Présenté au 2ème Colloque franco-japonais d'océanographie
3-13 octobre 1988 - SHIMIZU - (Japon)

A simple and reliable method for atmospheric effect removal from Meteosat IR data in SST extraction.

by

J.Citeau, H.Demarcq and G.Mahé
Orstom/Crodt B.P. 2241 ,Dakar ,Sénégal

Abstract

Numerous works have been done about SST retrieval using the various sensors on board of past and existing satellites.

A short review of the proposed techniques, shows that, for similar atmospheric and oceanic conditions, the higher accuracies need often a more or less complex data assimilation (multispectral methods, variation of viewing angle, multitemporal analysis and geostatistic) in order to remove atmospheric absorption. Moreover, as far as the software or the data ingest is concerned, the delivery of SST maps may be delayed and limit real-time applications.

The present paper using the unique thermal infra-red channel of Meteosat combined to the (numerous) ships of opportunity data, proposes a simple and reliable technique of parameterization of the atmospheric absorption observed in the intertropical area.

The estimated precision fits the needs either of large climatic studies or these of regional ones: After a check of the calibration in radiance, then an inversion of Planck's function, a discrimination of cloud free area is performed using equally a guess field or a climatological chart (Reynolds). Composite images are produced in retaining the warmest value over five days (with eight images per day).

On these ones, an empirical model for atmospheric absorption will be applied on the following scheme: As the distribution of water vapor in tropical area appears mainly as a zonal phenomenon (clearly linked to the ITCZ), it can be suggested to take it in account along (several) north-south transects by polynomial functions determined in order to have the best fit between (refined) sea truth data and Meteosat data.

In our area of work (50°W to 10°E), four meridional sections have been made, inside of which atmospheric correction is assumed to be only latitude dependent.

Along each line, another polynomial adjustement is performed in order to fit continuity needs.

Finally the resulting matrix is applied to the cloud free area of Meteosat data, and the other ones being covered with ships data and objective analysis. This adjustment process appears also to remove ship's data of poor quality, and the mean difference between Meteosat corrected data and sea truth is round 0.6°C.

The aim of this work is to improve the relevant data set daily produced with Meteosat (by ESOC,Darmstadt). Compared now with NOAA products (CAC), a general good agreement is evident on a large scale; but local discripancies remain on regional

scale for which our space and time resolution are better (i.e. senegalo-mauritanian upwelling).

By the way ,the above parameterization take into account both atmospheric effect and zenithal angle.

I. Introduction

Beginning in the first half of seventies with the successive launchs of Noaa satellite series and followed in 1977 by the launch of Meteosat, the first european meteorological satellite, a lot of studies have been prosecuted in order to improve the retrieval of sea surface temperature (SST) using satellite data.

Very quickly it appeared that the best description of SST conditions might be obtained with dedicated instruments as AVHRR on board of aforementionned Noaa series, or the HCMM (Heat Mapping Capacity Mission), for example. These instruments being able to offer both spectral and spatial resolution which fit needs of empirical or physical parameterization of atmospheric absorption.

In counterpart, the use of geostationary satellites with coarse spatial and spectral resolution with the same SST retrieval purpose seemed a challenge.

This paper presents an easy and reliable way to extract this parameter, using both Meteosat and ship's data, and valid for the Atlantic intertropical area, where atmospheric absorption may be parameterized by numerous ground or sea level data.

Before, a brief review of analytical concepts applied in existing or operating methodologies would be useful.

II. Short Review of Existing SST retrieval methods

The physical constraints for SST extraction from satellite data lay down :

- first of all, to retrieve the thermal energy emitted by the sea surface
- and then, to correct it from atmospheric attenuation which affects this signal when it passes through the atmosphere.

Two spectral bands have been used: the microwave region and the infrared, on board of either polar or geostationary satellites :

We must remind, as a matter of interest, the use of microwave instrument as SMMR on board of Nimbus-7 (and Seasat), which offers the ability to retrieve the thermal energy of the the sea surface in a spectral band weakly affected by clouds and atmospheric absorption. Numerous reports published by JPL detailed the successive improvements of data processing which allows a 1.2°C retrieval accuracy on a single field of view basis for SST measurement . In counterpart, the spatial resolution ,function of the frequency, yield a resolution of 150 km (with the 80 cm antenna), which may be sufficient for climatic studies, but remains very poor for numerous regional oceanographic studies. Notwithstanding the calibration problems encountered with this instrument, the benefit of this technique for cloud covered areas, will be essential.

Nowadays, the most commonly method used to retrieve the thermal energy of the sea on meteorological satellites is to measure it in the thermal infrared window (10 to 12 mu). The available radiometers in this region offer acceptable ground resolution but these are opaque to clouds, and very sensitive to "atmospheric absorption", this general term including various components...

Different methods exist referring respectively to the different sensors on board of either polar orbital satellites (AVHRR on NOAA serie) or geosynchronous ones (VAS instrument on GOES, METEOSAT and GMS thermal infrared radiometers:

The available techniques may derive from a purely physical approach, or from empirical regression using observed data, or a combination of both.

The so-called "split-window" or multispectral technique, and used on operational basis with AVHRR data (McClain, 1980 and Phulpin and Deschamps, 1980) proceed from simulations carried out with transmittance models and various radiosondes profiles (Weinreb and Hill,1980). Results of these studies show that the atmospheric effect may be parameterized by linear combination of brigthness temperature measured in two or more atmospheric windows (11µ, 12µ and in a lesser extent the 3.7 µ region) .

Another method developed in CMS (Lannion, Fr.) made simultaneous use of AVHRR and of HIRS also on board of NOAA satellite, the sounding's capabilities of the latter instrument being used to refine the aforementionned parameterization (TOVS inversion and improved tranfer functions).

In cloud-free area, these physical approachs give probably the best available technique today, and the spatial resolution (1km) fits to oceanographic requirements. The accuracy of retrieved SST ranges between 0.5-0.7°C, when satellite measurements are compared to selected data (oceanographic measurements).

But, in tropical areas where the cloud cover is persistent, the number of valid SST retrievals decreases, and the temporal resolution offered by polar orbital satellite may become a limiting factor.

The best combination of high temporal resolution and multispectral capabilities is precisely offered by the VAS instrument on board of GOES satellites; the procedure used to derive SST from VAS's data (Bates, 1983) is close to McClain et al.(1983) and the accuracy of SST retrieval ranges between 0.8 and 1.0°C.

This instrument is not yet available on Meteosat, and waiting for these refined sensors scheduled for the future Meteosat generation, our purpose was to improve one of the existing methodologies with this family of satellites.

Notwithstanding the rather coarse capabilities of the IR-radiometer of geostationary satellites (fig.1), the first

(Dudhia 1986)

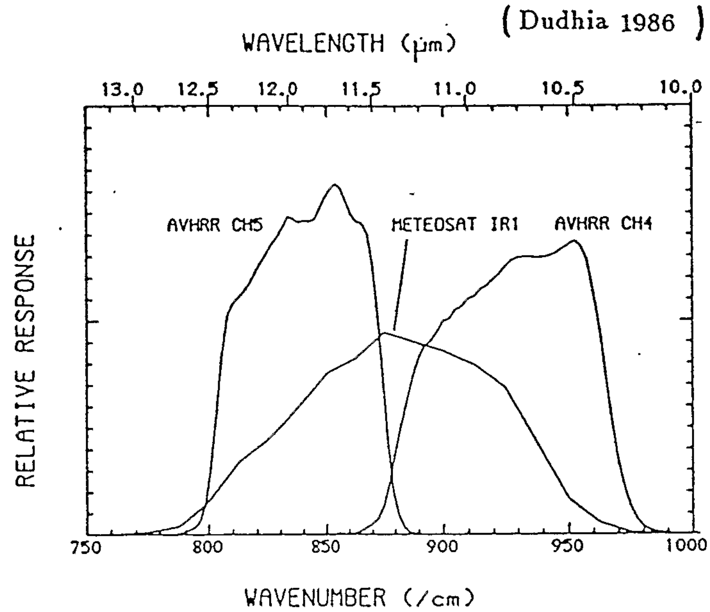

Figure 1
Spectral response curves of the satellite instruments.

advantage offered by these ones is most-often to achieve the coverage of cloudy region by composite imagery. As references among the tortuous path followed in the improvement of the geostationary satellite data processing, we can remind:

-the calibration of Meteosat-1 (IR) radiometer by the data of TIROS-N vertical sounder by Bériot et al.(1982)

-the multiple geostationary approach attempted with GOES-E and GOES-W : the different view angles enables the parameterization of optical depth (Smith,1980).

-the combination of geostationary and polar orbital satellites, the latter providing the water vapor correction applied to the former ; a complete review of these works can be found in Smith (1980).

-the application of both visible and infrared data to retrieve SST using radiative transfer parameterization provided by Lowtran-4 (Maul, 1981).

-the SST produced twice daily by ESOC (aforementionned) using both Meteosat data and ECMWF (European Center for Medium range Weather Forecast) analysis (humidity, air temperature) delivered in real-time to Darmstadt; the limiting factor of the resulting maps (SST Miec) is the quite coarse spatial resolution available (squares of 32x32 pixels) which follows the ECMWF grid (2.5°x2.5°).

-the derived SST from GMS IR image data, that was already operational at the Japan Meteorological Satellite Center in 1982. The method included:

- a discrimination cloud areas/cloud-free areas by histogram analysis and estimating SSt from 10 days data bases, with ingestion of IR data every 6 hours.
- a comparison of derived SST with a guess field and the neighboring values.

For what concerns now our own experience, developed at the opportunity of the "Skipjack Experiment" all over the 1981 year, and following the successful launch of Meteosat-2, a large oceanographic campaign took place in the tropical Atlantic, during which an operational Meteosat data processing was scheduled in order to supply research vessels and fishing fleet, with SST maps produced in near real time.

In these days, none of the aforementionned methods was really usable for our little team in charge of Meteosat data processing and based at the receiving station in Lannion, CMS (French Meteorology).

The need of an acceptable compromise between high accuracies and operationnal constraints led us to following observations relative to Meteosat performances and suggest a new and simpler methodology.

III. Remarks about Meteosat data specifications and requirements for an SST retrieval

From its geostationnary orbit by 0°,0°, Meteosat delivers data each half-hour on three channels, one visible (subsatellite pixel resolution: 2.5km) ,and two infra-red channels ,one band in the water vapor (3 to 5µ), and one in the thermal infrared (10 to 12 µ), these two latter channels with a subsatellite pixel resolution of 5km.

The relative precision of the infrared radiometers is round 0.5°K.

Whatever are satellite data, the SST extraction process needs :

- a radiance calibration
- navigation
- sea/cloud discrimination
- a correction field for atmospheric absorption
- validation and extra origin data ingest

- In the first age of Meteosat, data user's needed to correct by themselves the raw data in radiance, using blackbody internal count. Now, all data are now well calibrated by ESOC, sent to the satellite and disseminated again under so-called format A .
- The same observation is valid for the navigation, did now in real-time by ESOC and available on disseminated format.

- The sea/cloud discrimination is usually performed by a

Visible-infrared comparison (or bidimensional histogram); this technique can be operated with Meteosat data, but we take in mind the increase of disk space need and the fact that this method is valid only during daytime.

- For what concerns now, the atmospheric absorption field, it is clear that the rather coarse infrared windows of the infrared sensors are unable to deliver an integration of water vapor content along the radiometric path; more precisely, the so-called Water Vapor channel has its weight function near 600 mb, where the humidity in the atmosphere reaches its minimum values; in a rough sense, this channel maps the horizontal distribution of humidity at the 600mb level and does'nt fit a vertical humidity integration.

The need of an "extra channel" for Meteosat led us to consider more attentively ship of opportunity data; moreover, it's in the Atlantic ocean, area largely covered by Meteosat, where the highest density of data collected at sea level, may probably be found.

Notwithstanding their poor quality, after a severe selection process, as detailed on following methodology, these ones combined to satellite data, may supply a basis for an empirical parameterization of atmospheric effects.

IV. A suggested Methodology for SST retrieval with Meteosat data

The SST retrieval process follows several steps:

a) Processing of a composite imagery:

The aim of a composite imagery is to supply a significant imagery over a choosen time scale with a minimum of cloudy areas. The most common method used to remove clouds from satellite images is to realize over these a composite in retaining in each location the "warmest value" pixels.

This synthesis has been for our operational SST needs, performed on the basis of 5 or sometimes 7 days at the rate of 8 images per day; each of these yet calibrated, are processed on "satellite projection". As can be found in Citeau et al.(1984), a lot of oceanographic features are already revealed by this synthesis imagery.

As differents data flows are to be joined in the SST retrieval process (satellite imagery, and discrete or gridded data), it's easier to have all of these on the same mapping format. For this one, we choose the "geographic projection" (also called as equatorial equidistant transverse) which offers simpler software and save processing time.

Figures 2 to 4 display a rectified Meteosat image for a selected period, the distribution of available data from ship of opportunity at the same time, and the SST pattern given by the Reynolds Climatology(1982): For an easier analysis on usual remote sensing devices, all data sets have been put in the same unit (temperature); and Meteosat Ir data (calibrated in radiance) have been converted in brightness temperature ; the inversion of the Planck's function can be resumed to a simple linear relation

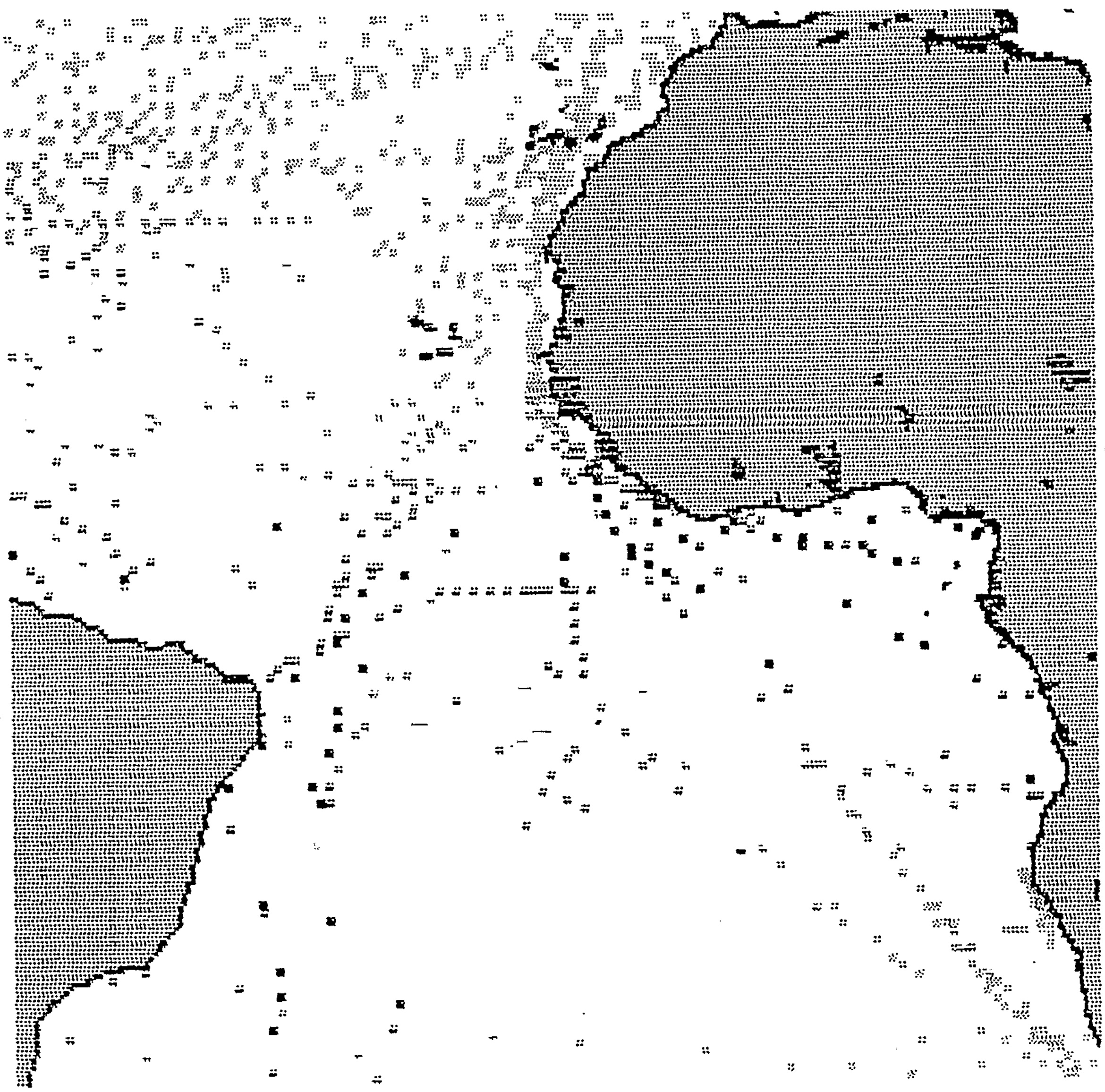

Figure 3

Available data from ships of opportunity for the period 02 to 08 february 1984. Color-scale same as fig.2.

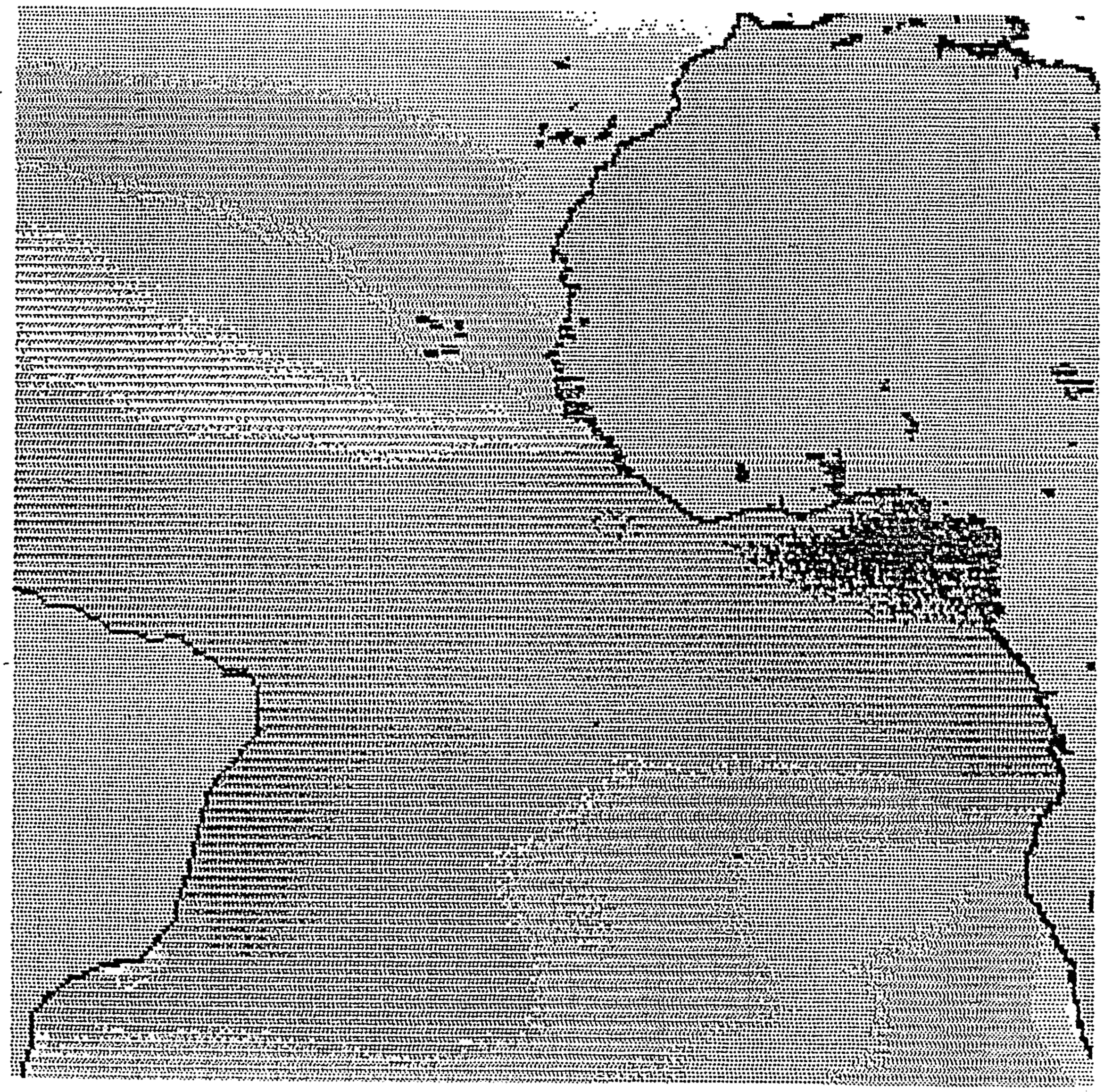

Figure 4
Averaged sea surface temperature, from Reynolds climatology.
Period: february 1984. Color-scale same as fig.2.

b)Sea/cloud discrimination :

Our sea/cloud discrimination, instead of the usual couple Vis/Ir, will be performed by a comparison of Ir imagery with an SST guess field.

For a selected period, the SST guess field maybe either an objective analysis of ship of opportunity data , or more simply the relevant climatology chart.

Our hypothesis, well supported by experiments, is that the difference between Ir Meteosat data and the guess field give a discrimination when appropriate threshold is set up:

As evidenced by several tests in the intertropical area, a threshold of 4°C allows to separate, when difference is greater, the areas of clouds or unrecoverable sea surface signal;

- if lower than 4°C, we admit for the remaining areas, that the apparent features reveals only SST gradients, and take in account SST anomalies.

A better account of the larger anomalies can be achieved in taking, as a guess field, the last SST map produced. In fact, if Reynold's climatology is choosen for reference, only minor differences on cloudy area discriminition appears .

Figure 5 displays the result of such a sea/cloud discrimination.

Atmospheric absorption parameterization :

- The water content in the atmosphere, is well known as the major component responsible of attenuation of radiometric signal in the infrared windows.

Using the ECMWF analysis data (European Center for Medium Range Weather Forecast, Reading), the mean distribution over a week of the integrated humidity between 1000 hpa and 100 hpa, reveals a regular and mainly zonal structures (fig.6), very similar and well correlated to the Intertropical Convergence Zone.

Due to the time delay to acess to ECMWF data, and also for possible biais of ECMWF analysis, we attempt to built a similar field based on the difference between satellite data and valid sea truth measurements.

Due to le large amount of SST measurements (2000 each week in the 36N-30S, 16E-50W area) did by ships of opportunity, this parameter available on GTS (Global Transmission Systenm) was preferred to the couple dry and wet air temperature, which would allow a more physical approach,but which is also less documented.

Using the same discrimination process as precedently, ship of opportunity data are compared to climatology and then submitted to a "neighbouring" statistical analysis which eliminates remaining poor quality values.

A map of differences between these discrete SST values and the relevant Meteosat brightness temperatures is then produced.

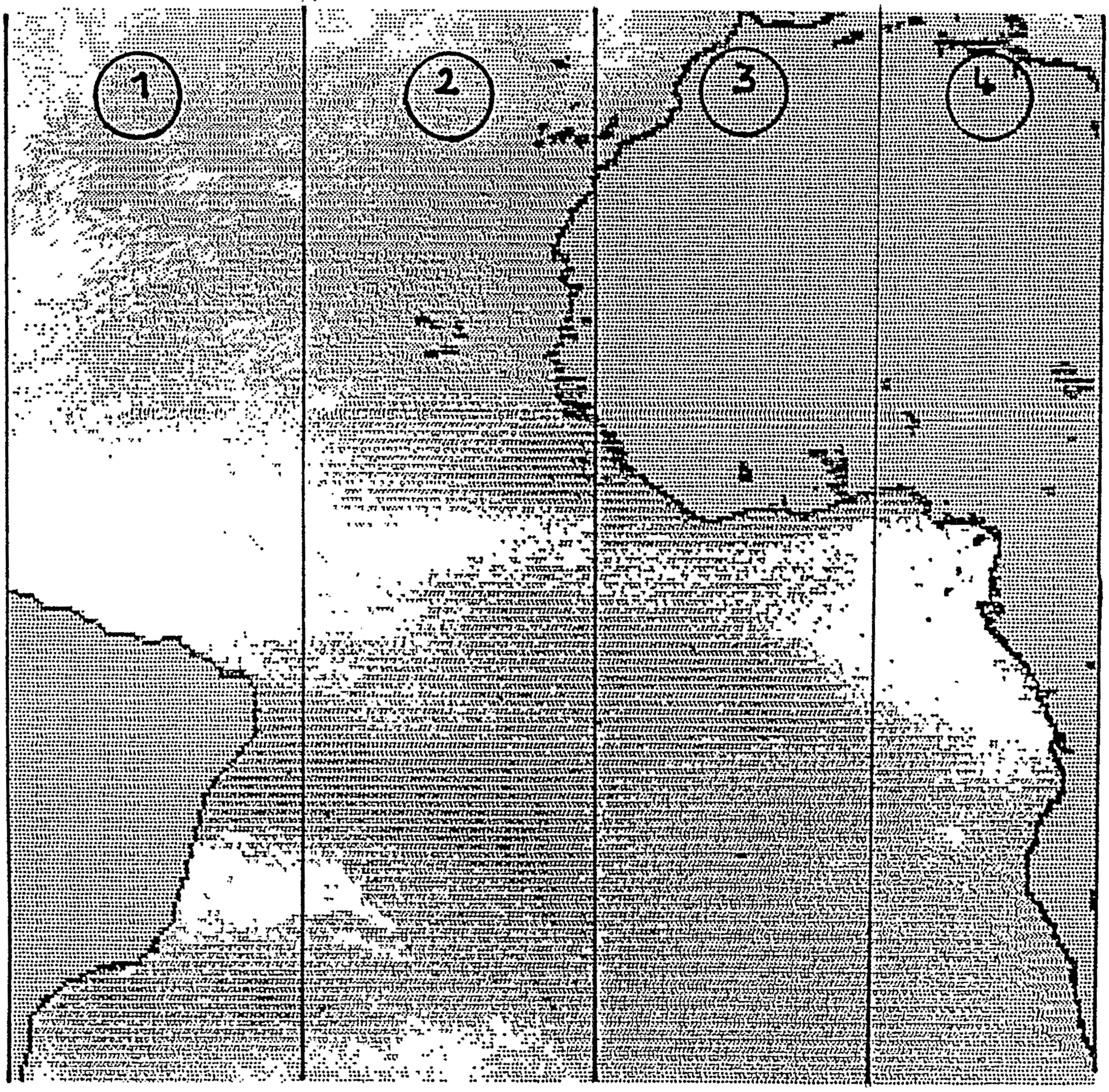

Figure 5
IR Meteosat remaining data after a sea-cloud discrimination with the Reynolds climatology. Period 02 to 08 february 1984. Color-scale same as fig.2.

The easier way we find to build a continuous field is to observe that (fig.6) the main gradient is meridionally oriented; then along a north-south transect, a polynomial function can be searched to fit the Meteosat-SST(ship) difference; as this difference may also vary zonally due to regional inhomogeneities and zenithal angle effect, we divide our area (36N-30S,16E-50W) in four meridionally bands, in each of these a specific polynomial function (5th degree) will be searched .

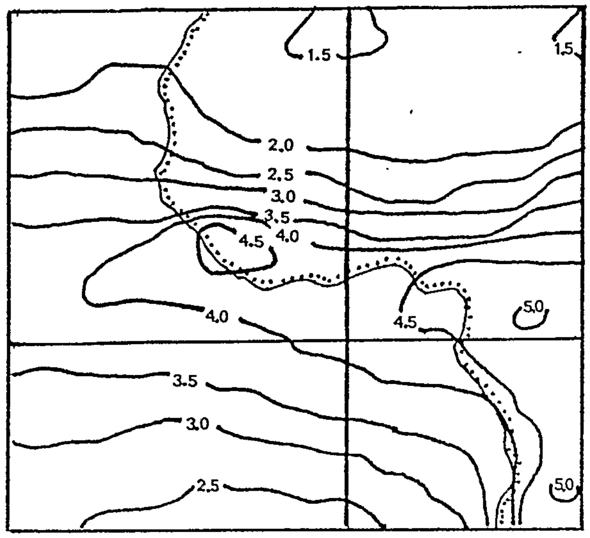

Figure 6
Total atmosphere Water Vapor content (g/cm²).
Mean of the months of November from 1980 to 1985.

In figure 7, are displayed such functions.

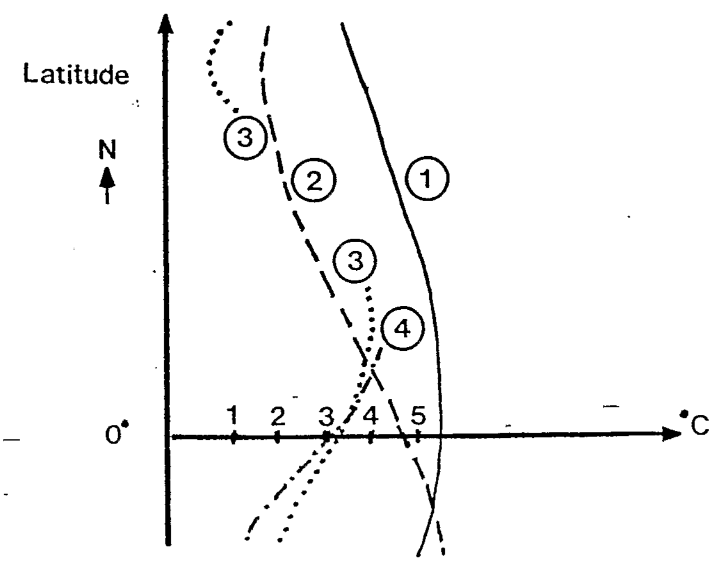

Figure 7
Polynomial adjustment of the four meridionally bands(see fig.5). These functions will determine the correction to be applied in each line of the image.

This polynomial adjustement is then performed along the lines, taking in the middle of each band the calculated values. This process achieves the field of correction which will be applied to Meteosat data.

Data ingest for cloudy areas:

In cloudy areas, where there is a lack of data, SST from ship of opportunity are submitted to an objective analysis taking in account the validated Meteosat data.

Smoothing process are then performed, with adapted procedures keeping the gradient SST pattern.

V. Results and Discussion

It is clear that this process is largely dependent of sea measurements.

In order to check our processing, we compare our SST maps with similar well-known maps produced by Noaa, namely Gosstcomp and NWS charts.

Our comparison was pointed towards specific areas well known by oceanographic cruises and ship's routes : the Senegalese-Mauritanian coast routinely covered by the R/V Louis Sauger (based at Crodt-Dakar) and the equatorial région of the Gulf of Guinea covered (but less regularly) by Orstom teams on oceanographic cruises, and well documented by the Dakar-Le Cap shipping route.

These are well known upwelling areas, and if there is no need to say their importance in term of nutrients renewing, the areas concerned are wide enough to influence climatic changes (equatorial area).

For what concerns the senegalese coast, our maps were always in agreement with data collected by oceanographic cruises performed every two months from December 1984 to nowadays (sometimes, as our maps were produced in less time than needed by a ship survey, they were used to optimize some oceanographic cruises).

For what concerns the equatorial area, on figure 8 are displayed the maps produced for selected period of July 86 and 87 and joined to equivalent maps delivered by NWS:

The two products are in agreement in 1986 and the equatorial upwelling is well evidenced on both. In counterpart, we observe a discrepancy in 1987, in that sense that the equatorial upwelling remains evident on NWS chart and absent on ours.

It is known by equatorial oceanographers (Oudot, pers.comm.), that the upwelling season in 1987 was less intense in time and in duration; the same discrepancy was also evidenced during the same year, in February-March along the senegalese coast where positives SST anomalies were found (Meteosat product and coatal station watch) instead of the negatives anomalies found by NWS maps (Reynold's climatology was in both cases the same used reference).

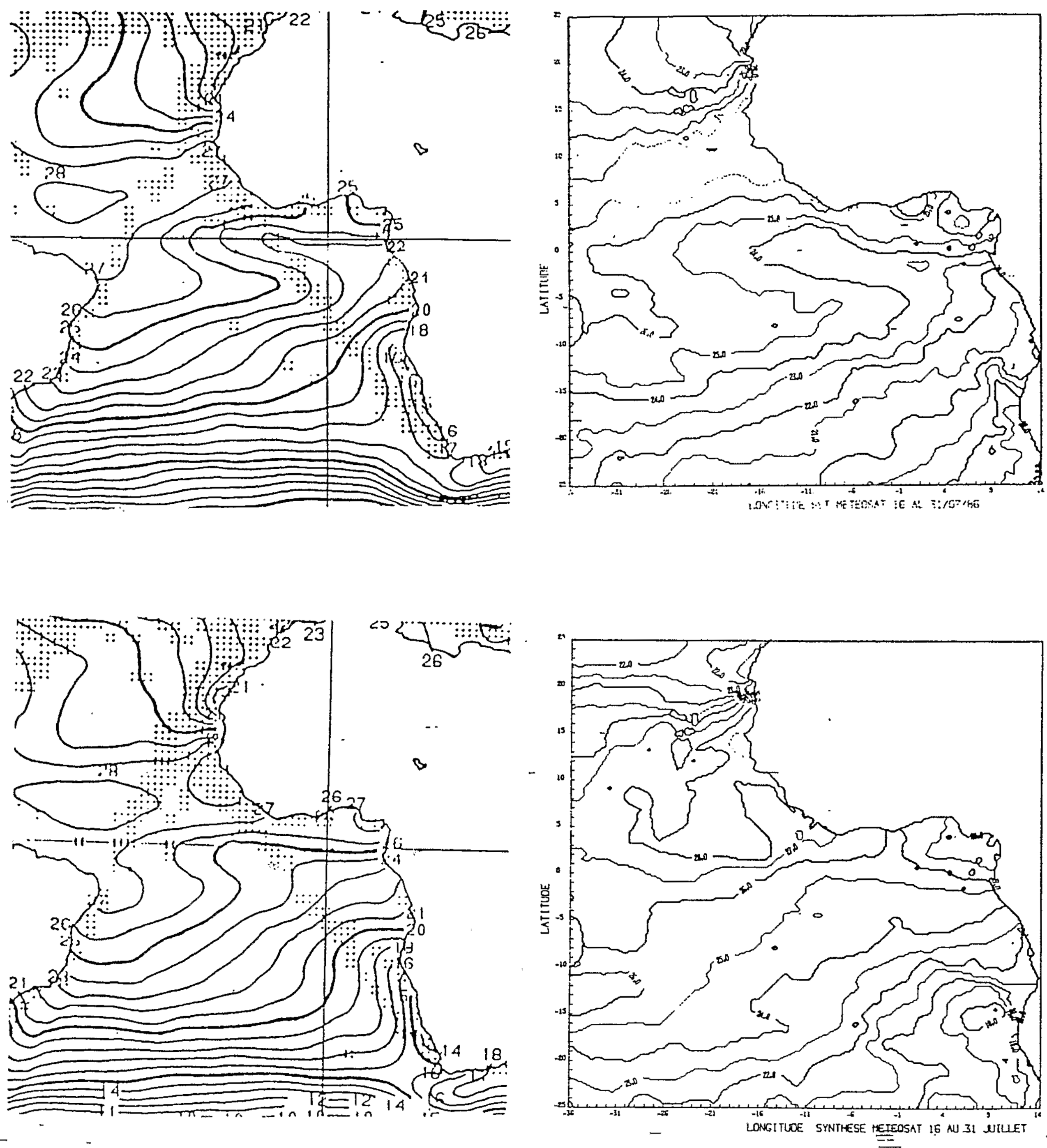

Figure 8

Sea surface temperature maps produced for the upwelling season in the Gulf of Guinea for 16-31 July 1986 and 16-31 July 1987: NOAA/NWS maps on left side and Orstom/Crodt product on right side.

We interpret this difference as due probably to a difference in the climatology weight in both softwares, and may results from the objective analysis used to fill lacking ares; as precedently mentionned, our software process in the cloudy areas ,where satellite data are missing, by neighbouring values and ignore climatology (the limitation is the number of available values).

The precision given by our chart can be estimated by the local difference between SST measured and SST estimated by our polynomial function; this precision ranges round 0.6°C.

This very simple software fits to local environmental studies along the senegalese coast; it is scheduled to use it in model validation and feeding (3D,Lodyc).

As a conclusion a wide area of applications can be found if sufficient data at sea remains (as nows) available. It does'nt differ in the terminal stage from more sophisticated software (Miec product from Esoc) which tries to minor biais with sea measurements.

In its concept, for this "extra" Meteosat channel, all data of other origin (Noaa, Tovs or Smmr spots) can be ingested, provided that geographic correction and temperature conversion has been processed.

Bibliography:

Bates, J.,1983: Use of VAS multispectral data for sea surface temperature determination; in- Satellite-Derived Sea Surface Temperature Workshop-I,JPL Public. 83-84, Pasadena, CA.,Appendix E.

Bériot N.,N.A. Scott, A. Chedin and P. Sitbon,1982: Calibration of Geostationary Satellite Infrared radiometers using the Tiros-N Vertical Sounder: Application to Meteosat. J. Appl. Meteor.,21, N° 1,84-89.

Citeau J.,B.Guillot and R.Lae,1984: Opération Listao: Reconnaissance de l'environnement physique en Atlantique intertropical à l'aide des satellites Meteosat et Goes-E,IDT ,63,Sér.Télédetection 10,Orstom Paris éd.

Dudhia A.,1986: Inter-calibration of Meteosat and AVHRR. Paper presented at the AES experts meeting"Measuring the greenhouse effect". Toronto, CANADA, 15-19 September 1986.

Japan Meteorological Satellite Center, 1982: An overview on the utilization of the Japanese Geostationary Meteorological Satellite. 3-235 Nakakiyoto, Kiyose-shi, Tokyo, 204, Japan.

Maul G.A.,1981: Application of Goes Visible -Infrared data to quantifying mesoscale ocean surface temperatures,J. Geophys. Res.,86, n°C9,8007-8021.

McClain, E.P.,W.G. Pichel,C.C. Walton,Z. Ahmad and J.Sutton,1983: Multichannel improvements to satellite-derived global sea surface temperatures,Adv.space Res.,2,(6),43-47,Pergamon Press.

Phulpin and Deschamps, 1980: Estimation of sea surface temperature from AVHRR infrared channels measurements. Proceedings of the 6th annual conference of the Remote Sensing Society, 18-19 Dec. 1979, University of Dundee. Edited by A.Cracknell.

Queney P., 1974: Eléments de météorologie. Collection de l'Ecole Nationale Supérieure de Techniques Avancées, Masson et Cie éd.,Paris.

Reynolds, R.W., 1982: A monthly averaged climatology of sea surface temperatures.NOAA Technical Report,NWS 31.

Smith W.L., 1980: Sea Surface Temperatures: improved observation from geostationary satellites in: Proceedings of a Workshop on Applications of existing satellite data to the study of the ocean surface energetics. 19-21 November 1980, University of Wisconsin, C.Gautier éd..