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REMOTE SENSING

FOR

OCEANOGRAPHIC AND FISHERY RESEARCH

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by

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SUMMARY

III. TUNA FISHING AID BY PREDICTIVE MODELS BASED ON SATELLITE AND SHIP DATA

INTRODUCTION

Remote sensing techniques has shown great improvements in the recent previous years. Originally used for meteorological purposes, the data have also been processed in order to describe oceanographic features.

The fall out in fishery research is very important. Since the spatial distribution of some pelagic species is under influence of the environmental context where they live in, the application of oceanographic interpretations to monitor the fisheries became obvious.

On the practical point of view, the problem is not so simple. The goal is to provide an operational fishing aid, but this has a major constraint such as the real time distribution of the information. To be fully useful to fishermen, it needs to be processed and synthetized. Besides, the relationships between some hydrological parameters and fish concentrations are rather complex as multiple factors (major part of them are not measured by remote sensing techniques) play together. However, in some cases, it has been possible to identify the processus leading to concentrations of fish, especially tuna in tropical Atlantic. This will be presented after the oceanographic application of satellite and the relation between some typical processus and fish production are described.

I. SATELLITES AND SENSORS FOR OCEANOGRAPHY

I.1. Satellites

Among the numerous satellites into orbit around the Earth, only those defined as "environmental satellites" are used for oceanographic purposes. They are divided into geostationnary and polar-orbiting satellites. The first function of these is meteorology but the sensors can also be used for describing some oceanographic features.

a) geostationnary satellites : Pacific and Atlantic Oceans are well covered by this type of satellites : GMS, GOES W and GOES E for Pacific, METEOSAT for Atlantic. Indian Ocean is still uncovered; in 1979, for GARP experiment, one of the GOES has been shifted over Indian Ocean and the imagery built up is still very useful.

METEOSAT is fully exploited by oceanographers in Atlantic Ocean. Multi-channel analysis (VIS and IR) are carried out in order to provide in real time the best estimation of the sea surface temperature (SST) on a large oceanic scale. In Atlantic Ocean, the resolution is 2.5 km for the visible channel (0.4 - 1.1 μm) and 5 km for the thermical infra-red channel (5 - 12.5 μm).

b) polar-orbiting satellites : they provide a great deal of information. Some of them are used in oceanographic studies:

- TIROS/NOAA : 3 types of data are transmitted through a high resolution picture system (HRPT) :

. AVHRR (Advanced very High Resolution Radiometer), 5 channels (VIS and IR), resolution : 1.1 km;

. TOVS (TIROS operational vertical sounder), which can measure the variation of atmospheric absorption used for correction of radiometric values;

. ARGOS Data Collecting System : oceanographers use it to describe current patterns and collect several environmental parameters (Temperature, salinity...) in real time with drifting buoys;

- NIMBUS 7 : an experimental satellite with eight experiments. Two of them have oceanographic applications:

. SMMR : microwave radiometry

. CZCS (Coastal Zone Colour Scanner) analysing the sea colour defining an index of productivity.

- SEASAT : an experimental satellite providing oceanographic data, using a radar altimeter, a scatterometer, a SAR (Synthetic Aperture Radar) whose characteristics are shown in Fig. 1 , and a SLR (Side looking Radar).

- LANDSAT : coastal currents, high productivity areas can be investigated by the images provided by the MSS (MultiSpectral Scanner).

I.2. Detailed applications

The major applications in the field of oceanography are reviewed.

I.2.1. Direction of marine waves

This parameter has recently been studied using SLR or SAR. The oceanic wavesinduce out of phase reflected frequencies which are the expression of successive waves period. If a current occurs, an asymetry of Doppler peak appears. When changing the HF frequency, the whole oceanic waves spectrum can be investigated (Fig. 2).

I.2.2. Wave height

It can be measured by the radar altimeter. When the sea is calm, the return time of the signal is minimum. Rougher the sea and longer the return time of the signal. This allows the computation of the satellite altitude and the description of the sea state. The

SEASAT-A
SAR CHARACTERISTICS

• FREQUENCY	1275 MHz
• WAVELENGTH	23.6 cm
• TRANSMIT POWER	800 W PEAK
• TYPE	SYNTHETIC ANTENNA, CHIRPED TRANSMITTER
• LOOK ANGLE	20 deg FROM NADIR TO RIGHT OF ORBIT PLANE
• RANGE RESOLUTION	25 m
• AZIMUTH RESOLUTION	7m, 1 LOOK OR 25m, 4 LOOKS
• NO. OF LOOKS	1.0 TO 4.0
• SWATH WIDTH	100 km (3.5 db PIXEL SNR, 1 LOOK, σ_0 = -13 db)
• SWATH LENGTH PER PASS	250 TO 4600 km
• POLARIZATION	HH LINEAR
• RANGE OF MEASURABLE SURFACE REFLECTIVITIES	-25 TO +5 db PER m^2
• INSTANTANEOUS DYNAMIC RANGE	16 db EXTENDED TARGET, 60 db POINT TARGET
• IMAGE GREY SCALE CALIBRATION	3 db ABSOLUTE, 0.5 db RELATIVE
• GAIN CONTROL	AUTOMATIC AND COMMANDABLE
• SENSITIVITY TIME CONTROL	COMMANDABLE
• DATA TELEMETRY	ANALOG, 19 MHz BANDWIDTH
• DATA RECORDING	DIGITAL, 110 MBps
• PIXEL LOCALIZATION	OCEAN: 50m ABSOLUTE, 10m RELATIVE LAND: 20m ABSOLUTE, 10m RELATIVE
• ANTENNA SIZE	2.3 m RANGE 10.75 m AZIMUTH
• SENSOR WEIGHT	110 kg (EXCLUDES ANTENNA AND TELEMETRY)

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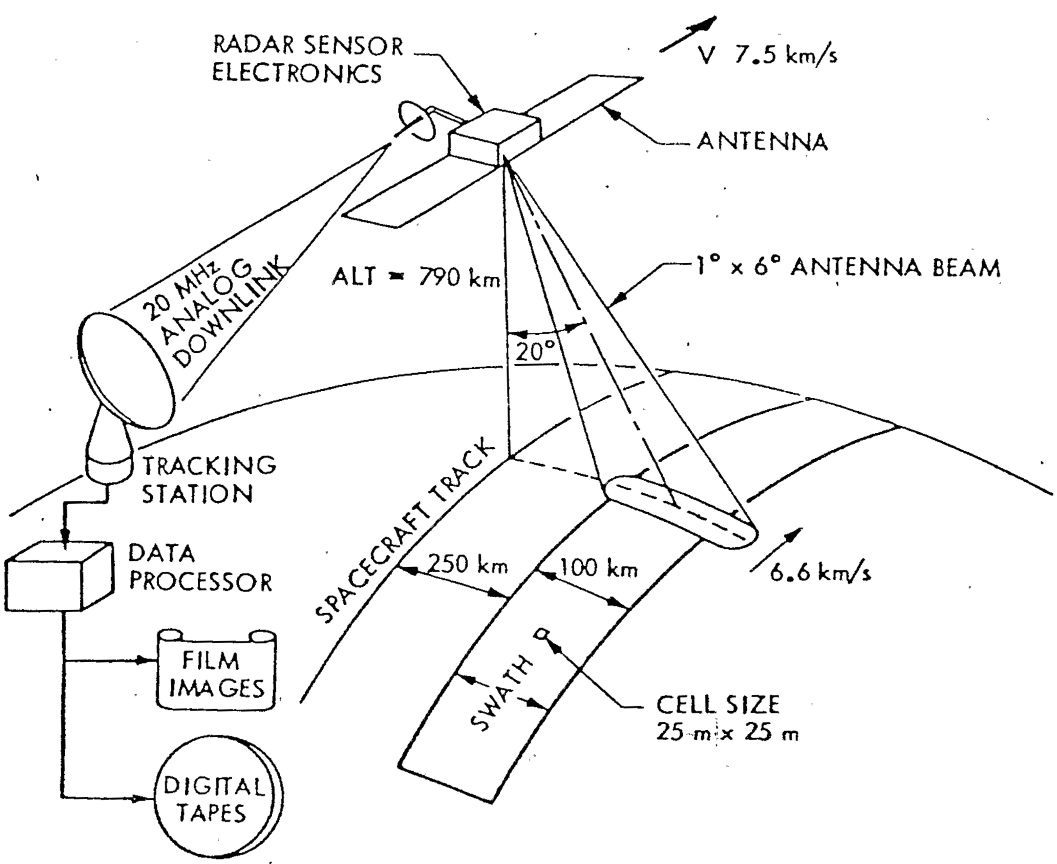
Fig. 1

SEASAT-A SAR
SYSTEM OVERVIEW



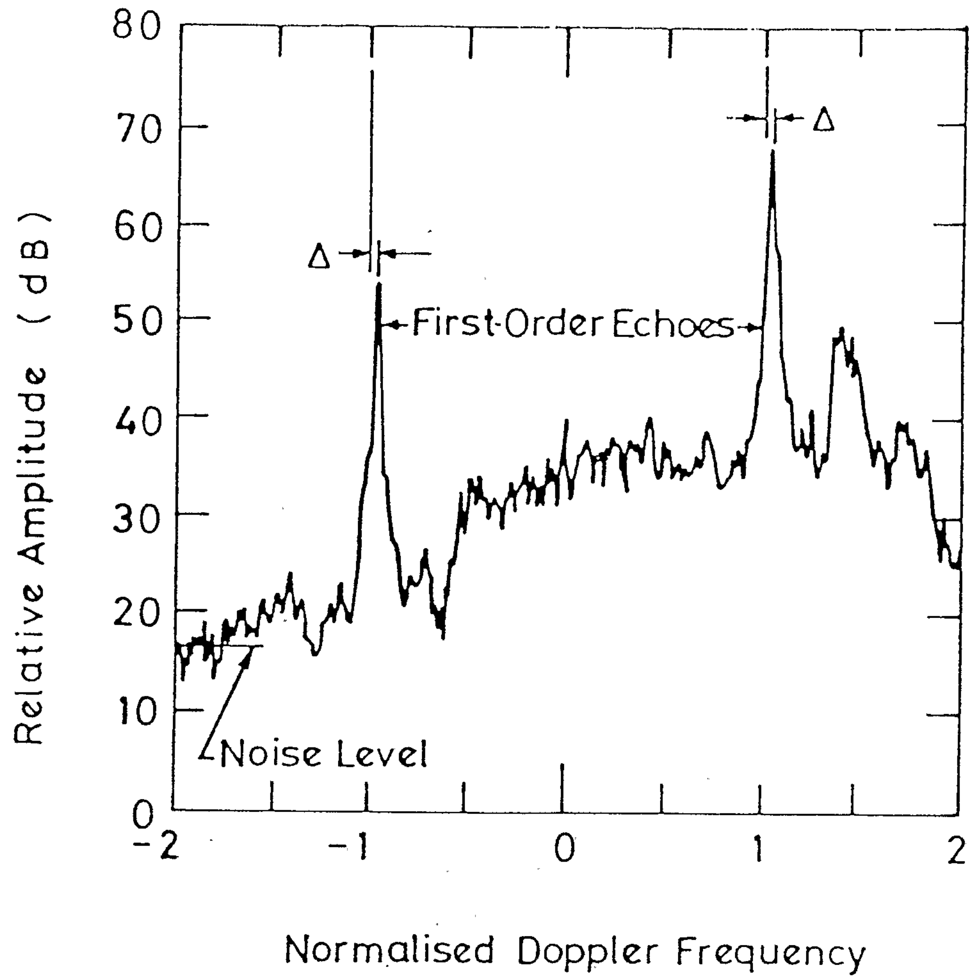


Fig. 2 - Figure 6. Measured Doppler spectrum at 13.4 MHz showing the two strong echoes. The displacement is caused by the presence of a current (Barrick, 1978).

resolution obtained by SEASAT is 6.5 km, and the accuracy on the wave height is ± 10 cm. The comparison with ground-truth data points out the good quality of the satellite data processing (Fig.3) .

I.2.3. Marine current patterns

Once again, such studies require the use of the radar altimeter. A surface current can be detected by the slope of the ocean surface, due to an equilibrium between the Coriolis force and the pressure gradient.

Therefore the altimeter can measure the geostrophic effect of the current. Complimentary knowledge of the density profiles of the water column allows the estimation of subsurface currents. Such measurements have been made over the Gulf Stream (Fig. 4). Eddies which generate weaker variations of the surface slope can also be detected.

I.2.4. Sea bed topography

This task can be achieved by using active systems (Laser) on areas of shallow and clear water. The measures are made in the blue-green radiations of the spectrum. The depth is calculated from the delay between sea surface and sea bed reflections. For coastal waters (rather turbids) the optimal wavelength is 530 nm; for clear water, 460 nm.

I.2.5. Sea surface temperature

SST can be determined by infra-red and microwave radiometry.

- IR radiometry: Two of the more commonly used instruments are the VISSR aboard the GOES satellites and the AVHRR instruments aboard the NOAA-7 and 8 satellites. Technical descriptions of these systems are to be found in the literature. Data from the VISSR sensor is easiest to use since the radiometric information retransmitted by NOAA/NESS is converted into an 8-bit table, from which temperatures are directly obtained. Geographic grid information is transmitted as part of the infrared channel and is easy to use. The thermal sensitivity is 0.5°C

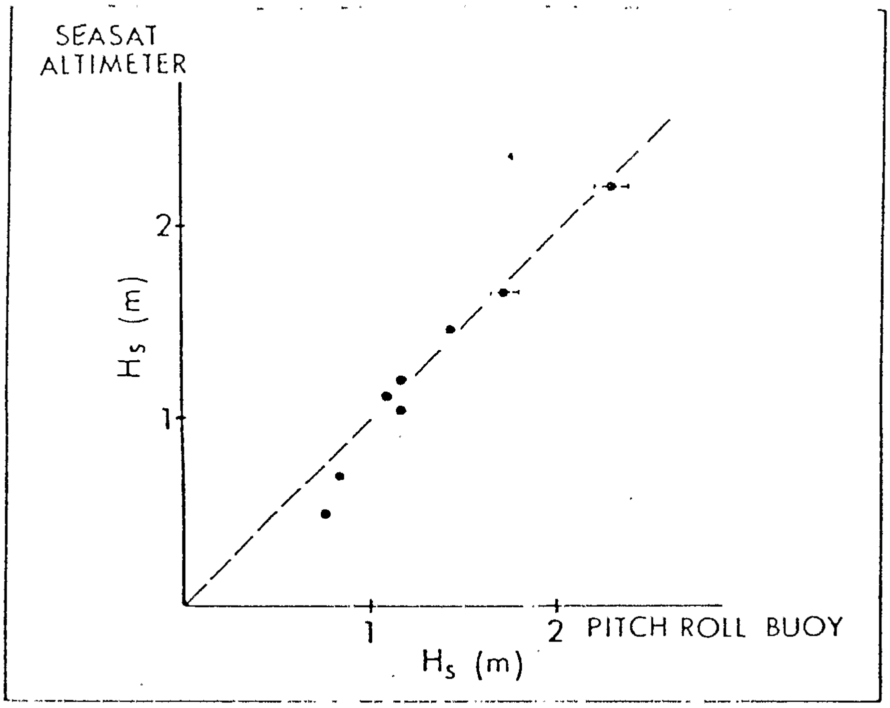


Fig. 3 - A comparison of significant wave height (H_s) measured over the JASIN area by Seasat's altimeter and by a pitch-roll buoy. The agreement for the eight passes shown was within the accuracy of the buoy

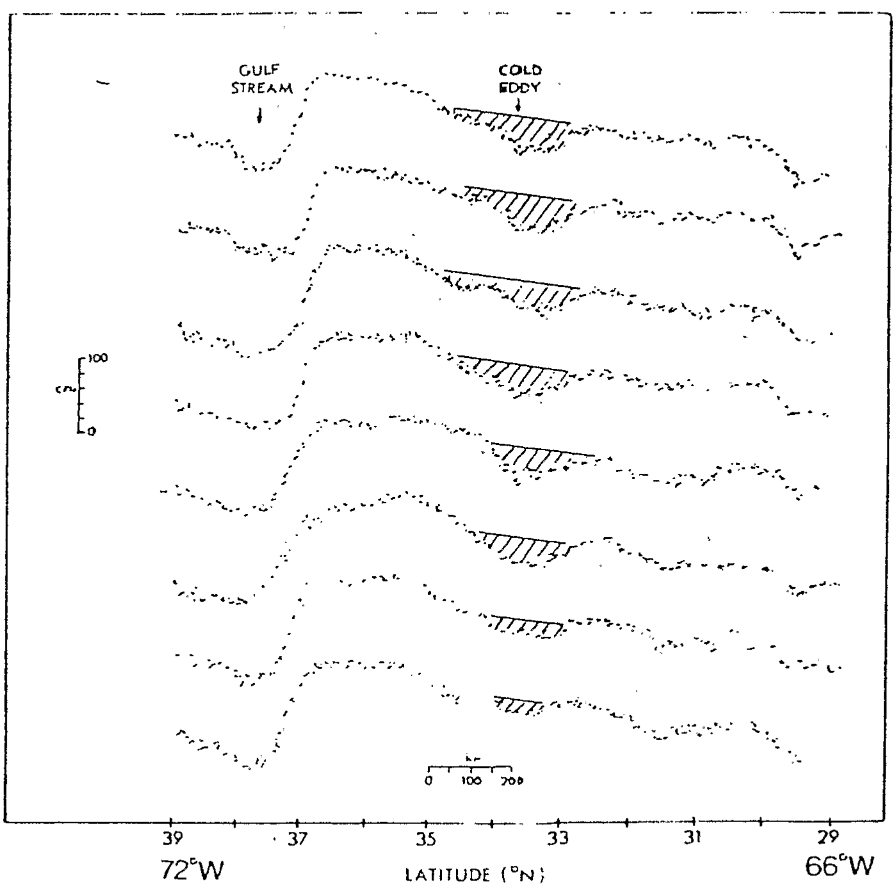


Fig. 4 - Eight successive altimeter passes repeated at 3 day intervals over the area of the Gulf Stream. The sharp rise of about 140 cm over the Gulf Stream represents a surface current speed of about 200 cm s (4 knots). The lower amplitude repetitive signal diminishing from 40 cm to 10 cm corresponds to a cold eddy passing under the satellite's track during the 21 days observing period.

and the spatial resolution at nadir is 8 km. The data are useful since it is possible to obtain data at 30 minutes throughout the day. The surface water temperatures, however, normally are 2-6°C cooler than the actual surface temperature, due to the presence of atmospheric water vapour within the field of view. While more sophisticated methods for correction of water vapour may be used, the simplest method utilizes several different measurements of actual temperatures in the same field of view. VISSR temperatures are then paired with the ground-truth measurements to obtain a least square fit, relating the observed temperature to the actual temperature. For small lakes and embayments, unfortunately, the sensor footprint is too large. The AVHRR instrument offers spatial and thermal resolution of about 1 km and 0.2°C, respectively. The 10-bit data, in contrast, must be completely processed and corrected by the user. Because the perspective angle from one orbital pass to the next pass changes, geometric corrections are also needed. The lack of a transmitted grid for the user further increases the difficulty of using these data.

- microwave radiometry : The temperature is a function of surface and atmospheric parameters, so that sea temperature determination needs a multispectral measurement. The resolution is still poor (50 km) but the SST can be known whatever the cloudiness is.

I.2.6. Salinity

For a given wavelength, the sea emissivity is a function of both temperature and salinity. The salinity effect is more important at low frequency microwaves when the temperature effect is maximum at high frequencies. Combined measurements of SST and salinity using twin frequency radiometer (1.43 GHz and 2.65 GHz) have been made (Blume et al, 1978). The accuracy for salinity is still moderate (±1‰) and make this technique only suitable in frontal areas, i.e. estuarines.

I.2.7. Phytoplanktonic density mapping

Water colour related to the concentration of chlorophyll (algae), may also provide important environmental information. A report by Ulbricht et al,(1977) noted the occurrence of lines in MSS Band 5 imagery (LANDSAT) which they subsequently determined to be due to the seasonal appearance of blue-green algae chains, in Lake Constance. Another report by Ulbricht and Horstmann (1978) documented the presence of blue-green algae in the Baltic, using MSS data and ground-truth data.

The most recent developments in water colour research relate to two instruments: the Coastal Zone Colour Scanner (CZCS) and the Ocean Colour Experiment (OCE) instrument. The 6-channel CZCS instrument was put into orbit with the 1978 launch of Nimbus-7. Technical details may be found in various publication, e.g., Hovis et al, (1980) and Gordon et al, (1980). Of the 6 channels, 4 are for chlorophyll pigments, 1 for near infrared (detection of land/water margins), and 1 thermal infrared band for extraction of radiometric brightness temperatures. Ground resolution is about 800 m, similar to that of the AVHRR aboard meteorological satellites. Data resolution is 8 bits (256 levels). Data for the European area are archived by the Joint Research Centre, Commission of European Communities, Ispra, Italy. South African data are archived at the National Research Institute for Oceanology, Stellenbosch, S. Africa.

The OCE instrument is flown aboard the Space Shuttle at present and normally concentrates on open ocean colour research. The instrument is similar to the CZCS but utilizes 8 channels, 7 of which are in the visible range and 1 channel in the near infrared. In a recent report of the 1981 OCE mission, Kim et al, (1982) were able to determine an empirical relation between chlorophyll concentration and upwelling radiance from the sea. Based on ground-truth data, the concentration of chlorophyll (mg/m^3) was determined to be

$$C = 17.5 \exp.(-5.44R), \text{ where } R = \frac{I_1 - I_3}{I_1 + I_3}$$

The subscripts refer to the band numbers of the instrument (I_1 = 486nm and I_3 = 553nm). The method of Kim et al, (1982) does not deal with suspended sediments but it does obtain a correction for atmospheric aerosols.

Although these instruments, as well as the thematic mapper aboard Landsat D, may be used to obtain water colour information, the 16-18 day interval between consecutive overpasses may seriously limit their usage for some resource assessments and research studies. The problem of repetitive coverage is made worse by the frequent presence of cloud cover.

These satellite data sources, however, may be very useful for selected case studies, or proof-of-concept experiments. Where frequent data coverage is needed and the study area is not large, survey by aircraft offers a number of advantages, including much improved spatial resolution for the sensors.

I.2.8. Surface winds

The wind stress induces the roughness of the sea; then it has a direct influence on the amount of diffused radiations. The hyper-frequency radiometry only provides the wind speed (accuracy $\pm 2ms^{-1}$) when the scatterometer measures at the same time wind speed and direction, with respective accuracies of 10-20% and 20%. The latter instrument is the most suitable for those topics.

Table 1 summarizes the major oceanographic applications of the satellite sensors.

I.3. Future developements

The European Space Agency (ESA) is developping a programme focused on oceanic surveys. The satellite ERS-1 will be the issue of numerous studies carried out during the previous experiments of SEASAT, NIMBUS 7 and TIROS-N (Fig.5).

The ERS-1 payload will consist of the following instruments:

- a C-band Active Microwave Instrumentation (AMI) (combining the functions of a Synthetic Aperture Radar (SAR), a Wave Scatterometer and a Wind Scatterometer), primarily for wind field and wave spectrum measurements and all-weather imaging;

- an Ocean Colour Monitor (OCM), primarily for the measurement of sea surface temperatures and ocean colours;

- a Radar Altimeter (RA) primarily for the measurement of significant wave heights.

N.B. In addition, the satellite platform provides the possibility for incorporating a data collection package.

Table 1 - Summary of Sensors and Observables

Observables	Imaging Radiometers			Short Pulse Altimeter	Imaging Radar	Scatter-ometer
	Visible	Thermal IR	Micro-Wave			
Chlorophyll and algaes	1	-	-	-	-	-
Current position	2	1	1	1	1	-
Current speed	-	-	-	1	3	3
Estuarine circulation	1	1	-	-	-	-
Fog	1	1	-	-	-	-
Ice cover	1	2	1	1	1	-
Icebergs	-	-	-	-	1	-
Internal waves	1	-	-	-	1	-
Marine geoid	-	-	-	1	-	-
Oil spills	1	-	-	-	1	-
Salinity	-	-	3	-	-	-
Sea state and swell	2	-	2	1	1	2
Sediment transport	1	-	-	-	-	-
Setup	-	-	-	1	-	-
Shallow water bathymetry	1	-	-	-	-	-
Storm surges	3	3	3	1	3	3
Surface winds	-	-	1	2	2	1
Temperature	-	1	1	-	-	-
Tides	-	-	-	1	-	-
Tsunamis	-	-	-	1	-	-
Upwellings	2	1	2	-	-	-
Water vapor	-	1	1	-	-	-
Wave refraction	1	-	-	-	1	-
Wave spectrum	2	-	-	-	1	-

Numbers indicate order or importance in determining the observable with 1 for primary, 2 for secondary and 3 for tertiary. Hyphens indicate no utility.

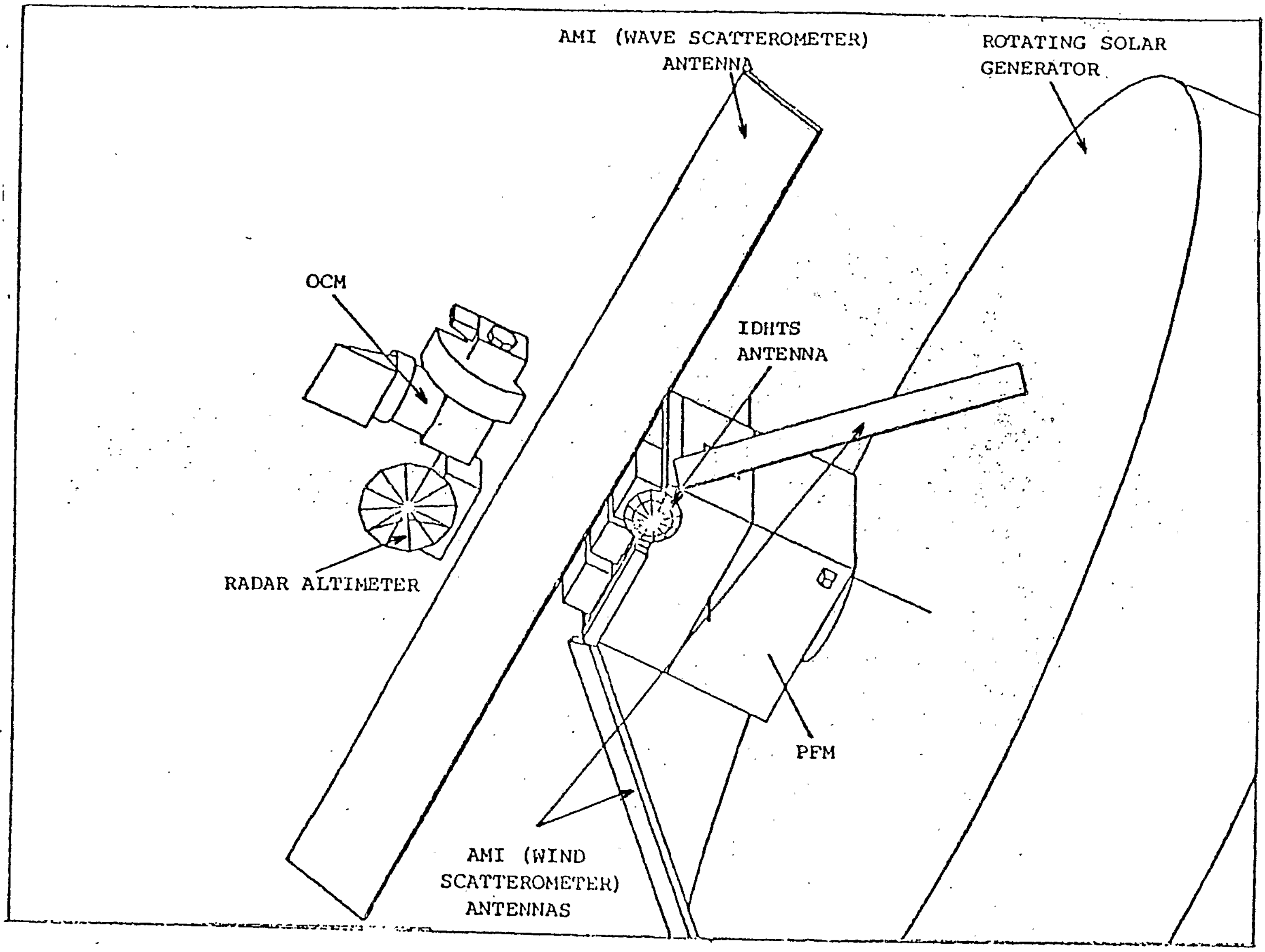


Fig. 5 - Possible in-flight configuration of ERS-1

The OCM will be composed of visible and IR sensors. The visible channels will be very similar to those of CZCS (NIMBUS-7) and the IR channels nearly the same as those used by the AVHRR (NOAA-7).

The system capability of ERS-1 is presented in Table 2, and the different mission objectives according to the instruments in Table 3.

II. REMOTE SENSING OF FISHERIES RELATED PARAMETERS

In the field of fisheries research, the most common parameters used are the wind, the sea surface temperature (SST) and the sea colour. A special note on bioluminescence experiments will end this section, as it only concerns aerial surveys.

We shall discuss different topics related to fisheries monitoring and present various experiments as illustrations.

II.1. Effect of surface currents on fish egg and larvae movement

Many finfish and shellfish which spawn offshore depend on surface currents to transport their eggs and larvae into estuarine nursing grounds. This period of egg and larvae drift represents the most critical survival period for certain marine nekton. When surface currents do not provide favorable transport, or fronts prevent their drift, the respective fishery may be severely affected. Surface transport is one of the most important oceanographic factor affecting recruitment in the fisheries. Strong and constant winds (inducing strong currents) break the water column stratification and disperses the plankton, a basic food for fish larvae whose survival is then affected. The amount of turbulent mixing caused by wind is roughly proportionnal to the cube of the wind speed. It appears that weak winds and suitable food during the larval stages of anchovies off California result in strong year classes of this species, and that strong winds, upwelling or unsuitable food,result in weak year classes (Forsbergh and Miller, 1978)

At the present time, surface transport for fishery applications is calculated by estimating geostrophic wind field from surface atmospheric pressure fields prepared by groups such as the U.S. Fleet Numerical Weather Service. Sea surface stress is normally inserted

MAIN PHYSICAL PARAMETERS	ACCURACY	RANGE	HORIZONTAL RESOLUTION	COVERAGE/ REPEAT CYCLE. DELAY.	MAIN CONTRIBUTING INSTRUMENT
WIND					
Speed Direction	+2m/s or +10% +20°	4 to 24m/s 0 to 360°	50x50 km² (Global)	Global/3 day 3 to 6 hours	Wind Scatterometer Altimeter (at nadir)
WAVE SPECIRUM					
Direction Height Wavelength	Angular resolution: 30° ±20% spectral resolution: 25%	0 to 180° 100 to 1000 m	<10 km²	Discrete measurement points. Grid size 900 km at equator in long, for 3 day repeat cycle. 3 to 6 hours	wave scatterometer
SEA SURFACE TEMPERATURE	±0.5° C	-2 to 35 C	800x800m²	Global/3day. 6 to 12 hours	OCM
WATER MASS DEFINITION					
Chlorophyll content Turbidity	±20% ±20%	0.1 to 10 mg/m³	800x800m² 800x800m²	Global/3 day Global/3 day	OCM
SEA STATE					
Sign. Wave Height	±0.5m or ±10%	1 to 20m	<10 x10 km²	Discrete measurement points. Grid size 900 km at equator in long, for 3 day repeat cycle 3 to 6 hours	Altimeter
CURRENTS					
Speed Direction	±15cm/s ±20°	15cm/s 0 to 360°			Altimeter
HIGH RESOLUTION IMAGERY	Grey level resolution:				
(All weather)	1 dB 2.5 dB Unspecified		100x100m² 30x30m² 15x15m²	75 km swath width. 3 day repeat cycle over selected areas (important gaps in coverage) or complete coverage achievable in 35 days	SAR (imaging mode)

Table 2 - Predicted ERS-1 System Capability

Table 3 - Relevance of instruments to Mission Objectives

	Altimeter	Ocean Colour Monitor		C-Band Active Microwave Instrumentation		
		IR	Vis.	Imaging Mode	Wave Mode	Wind Mode
Weather forecast		x				x
Sea-state forecast	x				x	x
Offshore forecast	x	x			x	x
Ship routing	x	x			x	x
Fisheries (Fish location)	x	x	(x)			x
Sea and iceberg monitoring	(x)	(x)	(x)	x		
Oil and pollution detection		x	x	x		
Coastal processes		x	x	x		
Land applications	(x)			x		
Ocean circulation	x (1)	x	x	(x)		x
Ocean tides	x (2)					
Wind field (3)	x			(x)	x	x
Wave field (3)	x			(x)	x	x
Sea surface temp.		x				
Polar oceans	x	x		x	x	x
Ice	x			(x)		
Marine biology		x	x			

x : Indicates a principal contribution to the objectives

(1) : For large-scale circulation, an accurate orbit determination over short arcs as required.

(2) : For solar tides, measurements from other satellites in complementary orbits is required.

(3) : The altimeter and the C-band Active Microwave Instrumentation are mutually suppertive in deriving the wind and wave fields.

into the appropriate Ekman formulation, including the Coriolis parameter, to obtain an estimate of the surface transport. However, this approach is limited by about 300 km in space and by about one month in time (Brucks and Leming, 1977).

Satellite remote sensors can be used to monitor certain oceanographic features synoptically over wide areas and with frequent temporal coverage. Specifically it appears that a SEASAT type scatterometer could be used to map sea surface stress with the following advantages: a) synoptic coverage over a large area (2 x 500 km swath-width); b) reasonably high resolution (50 km), c) a 36-hour repetition frequency, and d) a direct measurement of sea surface stress which can be converted into surface transport for correlation with actual fish larvae movement (drift). SEASAT-A scatterometer algorithms for estimating wind-induced surface layer transport are being modified for coastal conditions and their accuracy evaluated.

Another important aspect to be considered is the influence of coastal and estuarine fronts on the movement of fish eggs and larvae. Various scientists have found that coastal and estuarine fronts seriously influence the drift and dispersion of oil slicks, phytoplankton, and other suspended matter. In recent experiments in Delaware Bay, oil slicks and phytoplankton were found to line up along convergent fronts rather than follow the drift pattern predicated by a model using wind and current information (Klemas and Polis, 1977b). Convergent fronts have been observed regularly along the east coast on the shelf and in the Delaware and Chesapeake Bays. Fronts and their movements can be monitored by NOAA-5, VHRR, LANDSAT, MSS and aircraft cameras. The aircraft/satellite/ship techniques proposed will help determine the influence of such fronts on fish egg and larvae drift as was done with oil slicks and phytoplankton in previous studies (Klemas et al, 1977a).

II.2. Productivity of thermal fronts

Thermal fronts generally occur when different water masses come into contact. The most important phenomenous which cause such fronts are the upwellings.

Upwelling is a process of vertical water motion in the sea whereby subsurface water moves towards the surface. Upwelled water can introduce large quantities of nutrients (phosphates, nitrates,...) to the euphotic layer; thus, upwelling is conducive to high organic production. Knowledge of the location and prevailing conditions of upwelling areas is important for fishing fleets. Coastal upwelling are generally observed along the western coasts of continents (California, Peru, Morocco, Angola) except for Indian Ocean where a strong seasonal upwelling takes place along Somali Coast. Upwellings are also observed along the equator, in Pacific and Atlantic Océans. In both cases, upwellings are an oceanic response to a wind stress inducing, in certain conditions, a localised divergence of the surface water moving outwards. The food chain, starting in the upwelling by phytoplanktonic bloom, is built up while water is flowing outwards. Thus, the higher trophic levels are reached at some distance from the nutrient source.

II.2.1. The albacore fishery in north-eastern Atlantic Ocean

In the Atlantic, during its surface migration from Acores Isl. to Ireland, in summer, the albacore (*Thunnus alalunga*) is concentrated along thermal fronts ranging from 17° to 20°C. This clear relationship between this tuna and the environment renders the spatial radiometry very useful for locating best potential fishing grounds.

Le Gall and Citeau (1984) have tested METEOSAT-2 and NOAA-7 data. Both resultant thermographies appeared reliable when compared to ground-truth data (ships). Using the visible channel reduces uncertainties concerning the surface temperature distribution obtained by METEOSAT-2. The high quality of AVHRR (NOAA-7) data is gained at the expense of a reduction in geographical coverage. Corrective operations and geometrical adjustments must be performed in order to establish multi- temporal synthesis.

The type of data selected (NOAA or METEOSAT) depends firstly on the desired objective, immediate informations or analysis at a later date: according to the quality, the disseminated format and image transmission cycle of METEOSAT, these data are easy to process on mini-computers and well adapted to an operationnal fishing aid as the processing time is short. In the other hand, the use of NOAA for this purpose requires a longer processing time (1 hour).

In both cases, it has been demonstrated that an efficient aid to albacore fishery could be provided through satellite data collection system.

II.2.2. Tropical surface tuna fishery in east Atlantic Ocean

Concentrations of tuna are influenced by the temperature of the water and the food available (plankton, micronekton, sardines...). For this reason the yellowfin tuna (*Thunnus albacares*) is usually found in water with a surface temperature ranging between 23° and 29°C., whereas the listao (*Katsuwonus pelamis*) can move in much cooler water (even 18°C).

Stretta (1977) has investigated the relationships between a thermal front observed off Lopez Cape (Gabon) and the tuna catches made in the vicinity. This front is due to an upwelling occuring during northern summer (trade wind season). The cold side of the front is around 22°C, the warm side, 25-26°C. Tuna are generally found on the warmer side.

A comparison between the catch made within the frontal area and outward shows better results in the former area (Table 4).

Table 4 - Catch (in tonnes) of tuna within and and outward the frontal area of Lopez Cape in June and July (from Stretta, 1977)

	Yellowfin & Bigeye		Skipjack	
	Lopez Cape area	Other area	Lopez Cape area	Other area
June & July 1972	5702	2096	2147	746
June & July 1974	4506	5093	2557	2110
June & July 1975	2630	419	1429	514

Assumptions on the oceanographic process leading to tuna concentrations have been made. The first step is to consider different water masses (with different potential productivity) in an area : tuna is present but scattered. Then, if these waters come into contact, a front is created : tuna start to concentrate along the warm boundary, feeding on zooplankton and micronekton. While this front persists, tuna fishing is successful. As the front disappears, tuna disperse. This typical evolution is the key principle of a predictive model set up in Atlantic, which will be presented later.

II.2.3. Tropical surface tuna fishery in South Western Pacific Ocean

Satellite data and aerial radiometric surveys have described a semi-annual periodicity of a thermal front occuring between New-Caledonia and Vanuatu, in South-Western Pacific Ocean (Petit et al, 1980). This front appears between the southern edge of the South tropical counter-current (SST $\simeq$ 26 - 27°C) and the subtropical water (SST $\simeq$ 23 - 24°C), when they come into contact in both hot and fresh seasons.

In June - July, during the trade wind season, the nutrient rich subtropical waters flow northwards in the channel between New-Caledonia and Vanuatu. The front, then created, is rich and numerous yellowfin schools have been spotted by the aircraft on the warmer side.

II.2.4. Bluefin tuna fishery off the East Australian Coast

Australian tuna fishermen have for many years made extensive use of surface water temperatures in their search for southern bluefin tuna (*Thunnus maccoyü*).

They have found that the "rippling" schools of tuna that provide much of the catch are found only in waters lying within the range 16.7-20°C (62-68°F). Below 16.7°C (62°F) the fish are usually dispersed and feeding. Above 20°C (68°F) the fish form schools but do not bite well. Above 21.1°C (70°F) bluefin are rarely seen. Fishermen have also found that within the range 16.7-20°C (62-68°F) bluefin are more likely to be found where there are sharp discontinuities in surface temperature or "fronts". At these fronts, surface temperature may change as much as

1.7°C (3°F) in a matter of yards. The fronts are often visible to the eye, as the boundaries between two adjacent bodies of water of different colours.

To provide aid to fishermen, aerial surveys using an IR radiometer have been carried out. The temperature maps produced have indicated when and where the fishing season was to start, when this season would end, and have provided information for a better understanding of the seasonal progression of the fronts, leading to the prediction of the best fishing areas.

When asked to estimate the increased tonnage that could be directly attributed to the temperature maps, one fisherman said he estimated this increase in tonnage to be between 10 and 15 per cent and in addition the boats had been saved about 20 percent of their normal steaming time. Another estimated the increase in tonnage to be about 30 per cent.

The catch during the season was approximately 4000 tons. Accepting 20 per cent or 700 tons approximately of this as being attributable to the use of isotherm maps, the increased value to the fishermen of the catch was about $100,000. This was attained with an outlay of just over $6000. This points out the economic fall out of the fishing aid.

II.3 Temperature - sea colour combined analysis

- Experimental flights with an aircraft equipped with a precision thermometer (PRT-5) infra-red radiometer and a dual channel differential radiometer (DCDR) for ocean colour have been reported by Stevenson et al (1979). These flights were carried out off California Coast over the anchovy fishery.

The DCDR color sensor consists of a wide angle view lens cemented to one end of a fiber optic cable. The chlorophyll sensing is accomplished by use of two detector-filter combinations. One combination uses a 525μm band-pass filter for the reference signal as this is the wavelength region of minimum attenuation due to chlorophyll. The other combination has a 443μm band-pass filter, for maximum absorption of chlorophyll "a". A ratio between those detections is calculated by the instrument. The principal problem with the DCDR is its dependence on constant solar illumination of the sea surface. This condition is very difficult to carry out on the field (variation of cloudiness, changing of the probe viewing angle relative to the angle of the sun when the aircraft changes headings).

A comparison of the PRT-5 derived SST and DCDR - derived Chlorophyll Index data (CI) obtained a significant negative correlation. That means colder the sea and higher the chlorophyll content.

Anchovy, at least in their early life, feed first upon phytoplankton and later upon zooplankton. Therefore, it may be possible to define potential areas of anchovy concentration only after a few aerial surveys using both sensors as mentioned above.

- Another study analysing simultaneously SST and sea colour by satellite sensors has shown the usefulness of this kind of measurements for the management of a pelagic fishery. This experiment, reported by Cram (1979) has been conducted in south-eastern Atlantic Ocean, off the South Africa coast, on a pilchard fishery (*Sardinops ocellata*).

Aerial observations and hydrobiological surveys demonstrated the pilchard school concentrations tend to avoid dense plankton area, but feed in areas of intermediate concentrations of phyto and zooplankton (Fig. 6). There was also an inverse relationship between SST and phytoplankton (i.e. chlorophyll), as presented in the previous study (Table 5).

Table 5 - Changes in proportions of phytoplankton and zooplankton with increasing mean temperature (0-50m) seawards (from Cram, 1979) .

Zone	Mean temperature (°C)
Phytoplankton	13.22
2/3 phytoplankton and 1/3 zooplankton	13.68
1/2 phytoplankton and 1/2 zooplankton	14.36
1/3 phytoplankton and 2/3 zooplankton	14.76
zooplankton	14.64

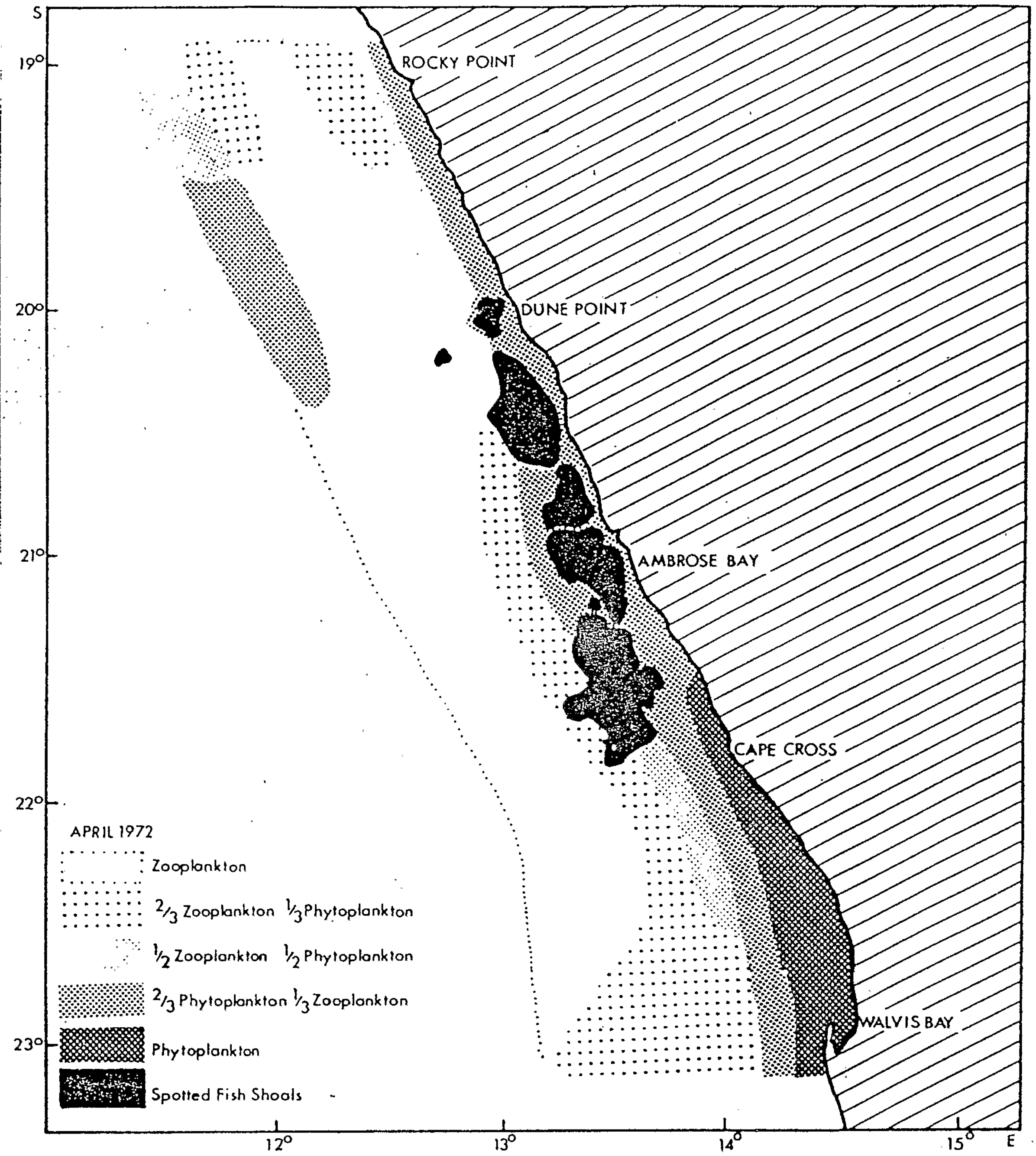


Fig. 6 - Plankton distribution and observed positions of pilchard shoal groups - cumulative over 10 days (after Visser et al, 1973)

A basic concept of investigation using CZCS (NIMBUS-7) was proposed. As the phytoplankton community dominating the area appears to be typically brown-green in colour ,it was suggested that the CZCS may be able to discriminate between this and other communities. If so, then algorithms may be developped for the CZCS to allow delimitation of areas where fish should be potentially absent, as pilchard avoid high planktonic densities. This can lead to a better-fishing strategy for the fleet and to a reduction of expensive searching time.

II.4. Bioluminescence

This is the phenomenon whereby organisms, especially certain phytoplankton species, emit visible light energy when disturbed, for instance when a pelagic fish school is feeding upon. Bioluminescence provides an excellent means for detecting at night some species of fish. A Low Light Level Image Intensifier can identify the light energy emitted. The principle of its use is based on a more basic premises, that of spotting fish from an aircraft. Squire (1972) has noted that the procedure of fish spotting from aircraft may be reduced to 3 basic steps: (i) distinguishing a fish school, (ii) identifying the species, and (iii) estimating the weight of the school. Since the light intensifier allows the scientist or observer to use lower levels of light , it is an improvement on the basic technique of fish spotting. Such fish spotting is of course done at night, so the bioluminescence is visible.

To use bioluminescence, an observer aboard a small aircraft flies over the area of interest and looks for faint patches of light emanating from the water. The movement of fish through the water usually causes the generation of sufficient bioluminescent light so as to outline the fish school.

With the development of light amplication devices, it became possible to make much more efficient aerial surveys. Roithmayr and Wittmann (1972) noted that with an instrument of about 40 000 times amplification, schools of fish were readily detectable from altitudes of several hundreds of metres. Roithmayr (1971) also noted that more than 30 types of fish could be detected at night through bioluminescence, in various oceans of the world, but with most species in coastal waters. A reasonably sophisticated low light level system uses a small video camera, video monitor and tape recorder, together with the low light level device.

The taped images can be later analysed in the laboratory for biomass assessment and species identification. Analysis of videotaped data showed that fish schools covered an area of 0.8 percent for a surveyed area of 0.64 km² (Roithmayr and Wittmann, 1972).

More recent systems are capable of 60 000 times light amplication (or more) and allow the aircraft to fly at altitudes of up to 1 800m (Stevenson,1975), while attempting to locate fish schools. In all cases, however, the depth of fish schools is normally limited to the upper few metres of water, depending upon water clarity.

III. TUNA FISHING AID BY PREDICTIVE MODELS BASED ON SATELLITE AND SHIP DATA

The prediction of the best potential areas where tuna may be concentrated in the ocean is the result of a long term analysis of major tuna-environment relationships. In tropical Atlantic Ocean, ORSTOM scientists have been surveying the tuna fishery for 15 years; some hydrological patterns leading to a high occurence of tuna have been pointed out and a model dealing with these environmental parameters is now operating with good success rate.

In Indian Ocean, since industrial surface tuna fishery is recent (1983), further investigation is required to set up a computerized predictive system. However, ORSTOM scientists based in this region can gain a profit from the Atlantic experiment, so that the operational phase could be expected in the near future.

Before presenting the environmental data and their processing, it is necessary to examine a basic point : the ecology of tuna.

III.1. The ecology of tuna

Tuna are high metabolism fishes; their body is generally warmer than the surrounding water, which is not common within fishes. These species are continuously searching for appropriate areas where food is concentrated, since their daily food requirements can reach as much as 15% of their body weight. Therefore, the tuna schools do not concentrate at random but around enrichment areas which can be detected - even fore-casted - from the observation of the environment on a regular basis.

Physiological requirements of tuna have been investigated: they can vary according to the species. Studies demonstrated that SST and dissolved oxygen level could be sufficient to mark the limits of the appropriate habitat of tuna.

Dizon et al (1977) found the lower lethal temperature for skipjack was 15°C. In eastern Pacific, no catch of skipjack has been reported in temperature below 17°C. The upper lethal temperature would be 32-34°C which is never found in the ocean.

Sharp (1979) has estimated the temperature and dissolved oxygen ranges for 4 species of tuna (Table 6). The dependence of the fish regarding these two parameters is subject to variations during their life, according to morphological and physiological status.

Table 6 - Boundary conditions in temperature and dissolved oxygen levels for 4 species of tropical tuna (from Sharp , 1979)

Species	Common name	Temp. pref.	10 minute tolerance: O_2 limitation for small fish (50 to 75 cm long)
K. Pelamis	Skipkack tuna	20° to 32°C	2.5 or 3.0 ml/L
T. Albacares	Yellowfin tuna	23° to 32°C	1.5 to 2.5 ml/L
T. Obesus	Bigeye tuna	11° to 23°C	0.5 to 1.0 ml/L
T. Alalunga	Albacore	15° to 22°C	1.7 to 1.4 ml/L

However, those boundaries only defined optimal habitat, however fish can escape for some time in cooler or less oxygenated water if necessary. In Indian Ocean, Marsac et al (1983) have detected tuna in great depth where the temperature was 5° to 8°C below the lower boundary indicated in Table 6.

III.2. Source of data

Four levels can be identified :

historical data : result of the compilation of oceanographic cruises. The whole set of hydrological parameters is available. Regarding the temperature, atlases provide a general idea of the trends in the area studied. In the Atlantic Ocean, Merle (1979) has built block diagrams based on the NANSEN data collected by the NODC; this has the advantage of bringing out the monthly temperature trends from 5 to 200m per surface unit of 5° longitude and 2° latitude. Then, it is easy to identify the zones with considerable surface cooling and reduction of the mixed layer, where enrichment takes place.

message - ships: sea temperature measurements made by meteorological and merchant ships while cruising are sent through G.T.S. (Global Telecommunication System) to data bases. Those information need to be validated by using various analysis techniques. The final product is useful as it provides a ground-truth for satellite calibration.

satellite temperature maps : in both Atlantic and Indian Ocean, we use the weekly GOSSTCOMP product from NOAA (U.S.). The temperature observations are obtained daily from polar orbiting satellite's AVHRR sensor in the IR spectrum. The maps are produced by a fully automated computer procedure of GAC data (4 km resolution); the target arrays have a 50 km resolution. The values of these arrays are calibrated by information provided by the on-board satellite sounder (HIRS/2) and buoys at sea. The actual accuracy is $\pm$ 1°C.

Three weeks are needed at least to receive the charts due to mail delivery, therefore this data cannot be used for real time analysis.

In Atlantic Ocean, real time analysis has been performed by using METEOSAT thermographies. This will be discussed later.

aerial surveys : zones recognized as favorable to tuna concentrations are then analysed in more details by an aircraft suitable for long range flights and equipped with an infrared radiometer.

When in operation, the data are often recorded both in analogue form (strip-chart record) and in digital (tape) form. The data record usually consists of several flight lines made over the sea. Due to the atmospheric moisture, the radiometer data do not register the true surface water temperature, but usually a temperature several degrees cooler than the actual temperature. Separate from the atmospheric water vapour problem, there is also another correction needed due to the fact that the water surface does not radiate exactly as a black body. For these reasons it is best to obtain some ground-truth measurements in order to correct the radiometer data. If the aircraft flies at the same altitude during the mission, a simple statistical comparison of the actual and observed temperatures is sufficient to determine the necessary correction function. If it is known prior to the mission that there will be no ground-truth measurements, an alternate method may be used to obtain the general correction. If the aircraft flies at a specified altitude over the water, we consider the vertical path length to be equal to 1 (arbitrary) path length. If during the flight we point the radiometer to either side of the axis of the flight line at an angle of 60°, the path length becomes twice the vertical, since the sec (60°) = 2.0. Now making the assumption that the actual water temperature at 60° is the same temperature as that beneath the aircraft, the observed temperature difference for the 0° and 60° data is equal to the desired temperature correction. This ΔT value is then subtracted from the airborne radiometric temperatures . The presence of clouds over the flight areas, however, will introduce a somewhat larger error.

It is possible to calculate with ground-truth measurements the correction to be applied. We have expressed it in tenths of degrees centigrade which are added to the radiometer-derived temperature.

III.3 Data processing

- On real time basis, operational procedures have been performed in many places. In Atlantic Ocean, the combination METEOSAT-aerial surveys has provided very significant results.

The procedure used in tropical eastern Atlantic, from Abidjan, is the following. METEOSAT data (visible + IR) are collected at the Spatial Meteorological Centre (CMS) in Lannion (France). Images are displayed on the screen of the computer for cloudiness analysis. Then, the oceanographers, outposted in this centre, select the image to be archived according to the quality of the information. The images archived for one week are processed by a software designed by the ORSTOM Remote Sensing Workshop. This brings to the production of a synthesis image for each week.

Each image can be displayed on a colour screen and edited on a colour printer. This instantaneous view can be combined with other images in order to illustrate some thermal structures. The general principle is based on the assumption that oceanic phenomenon evidences are more stable than meteorological disturbances which can cover them. The weekly thermal synthesis can then be realised due to the fact the sea temperature is higher than cloud temperature as well as sea signal has a greater permanence. These weekly charts are comparable with message ship data (Fig. 7).

These maps are transmitted through telecopy to Abidjan. Another level in real time analysis is obtained by the reception of daily temperature maps from METEOSAT processed with a software set up by CNES (France). These maps are used to design the aerial survey flights in order to search for the frontal areas, if such structures are detected.

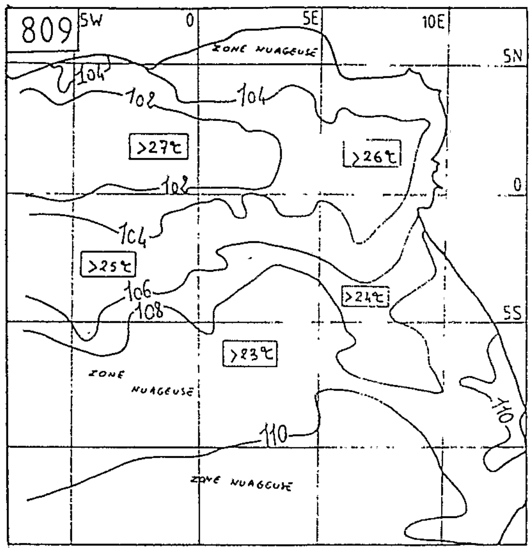
Aerial surveys include also tuna spotting, in order to get a real time vision of the location of the schools according to the thermal evolution.

Then, an effective aid can be provided to fishermen. This point is very important when the surveyed fishery is well developped. During the flight, temperature are spotted, which allows:

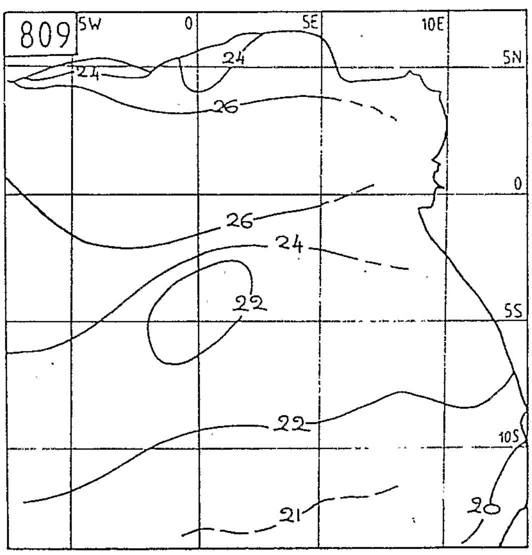
- the modification of the flight path if the thermal structure is not suitable to tuna concentration,
- the broadcasting to the fishing vessels of general information on thermal structure and evolution expected (this task is very important in the case of a frontal zone which can shift rapidly), as well as sightings, location of the schools and short term prediction of the best potential fishing grounds;
- the elaboration of synthetic temperature maps provided to fishermen.

Other tasks are achieved in a delayed time, such as the estimation of stock abundance and the long term prediction of best fishing grounds.

Estimation of stock abundance is restricted to the tuna biomass available to the surface fishing gears (purse-seine or pole and line). Models have been tried in south-west Pacific Ocean (Petit, 1984) and in Indian Ocean (Marsac, 1983). They are affected by the high migratory behaviour of tuna and their frequent vertical movements in the water column which don't make them visible at any time. However, they can



(a)



(b)

Fig. 7 - METEOSAT-derived SST field and radiometric **values** (102:warm 110:cold) between 27th and 31st of August, 1981 (a), and (b) ground-truth SST map from message-ships collected between 25th of August and 2nd of September, 1981 (from Citeau. <u>et al</u>, 1981)

provide a rough estimate which is possible to improve with catch statistics analysis.

As far as we know, few experiments on prediction of best tropical tuna fishing grounds have been carried out. A successful procedure has been set up in Atlantic; this is the topic of the following section.

III.4. A predictive model for the tropical Atlantic tuna fishery

The first step has been previously described : selection of areas where tuna could be concentrated according to the temperature evolution. This empirical approach needed to be improved by a computerized analysis modelling the enrichment processus of a water mass. Then was created a predictive model called "PREVI -PECHE" (Stretta et Slepoukha, 1983), which description follows :

Intertropical Atlantic Ocean has been divided into 160 zones of 2° latitude and 5° longitude. The studied area extends from 20°N to 14°S and from the West african coast to the south american coast. The zones are coded on a map distributed to the skippers.

In each of the 160 zones defined, historical monthly temperatures have been reported. A historical temperature is a mean of numerous observations made by merchant ships or research vessels. Furthermore, depth of thermocline, current direction and meteorological conditions are also provided for each zone. All these parameters, for a given area, are going to be used for calculating a "theorical fishing probability". The programme retrieves the historical temperature of the month analysed, the temperatures of both previous and following months and the lower temperature recorded in the zone studied. It is then possible to know whether a cooling, a heating or a thermal stability of the water mass can be expected. The model can estimate the potential productivity of the water mass. Higher the productivity and higher the theorical fishing probability.

The analysis of the SST evolution from the GOSSTCOMP charts on a 6 week period provides a "thermal pattern" which will be compared with the "optimal thermal pattern". Then the "actual fishing probability" is calculated.

The comparison between theorical and actual fishing probabilities gives a probability level ranging from 0 to 6. 0 or 1 means an area where unfavourable conditions for tuna concentration prevail; in the other hand, 5 or 6 is a high fishing probability. This probability so calculated covers the 10 or 15 days following the last GOSSTCOMP chart analysed.

As GOSSTCOMP charts are not available in real time, the model also performs a projection in the future to estimate new fishing probability according to the possible evolution of the temperature up to 1 month after the last SST chart. A print out of the model is shown as an example in fig. 8.

III.5. Recent developments in Indian Ocean

PREVI - PECHE has been experimented in Indian Ocean. The results, without being fully satisfactory, are encouraging and suggest that further investigations are necessary in Indian Ocean as the model must be adapted to this region where hydrological patterns are very specific due to monsoon system.

In 1981, a preliminary analysis concerning the Mozambique Channel has been conducted by using METEOSAT. Obviously, this satellite is not the most suitable for the region, but no other geostationnary satellite is operating over the Indian Ocean. The resolution is poor as the pixel, equal to 25 km² in Guinea Gulf, is only in the order of 50 km² over Madagascar. Process have shown a great difference between the radiometric values measured in Mozambique Channel and those of the eastern part of Madagascar . The difference can reach 3°C although real temperatures are rather similar. This is due to a drastic increase of the atmospheric absorption as the region is on the edge of the area covered by METEOSAT.

The Mozambique Channel SST field visualized by METEOSAT is relevant to historical observations : warm water accumulated along the NW coast of Madagascar, and along Mozambique coast, cooler patch in the middle of the Channel which could be related to a local current divergence.... Such coolings could initiate enrichment leading to tuna concentrations.

MINISTERE DE LA RECHERCHE SCIENTIFIQUE   OFFICE DE LA RECHERCHE SCIENTIFIQUE ET TECHNIQUE OUTRE MER

CENTRE DE RECHERCHES OCEANOGRAPHIQUES
BP V 18 ABIDJAN COTE D'IVOIRE

BUREAU D'AIDE A LA PECHE ORSTOM/INTERTHON

BULLETIN N : 28   DU : 4/10/1982

Ref.1583/JMS/hp

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*                                *
* PROBABILITES DE PECHE THONIERE *
*                                *
*    EN ATLANTIQUE INTERTROPICAL *
*                                *
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PROBABILITES VALABLES POUR LA PERIODE DU: 29/9 AU 12/10/1982

Probabilites de peche calculees a partir de temperatures de surface mesurees par satellite
Origine des donnees: NOAA (USA)

ZONES TRES FAVORABLES :

81 82 108

ZONES MOYENNEMENT FAVORABLES :

40 48 58 59 60 62 69 72 73 80 84 86 87 91 94

95 96 105 106 107 115 120 128 132 137

ZONES PEU FAVORABLES :

4 18 27 28 35 39 42 43 49 50 55 63 68 74 75

83 92 93 97 98 101 102 103 104 110 111 112 113 121 124

130 131 133 134 135 138

ZONES EN EVOLUTION FAVORABLE :

58 73 86 95 105 137

PAS D'INFORMATION EXPLOITABLE POUR LES AUTRES ZONES

PREVISIONS FAITES PAR J.M.STRETTA ET M. SLEPOUKHA
sur ordinateur HP/1000 avec le logiciel PREVI-PECHE

PROBABILITES DE PECHE ET EVOLUTION
POUR L'ATLANTIQUE INTERTROPICAL
BULLETIN N:28

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PREVISIONS FAITES PAR J.M.STRETTA ET M.SLEPOUKHA
BUREAU D'AIDE A LA PECHE ORSTOM/INTERTHON ABIDJAN LE:4/10/82

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NUMERO DE LA ZONE :  13     TEMPERATURE HISTORIQUE : 26.0
LA DERNIERE CARTE THERMIQUE RECUE COUVRE LA PERIODE DU:8/9 AU 14/9/82
TEMPERATURE DE SURFACE DANS CETTE ZONE A CETTE PERIODE: 23.0C
PROBABILITE DE PECHE POUR LA PERIODE DU:15/9 AU 28/9/82      : 0/6
                                -----------                 *****
EVOLUTION DE LA PROBABILITE DE PECHE DANS CETTE ZONE
POUR LA PERIODE DU:29/9 AU 12/10/82      SI LA TEMPERATURE
DU 15/9 AU 21/9/82       SE TROUVE ETRE EGALE A:
     25.0C LA PROBABILITE DE PECHE DEVIENDRAIT EGALE A: 0/6
     24.0C LA PROBABILITE DE PECHE DEVIENDRAIT EGALE A: 1/6
     23.0C LA PROBABILITE DE PECHE DEVIENDRAIT EGALE A: 0/6
     22.0C LA PROBABILITE DE PECHE DEVIENDRAIT EGALE A: 0/6
     21.0C LA PROBABILITE DE PECHE DEVIENDRAIT EGALE A: 0/6

NUMERO DE LA ZONE :  48     TEMPERATURE HISTORIQUE : 27.0
LA DERNIERE CARTE THERMIQUE RECUE COUVRE LA PERIODE DU:8/9 AU 14/9/82
TEMPERATURE DE SURFACE DANS CETTE ZONE A CETTE PERIODE: 26.0C
PROBABILITE DE PECHE POUR LA PERIODE DU:15/9 AU 28/9/82      : 1/6
                                -----------                 *****
EVOLUTION DE LA PROBABILITE DE PECHE DANS CETTE ZONE
POUR LA PERIODE DU:29/9 AU 12/10/82      SI LA TEMPERATURE
DU 15/9 AU 21/9/82       SE TROUVE ETRE EGALE A:
     28.0C LA PROBABILITE DE PECHE DEVIENDRAIT EGALE A: 3/6
     27.0C LA PROBABILITE DE PECHE DEVIENDRAIT EGALE A: 4/6
     26.0C LA PROBABILITE DE PECHE DEVIENDRAIT EGALE A: 3/6
     25.0C LA PROBABILITE DE PECHE DEVIENDRAIT EGALE A: 3/6
     24.0C LA PROBABILITE DE PECHE DEVIENDRAIT EGALE A: 3/6

NUMERO DE LA ZONE : 108     TEMPERATURE HISTORIQUE : 23.0
LA DERNIERE CARTE THERMIQUE RECUE COUVRE LA PERIODE DU:8/9 AU 14/9/82
TEMPERATURE DE SURFACE DANS CETTE ZONE A CETTE PERIODE: 21.0C
PROBABILITE DE PECHE POUR LA PERIODE DU:15/9 AU 28/9/82      : 4/6
                                -----------                 *****
EVOLUTION DE LA PROBABILITE DE PECHE DANS CETTE ZONE
POUR LA PERIODE DU:29/9 AU 12/10/82      SI LA TEMPERATURE
DU 15/9 AU 21/9/82       SE TROUVE ETRE EGALE A:
     23.0C LA PROBABILITE DE PECHE DEVIENDRAIT EGALE A: 4/6
     22.0C LA PROBABILITE DE PECHE DEVIENDRAIT EGALE A: 5/6
     21.0C LA PROBABILITE DE PECHE DEVIENDRAIT EGALE A: 4/6
     20.0C LA PROBABILITE DE PECHE DEVIENDRAIT EGALE A: 4/6
     19.0C LA PROBABILITE DE PECHE DEVIENDRAIT EGALE A: 4/6
CES PROBABILITES DE PECHE NE TIENNENT PAS COMPTE DES POSSIBILITES
DE PECHE SUR EPAVE A CES TEMPERATURES DANS CETTE ZONE
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Fig. 8 - Fishing Aid Bulletin distributed to the Atlantic tropical tuna fishery (from Stretta et Slepoukha, 1983)

Considering the limited suitability of METEOSAT to Mozambique Channel, we are experimenting a new procedure to get a coverage of the whole Indian Ocean tuna fishery, which extends now from 12°S to 7°N and from 40°E to 72°E. This task can be achieved by analysing digital GAC data (from NOAA polar - orbiting satellite).

A software is being designed by IFREMER (Brest). The goal is to provide synthetic temperature maps, on several days, as it is done with METEOSAT in Atlantic. The specific problem of orbiting satellites is the geographic rectification of the images to a standard projection as Mercator. The software called PESKET, is written in FORTRAN 77 and developped on VAX 11/780. 7 routines are actually operating:

- decoding (DEMAGO - DEGAGO);
- rectification to a standard Mercator projection (REDRES);
- automatic procedure for masking the lands (TERRE);
- cloud detection by vertical sounder TOVS or AVHRR data (NUAGE);
- estimation of correlation coefficient for the best determination of SST, by using AVHRR channels 3,4,5 (DELTAT);
- creating a SST data file from coefficients estimated by DELTAT (TEMPEMER).

Other routines are going to be designed in the next months :

- improvement of visualisation techniques on image restitution device, to be relevant with the real time constraints of an operational fishing aid ;
- possibility to join 2 swaths in order to cover a greater oceanic area at a time (mosaic technique);
- superposition of images;
- entering ship data and mixing with satellite data. This will use the software named MAGIK (Geostatistic procedure) designed by ORSTOM and will outline isotherms of the synthetic SST field.

This experimental processing phase will have to be tested with catch statistics. If relationships are found between particular SST evolutions and good catch rate (catch per unit of effort - CPUE - expressed as tonnes/day), then we shall face to build up a predictive model on the basis of PREVI - PECHE analysis.

Two years of AVHRR data (1984 - 1985) are now being processed by IFREMER and the comparison with fishing results will provide a basic feasibility study of the usefulness of satellites for monitoring tuna fisheries in Indian Ocean.

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