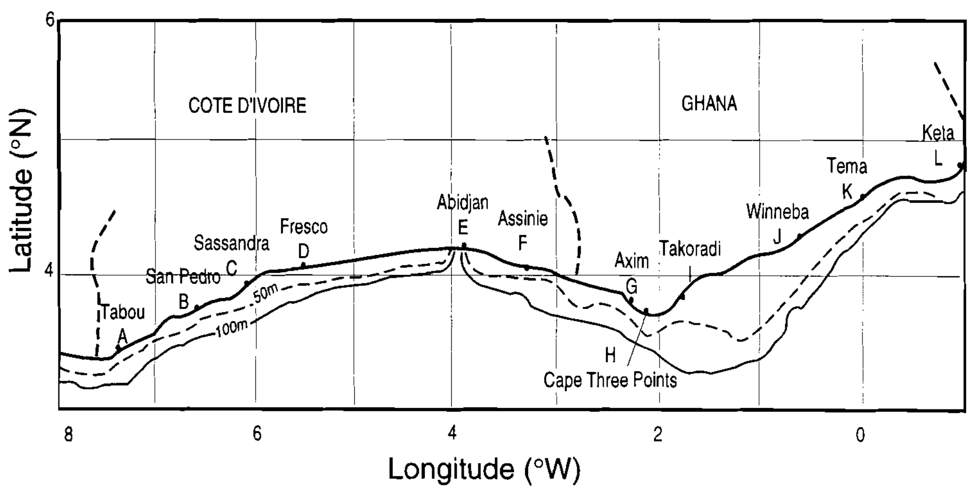


Fig. 1: The study area, along the coasts of Côte-d'Ivoire and Ghana.

In these two cases, there is a decrease of the level of rainfalls in the eastern sides of the capes (Cautenet, 1979). The monsoon is the main provider of precipitations during the long rainy season along the Gulf of Guinea, while the sea breeze circulation is the only factor which determines the precipitations during the dry season (Cautenet, 1979). The sea breeze circulation is due to the difference (ΔT) between the air temperature on the ground and the sea surface temperature. During the minor upwelling, ΔT is positive and favours the development of the sea breeze circulation. Thus, SST can be considered as an important factor for determining rainfall during the minor upwelling period.

2. THE DATA SET AND THEIR PROCESSING

We have two data sources for this preliminary study:

a) The five coastal stations sampled by the Centre de Recherches Océanologiques (CRO) of Abidjan. These stations are located along the open Ivoirian gulf (Fig. 1), from Tabou (near Cape Palmas) to Assinie (near the border of Ghana). The available ground SST measurements are carried out from January to March 1993;

b) The Meteosat data, which cover the coast of Ghana and Côte-d'Ivoire for the year 1993. These data consist of TIR images over the area from 10°W to 0° and 0° to 10°N (from Cape Palmas to Takoradi). The TIR images acquired cover the two upwelling periods.

Scanning of the earth nominally takes place every half-an-hour, providing images in all three spectral channels. The infrared and water vapour images are composed of 2500 lines, each of 2500 pixels, whilst the visible image consists of 5000 lines of 5000 pixels. The corresponding spatial resolution at the sub-satellite point are 5 km and 2.5 km, respectively. The TIR images used for this study are from the formats AI and AIVH. The latter is a combination of visible and infrared images. In the AIVH format, visible channel data is reduced to the spatial resolution of the infrared channel. The Thermal InfraRed image, the administrative message and the calibration coefficients are extracted from the raw data. The raw TIR is converted to radiance image by using:

$$\text{Radiance} = (\text{NC} - \text{SPC}) \times \text{Ircal}. \qquad (1)$$

where NC is the numerical count, and SPC and Ircal are calibration coefficients disseminated with the raw image.

The radiance data, in the form of digital counts for each pixel, are produced by transcription to temperature through transcription table (inversion of Planck's Law). The spatial resolution of the images is 5 km and the temperature resolution is 0.5°C.

47 digital TIR half- hourly images are received, processed and archived every day by the Department of Physics of the University of Abidjan. A daily synthesis image is obtained from the 47 half-hourly images of temperature brightness maxima. The presence of cloud cover leads to a severe reduction of our ability to observe daily oceanic structures. So, for every period of five days, a period synthesis of temperature brightness maxima is routinely carried out. No correction for atmospheric attenuation is carried out, but the method of processing the synthesis image minimizes this attenuation effect. In our study, the image of January 12th was used to hide the land. Meteosat images data from January 1st, 1993 to September 31th, 1993 have been analyzed at the time of writing.

3. Results and discussion

3.1. Minor upwelling

Table 1 presents the percentage of cloudless daily images (56% of total) archived from January to March. The observational studies based on Meteosat TIR images have shown that the diurnal cycle of convective activity can be described by a beginning of cloud growth around 12h and a maximum of cloudiness 5 or 6 hours later; this process occurs in similar fashion along the West African coastline, from Côte-d'Ivoire to Nigeria.

Location	Tabou	San Pedro	Fresco	Abidjan	Assinie
Cloudless images (%)	57	53	60	56	53

Table 1: Percentage of cloudless images from January 1993 to March 1993 for the five coastal stations.

Figure 2 shows the temporal evolution of ground SST measurements in January 1993. This figure documents a decrease of the SST from January 4 to January 9, 1993 for the all sites studied, except Assinie, where there was a weak increase of SST during this same period.

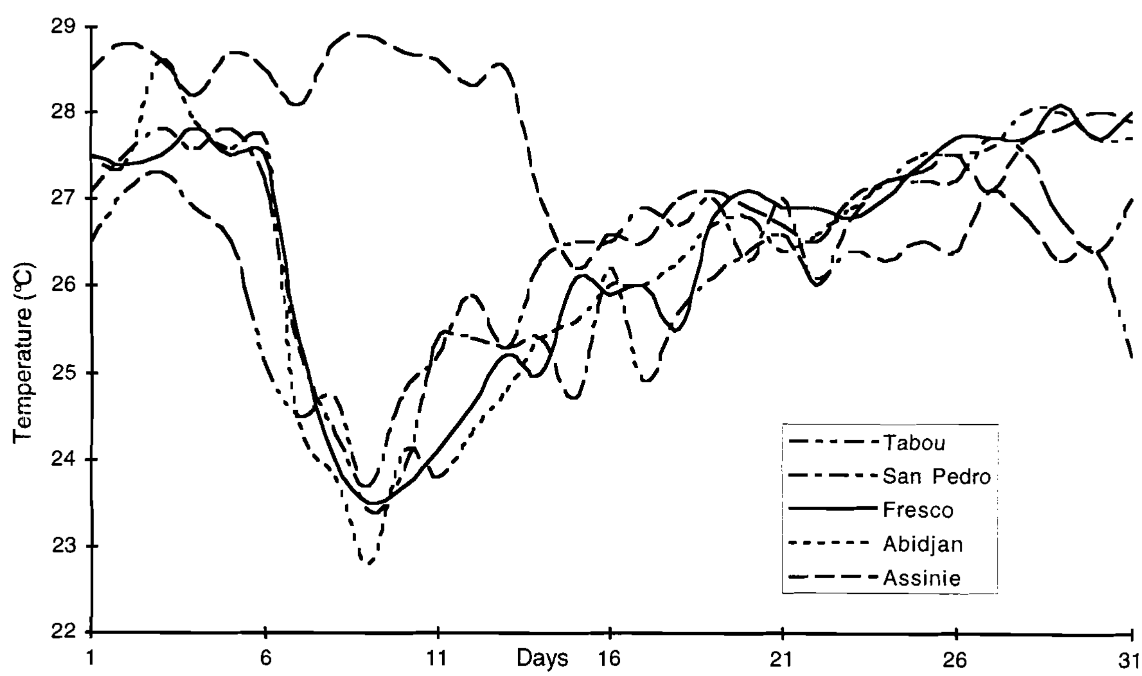


Fig. 2: Temporal evolution of ground SST measurements in January 1993 at different coastal stations off Côte-d'Ivoire.

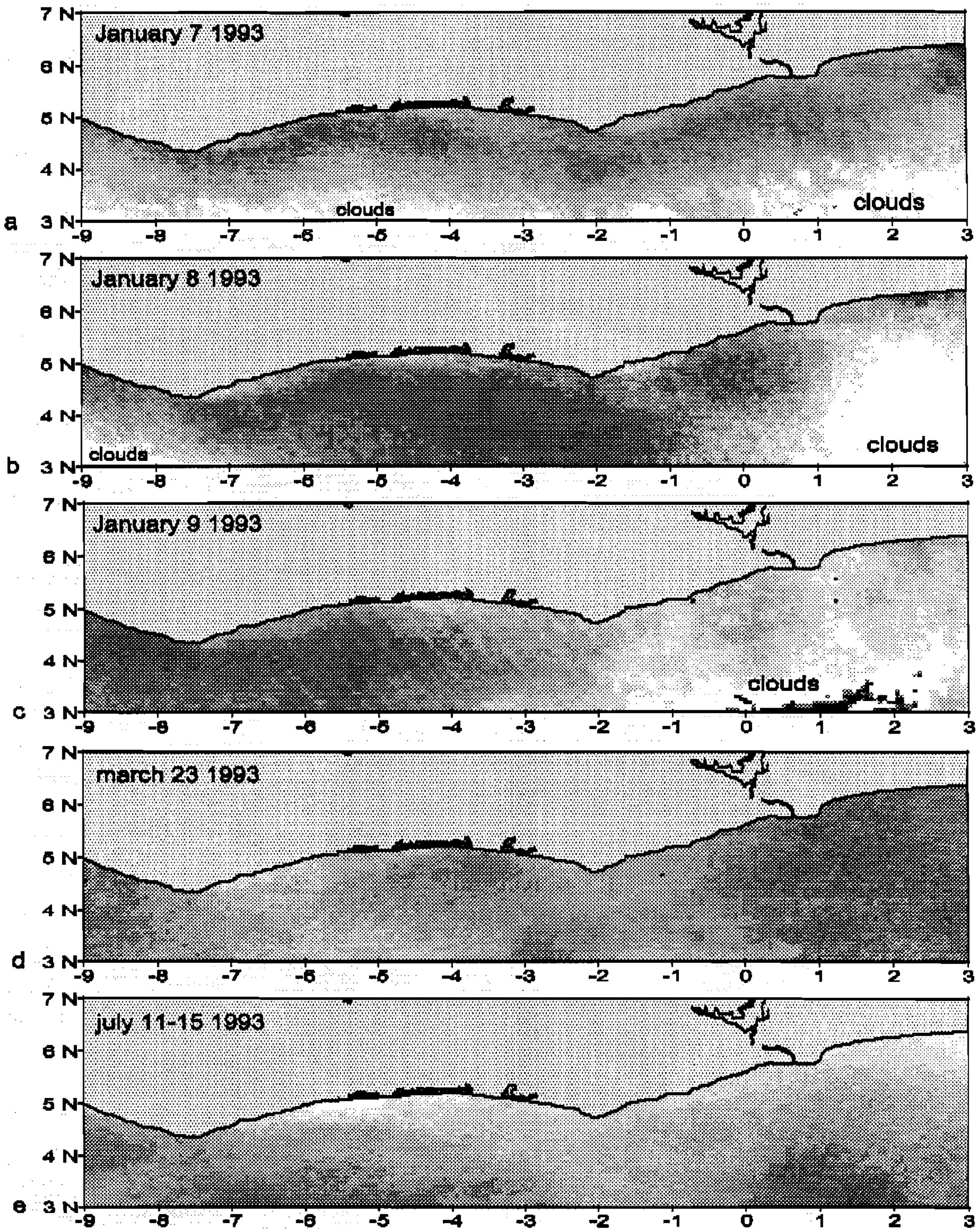
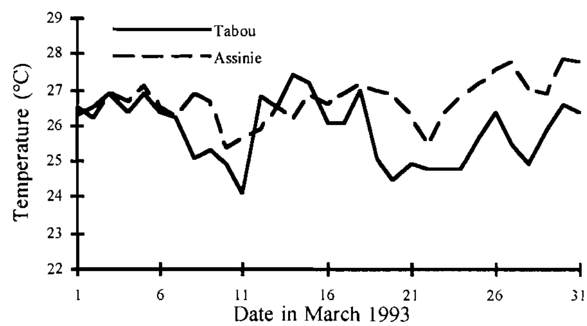


Fig. 3: Daily synthesis images derived from Meteosat TIR Channel off Côte-d'Ivoire and Ghana, January-July 1993.

In order to better detect and analyze the spatial extension of this phenomenon, three daily SST images derived from Meteosat TIR channel were carried out from January 7 to 9 (Fig. 3a,b,c). They confirm the cooling observed with the coastal SST measurements and show that the eastern sides of the two capes were more affected by the decrease of the sea surface temperature than the western sides. The coastal SST during March 1993 at Assinie and Tabou (Fig. 4) show a global decrease from March 6 to March 11. The minimum SST is observed on March 11. The relative decrease of the SST was not observed on the corresponding TIR images because of the strong nebulosity dynamic during this period. The same figures show another decrease of the sea surface temperature during the fourth five-day period of March. The cooling trend seems more persistent at Tabou than at Assinie. The analysis of the SST images corresponding to March shows that the second minor upwelling took place during the fourth five-day period of March. The daily synthesis image of March 23 (Fig. 3d) was selected to illustrate this phenomenon, located in the western coast of Côte-d'Ivoire, from Tabou to Grand Lahou along 200 km approximately. The observed sea surface temperature was about 23°C.

Fig. 4: SST in March 1993, at Tabou and Assinie, Côte-d'Ivoire.



3.2. Major upwelling

In contrast to the minor upwelling, the major upwelling is not difficult to observe, as it lasts approximately 3 months. Thus, it is straightforward to observe this phenomenon with Meteosat. However the occurrence of cloud is important during this period; it is quite common to have four or five consecutive cloudy days.

The available Meteosat SST images reveal that in 1993, the major upwelling effectively began on July, or even at the end of June. It was located all along the coast of Côte-d'Ivoire and Ghana and its offshore extension reached to 2°S. Figure 3e shows the clearest five-day period synthesis image for July.

3.3. Cumulative negative thermal anomalies on the coastal stations: case of the minor upwelling

A computation of the cumulative thermal negative anomalies (T_a) was carried out from January to March in relation to the monthly mean SST value.

For a given site, T_a is obtained by:

$$T_a = \sum_{i=1}^{n}(T_i - T_m) \qquad (2)$$

where T_m represents the monthly mean SST value and T_i the daily SST value, with $T_i < T_m$

Four sites have been chosen: Assinie and Abidjan (eastern coastal stations) and San Pedro and Tabou (western coastal stations). T_a gives an indication on the intensity of the upwelling (Fig.5).

Two patterns were observed:

a) The cumulative index of negative anomalies observed during the study period is relatively high for the eastern coastal stations (Fig. 5). There is a weak decrease of T_a in February and March;

b) In the western stations, the cumulative total index of negative anomalies is relatively important in January and March and very weak in February. Fig. 5 shows that Tabou is the only station affected by the cooling water in March.

These patterns show that there is a spatial variability of the SST between Assinie and Tabou. In the west of Côte-d'Ivoire, there is a global trend of increase of the SST between the two periods of upwelling.

In conclusion, the net cold ocean negative anomalies observed in January and March are in agreement with the temporal evolution of coastal SST measurements (Fig. 2 and 4)

CONCLUSION

In this paper, coastal SST measurements and images derived from Meteosat TIR channel are used to study the spatio-temporal evolution of the minor upwelling off Côte-d'Ivoire. This study shows that:

a) in spite of its local aspect, the use of the coastal SST measurements can be considered as a good parameter to detect the presence of the coastal upwelling. The TIR images derived from Meteosat provide a comprehensive view of the spatial dynamics of the upwelling off Côte-d'Ivoire. However, the cooling water has been detected by Meteosat sensors because there is generally a clear sky situation and a sufficient spatial extension of the upwelling each time it takes place. The use of the Meteosat data seems to be sufficient to localize the surface coolings off Côte-d'Ivoire;

b) the minor upwelling is more persistent in the western sides than in the eastern sides off Côte-d'Ivoire;

c) there is a need for collecting data along the two capes from January to March for a better knowledge of the decrease of sea surface temperature as these play an important role in determining the minor upwelling.

For future investigations, it should be required to analyze the impact of SST on rainfall during the dry season, when there is an important development of convective clouds in the study region; this may be very useful for local and global climate monitoring.

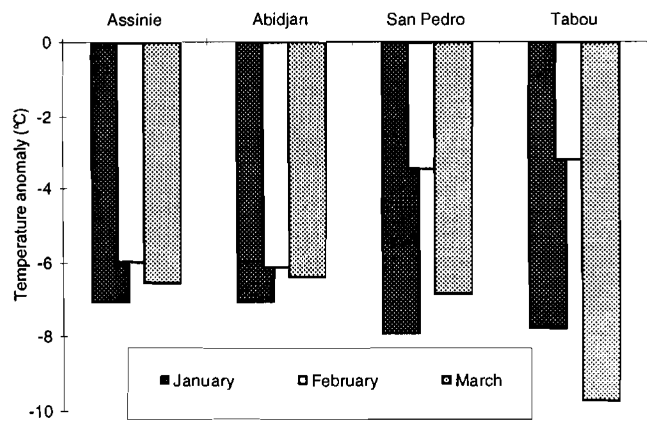


Fig. 5: Cumulative index of negative SST anomalies off Côte-d'Ivoire.

ACKNOWLEDGMENTS

The present study was funded through ORSTOM, by the Centre de Recherches Océanologiques and the Département de Physique de la Faculté des Sciences et Techniques de l'Université d'Abidjan. We also wish to acknowledge the important contributions of H. Demarcq (UTIS/Dakar), who provided most of the algorithms used for the restitution of the sea surface temperature.

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