Oceanic Landscape Concept and Operational Fisheries Oceanography

by

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L'intégration du paysage océanique en océanographie opérationnelle des pêches

RÉSUMÉ

Le présent article est un commentaire général sur l'usage d'outils technologiques nouveaux pour aider à résoudre certains aspects fondamentaux des problèmes du monde de la pêche.

Il est ainsi établi que la crise émergente est tout autant, si ce n'est plus, liée aux spécificités du milieu océanique et à la façon de pêcher qu'aux contraintes économiques ou encore à la diminution des ressources.

Le concept de "rendement écologique", c'est-à-dire la quantité de poissons débarqués par la quantité d'énergie dépensée, est rappelé et l'on démontre comment les nouveaux outils de la télédétection peuvent en diminuer le dividende et donc augmenter ce rendement.

En fait, ces outils apparaissent nouveaux par la bonne adaptation des données satellitaires acquises à une échelle spatio-temporelle qui correspond bien aux phénomènes océaniques biotiques ou abiotiques.

Les exemples sont pris pour la plupart parmi les programmes et études de la station de télédétection SEAS (Surveillance de l'Environnement Assistée par Satellite) de l'ORSTOM à La Réunion (océan Indien).

Les océanographes, aidés par l'assimilation de ces données dans leurs modèles, peuvent concevoir et décrire un véritable "paysage océanique" et sa dynamique qui deviennent les fondements de l'océanographie opérationnelle des pêches.

ABSTRACT

This is a general commentary on the implication of remote sensing into the problematic of fishing field. After a brief surrounding of present fishing situation, are analysed the new remote sensing tools and, above all, their integration in the larger field of Operational Fisheries Oceanography. Most of the described examples come from the studies and programmes led in SEAS' station of ORSTOM La Réunion (Indian Ocean). In 1989, the first international symposium on Operational Fisheries Oceanography has been held in St John's, Newfoundland. In this framework, the Operational Fisheries Oceanography has been defined (LAEVASTU, 1989) as the provision of services to minimize search time by directing fleets and fishing vessels to areas of optimum availability of desired species, based on a knowledge of the environment and a knowledge of fish behaviour under different environmental conditions. The scientific purpose of this provision is to increase the ecological efficiency, i.e. the rate between the fish catches and the spent energy for these catches. The specific knowledge which is required for the improvement of fishing decision concerns the fish (state of the stock, ecophysiology, etc.), the marine environment (real time analysis of physical parameters) and search methods of the fish (fish moving model, etc.). Essential difference between terrestrial and marine environments is that the ocean dynamics inertia is relatively much narrower. Added to the observing difficulty and surrounding hostility for human, this specificity explains why the idea of oceanic landscape we have is quite rough. Since 1989, several technical and modelling jumps have been done to improve significantly the describing of this landscape and can contribute to establish the basis of operational fishery oceanography. In particular, we shall see the contribution of the new satellite sensors and the new remote sensing data assimilation techniques to outline an authentic oceanic landscape and the manner to move inside.

I. GENERAL SURROUNDINGS

Fishing and fisheries is a world-wide primary human activity that involves the capture of over one hundred million metric tons (1993) of marine products and the work of several hundreds million of people. They represent also more than thirty percents of all the human marine activities. Almost half the production is caught by Asian countries and the fishing gear is nearer factory ships equipped with modern technology than small boats with hand hauled nets. A great tuna purse seiner is a true production unit with basic cost around nine million of ECUS. As for agriculture or others biotic resources, fishing has had to increase its technology and to decrease the number of workers, the result being to get a better rate production/worker. A long analysis would be necessary to understand why these "solutions" have emerged from the constraint of economic structure.

At present time, for the developing countries, it is evident that even if they controlled a great area following the 200 nautical miles national jurisdiction extension, the fishing development is going through joint-ventures with northern countries in a first step: the cost of production units are often out of proportion with national products.

In the northern countries, more and more often, slumps and shortages occurred. Experts seem to agree with the fact that the catches are realized at too heavy expense. They link it with the equipment and human costs to find, to harvest and to process the fish, with the fuel costs and with the depletion of fishery resources. Through an ecological and scientific approach rather than "ecologist" approach, it appears that this last cause is not quite realistic. In a lot of cases, what the experts have called a resource depletion is in fact a time/space moving.

A serious analysis of the causes of these slumps will compare them with similar events of agriculture world. A lot of problems have common origins in economical structure and commercial distribution systems. However, in the case of agriculture, no expert is involving in the resource depletion.

A specificity of fishing – may be the specificity of fishing – is not enough often reminded: it is a picking and harvesting activity. However fishing activities are at least as old as agriculture. It is proved that some prehistoric people were fishermen and that during Neolithic Period some tribes were completely depending on fishing. But, because of the specificity of oceanic environment, the major strides in fishing are coming from fishermen themselves and their experience, not really from science field. Aquaculture stays marginal and difficulties to develop scientific methods as for equipment profitability as for resources management stay great. As early as the end of past century, after acknowledgment of limited resources feature, international organisms (ICES, for example) have been formed by the northern countries. During a century most of their political or technical actions were led in the purpose of the famous "maximum sustainable yields" with limited tools as quota and bad understanding of ecophysiological processes as natural mortality and environmental influences. The limited efficiency of this management system is now acknowledged.

Probably to solve a part of fishing problems is not staying, not at all, in an increasing of the catches but in the improvement of the "ecological rate" (PETIT and WADSWORTH, 1990). It concerns the rate (R) between the produced energy *i.e.* here the catches, and the energy spent to get this last one.

By this way, we are slowly going from classical harvesting system to rational management of fishing system. To improve (R) is one of the goal of operational fisheries oceanography and the ISOFO symposium (mentioned at the beginning of this paper) has shown that a great part of the fishing professional field is quite ready to assume this kind of mutation which is coming through the creation interface groups between profession and research. Though the past of communication system has preponderant part in these groups, the remote sensing has a leading role, considering the stride of this tool during last years, particularly in marine fields.

II. REMOTE SENSING AND OCEANIC LANDSCAPE EMERGENCE

As a matter of fact satellite remote sensing data, thanks to their global and homogeneous coverage, provide a continuum of observation scales for the oceanic structure and their dynamics. However this classical assertions can become reality in so far as an operational structure is available for acquisition process archiving of remote sensing data in real time. An enormous energy in term of brain, calculation, computer time, data format transfer, etc., is generally lost between acquisition stations and processing structures. In the world, some sites gather up acquisition and processing of satellite data. That is the case in La Réunion Island, Indian Ocean.

1. SEAS Station

During 1989, the French governmental Institute for scientific research and development through cooperation (ORSTOM) has installed in La Réunion Island a satellite receiving and remote sensing processing station. This is a logical action, considering the ideas that long term development is dependent on calculated environment management and that the remote sensing tool is really well adapted to the developing countries studies. So, the Survey of Environment Assisted by Satellite station (SEAS) is born and, from then on, is archiving and processing the high resolution data, directly received by antenna of the station (NOAA satellites, as example) or through international remote sensing nets (ERS-1 satellite, as example).

First of all, SEAS Station is a High Resolution

Picture Transmission Resolution (HRPT) station which is contributing to the data acquisition, archiving, processing and delivery for the EARTHNET Programme. This programme is the operational Earth observation branch of the European Space Agency. For the moment the concerned data are coming from the Advanced Very High Resolution Radiometer (AVHRR) which is a sensor in board of four available polar meteorological NOAA/TIROS satellites, launched by USA. From Indian Ocean, SEAS Station, through ESA agreement attends the international cooperative effort to integrate existing AVHRR research in a coordinated network. This network is supporting major international and European environmental projects as TREES, ASEAN-RS, Global Change.

A similar cooperation will concern the data of the SeaWifs instrument which will be launched on the SEASTAR/NOAA mission in May 1995 and adapted to sense the vegetation and sea colour chlorophyll). The station is upgrading to get sea colour data from the SeaWifs sensor.

In collaboration with Canadian Centre for Remote Sensing (CCRS), French Space Agency (CNES) and ORSTOM-Montpellier, SEAS station is involved of a pilot Project for ESA (PPF-11): evaluate the potential of microwave data of ERS-1 satellite in the halieutic field.

The role of SEAS station is to support the programmes conducted by the ORSTOM searchers who are present in the countries of the region: Seychelles, Madagascar and Mauritius. In particular, the station is equipped with a performing image processing system which is well adapted to study high resolution satellite as SPOT data for coastal management (mangroves in Madagascar, for example).

The geographical zone (**figure 1**) which is covered by NOAA/TIROS data stretches out as far as 5°N to 41°S and the African Great Lakes to the middle of Indian Ocean (96°E). The whole 1990 year is archived, 1991 year is not available but the archiving is automatic since February 1992.

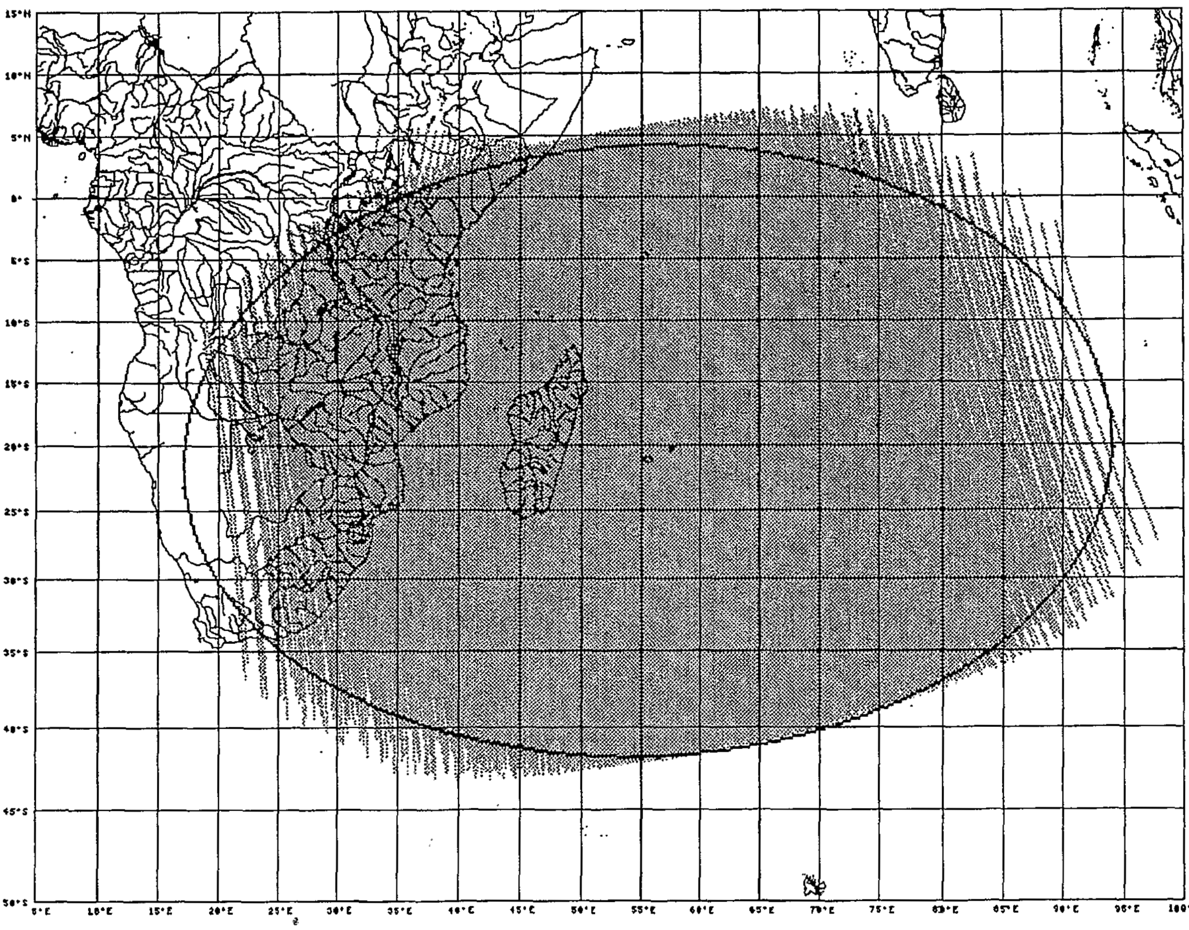

Figure 1 – The geographical acquisition zone for NOAA satellites from HRPT receiving antenna of SEAS' station at ORSTOM – La Réunion. The ellipsis is theoretical area and dashed part corresponds to the frames of images which are truly acquired in some days.
Aire d'acquisition des satellites NOAA depuis la station SEAS – ORSTOM La Réunion. L'ellipse correspond à l'aire théorique et la partie ombrée provient de la trace des bords d'images réellement acquises en quelques jours.

This zone is extended to 30°N-30°S and 0°-90°E for the scatterometer, altimeter and wave mode SAR data caught on board of ERS-1 satellite and which are available at the SEAS station. The automatic archiving has begun in November 1992.

Shortly, ORSTOM-LA REUNION/SEAS station is a centre where as many as possible data concerning the land and ocean physical environment are collected, processed and modelled to produce analyzed situation and high value forecasting in collaboration of the region countries scientists and developing experts and in the framework of cooperating programmes.

2. SST products of SEAS' station and thermal landscape

From the AVHRR sensor of NOAA satellites series, thermal infrared data values are classically converted to brightness temperature values using the inverse of Planck's radiation equation. Calibration coefficients were calculated from measurements of the onboard blackbody and the deep space blackbody. A geometric correction was applied and is derived from knowledge of the characteristics of the sensors (BARTON, 1989; SAUNDERS, 1988). The location was refined manually (FUSCO *et al.*, 1989). Data have been re-sampled onto a chart projection with a fixed resolution of one nautical mile ; the land has been masked.

A cloud mask was applied to the images. This takes the form of a simple threshold on the thermal channels 4 and 5. In tropical zone, to ensure that the brightness temperature calculated was not cloud contaminated pixels displaying temperatures less than eighteen Celsius degree were masked. This threshold is high enough to ensure few erroneous categorisations. A local uniformity test on a 2 x 2 pixels array of the brightness temperature of channel 5 was applied.

Furthermore we add a correction linked with the values of the zenith view angle for each pixel (LENA *et al.*, 1993). The validation tests we have done with TOGA programme data base XBT (eXpendable BathyThermogram), ARGOS buoys and fishing boats measures have given a standard error inferior to 0.5 degree Celsius. So, on SEAS station, a SST value is daily archived in each elementary box of one nautical square mile for all the acquisition zone (**figure 1**). To by-pass the nebulosity cover problem, a synthesis is realized on five days base (**figure 2**). These charts/files are available for the 1990 year and since the beginning of 1992. By this way, this is the first time that the West Indian Ocean thermal surface is described at a such space/time resolution. Moreover, a software has been developed by one of the SEAS team to animate this charts days after days, adding so the movement information to the charts (BERNARDET, 1994). We try to give an idea of this animation with a temporal series of quick looks (one pixel for five in line and column) in **figure 3**.

For any oceanographer, a look at these data is enough to understand the oceanography of the study zone. The southward flow of the warm Mozambique Current in its western boundary is quite visible, in particular at the beginning of the animation.

The general cooling of the SST during this transition month to southern winter. A vortex, one hundred nautical miles sized, is generated near the centre of image (20°S – 43°E). During this animation, East coast is quite colder than Western coast which benefits by the warm Mozambique Current. However, along the West coast, a narrow band of colder water could be noted. It could be the result of local upwelling, general wind being East to ESE at this season. Smaller vortex (10-20 nm size) are also present in the South of Madagascar. It is difficult to see them correctly because the colour palette of the animation has been chosen to enhance the 25-29°C water which is the interesting thermal window for the tropical tuna fishing activity. A zoom on this region and a new palette enhance these vortex (**figure 4**). Concurrent data from ARGOS buoys experiments (MOLINARI *et al.*, 1990; Marsac, com. pers.) proved that the structures which are observed on the sea surface temperature (SST) charts are not only a skin thermal effect but concern a currents system (**figure 5**). These vortex structures outlined from satellite SST data are known since numerous years but at the scale of great current as Gulf Stream. With the AVHRR high resolution data, several authors find smaller vortex everywhere in the world: Canaries Islands (RAMOS, 1992), Mediterranean (LE VOURCH *et al.*, 1992), ZÀVODY *et al.*, 1994) *etc.*

So, the classical vision of the currents (**figure 6**) and our vision of ocean surface dynamics is slowly becoming more fractal. This is quite confirmed by the Synthetic Aperture Radar (SAR) onboard ERS-1 satellite which is able to discriminate internal waves. **Figure 7** gives an example of SAR image in occidental Mediterranean sea. This kind of data are very rich for any oceanographer although eighty percents of the features are difficult, or impossible, to interpret. They relegate classical concepts to the level of sixteenth century continents charts, considering an analogy with the evolution of geography science.

A great jump has been done with microwave sensors, even if all of them are more in the experimental field than in the operational field. This is the case for the SAR of ERS-1. The altimeter of TOPEX/POSEIDON experiment is an intermediary case because of the system performances (5 cm for the standard error on the sea surface height instead of the 13 cm given for the pre-launch specifications). Considering the quality of this data and their global coverage, it is now out of the question to miss out altimetric data in the constraint models used for describing of ocean layers. Now, the necessity of ensuring the continuity of altimetric data time series over several years is quite absolute for all the environmental applied marine sciences, so for the operational fishery oceanography.

TOPEX/POSEIDON is an experiment which has its origin in the very brief life of SEASAT. Scientists have not yet exploited all its data, in spite of just three months acquisition. There is the same kind of analogy with Coastal Zone Colour Scanner (CZCS) of Nimbus 7 and SeaWifs, the future sensor of SEASTAR. After several years of international experts discussions, the process of sea colour satellite data, from CZCS sensor, is available to have a good index of primary productivity of the ocean, one of the most critical parameters for the fishing. In these conditions, the SeaWifs sensor onboard SEASTAR satellite – which has to be launched this year – would bring a lot and quite significantly enrich our oceanic landscape by ensuring a correct acquisition times series as for TOPEX/POSEIDON.

III. REMOTE SENSING INTEGRATION INTO OPERATIONAL FISHERIES OCEANOGRAPHY

In the previous part of this paper, we tried to give some examples of the progress of remote sensing which is greatest in lot of cases to understand "the new oceanic landscape". This word concerns so much the describing as the concepts and the oceanographers community is quite beginning to integrate it. But, it does not mean that the Operational Fisheries Oceanography is far from this integration (PETIT, 1991; STRETTA, 1991; RAMOS, 1992).

1. Artificial Intelligence and tropical tuna studies in SEAS remote sensing station

The improvement of the "ecological rate" evoked at the end of the first part of this paper will come from a better knowledge of fish behaviour. In the case of tropical tuna, we have a programme which proposes to use Artificial Intelligence (A.I.) for modelling of schooling and tuna moving.

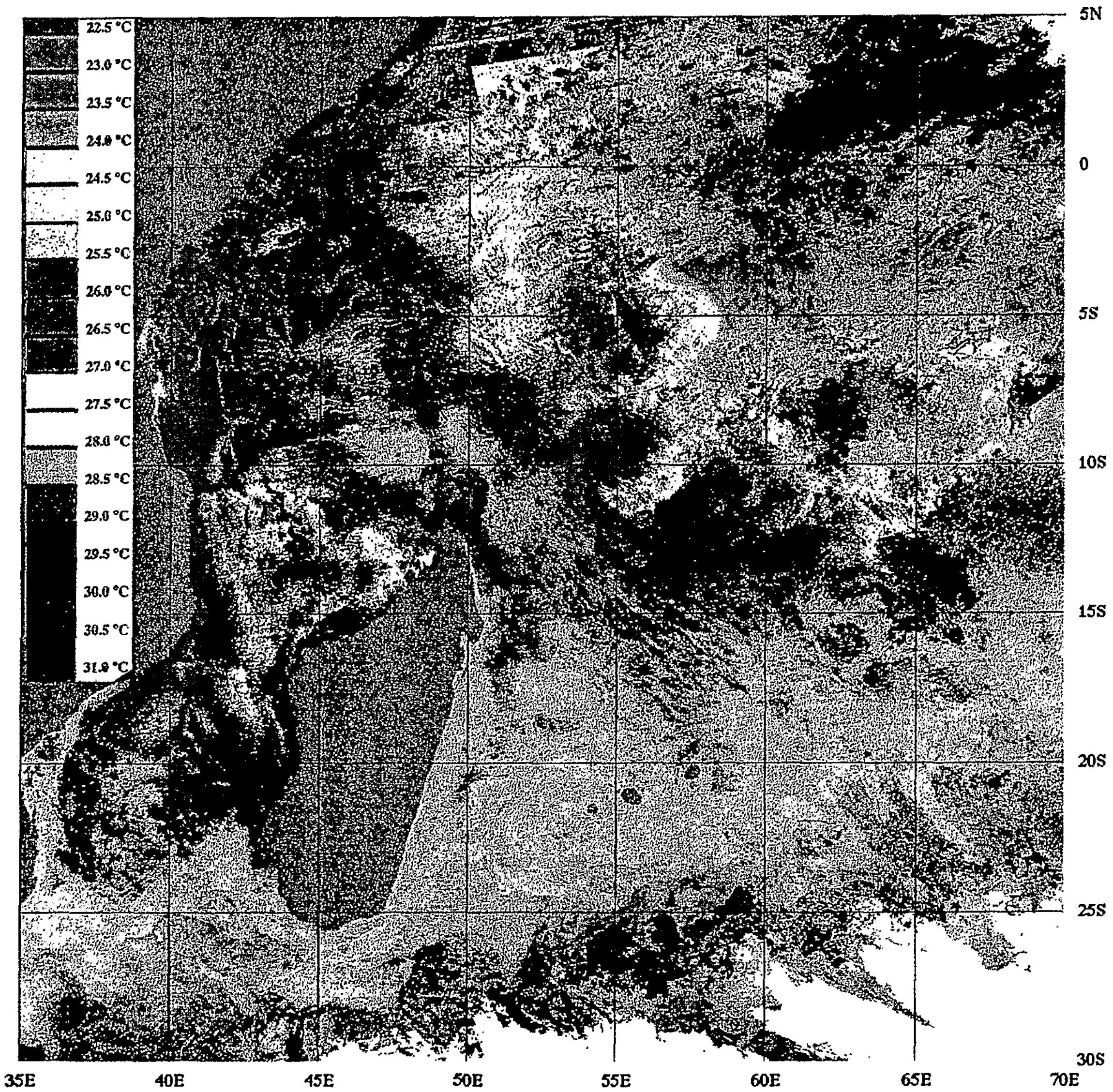

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Figure 2 – A sea surface temperature synthesis is realized on five days base. Here the chart of 16th August 1993.
Exemple de synthèse pentadaire des températures de surface de la mer.

5-06-1993 | 7-06-1993

9-06-1993 | 11-06-1993

12-06-1993 | 14-06-1993

16-06-1993 | 18-06-1993

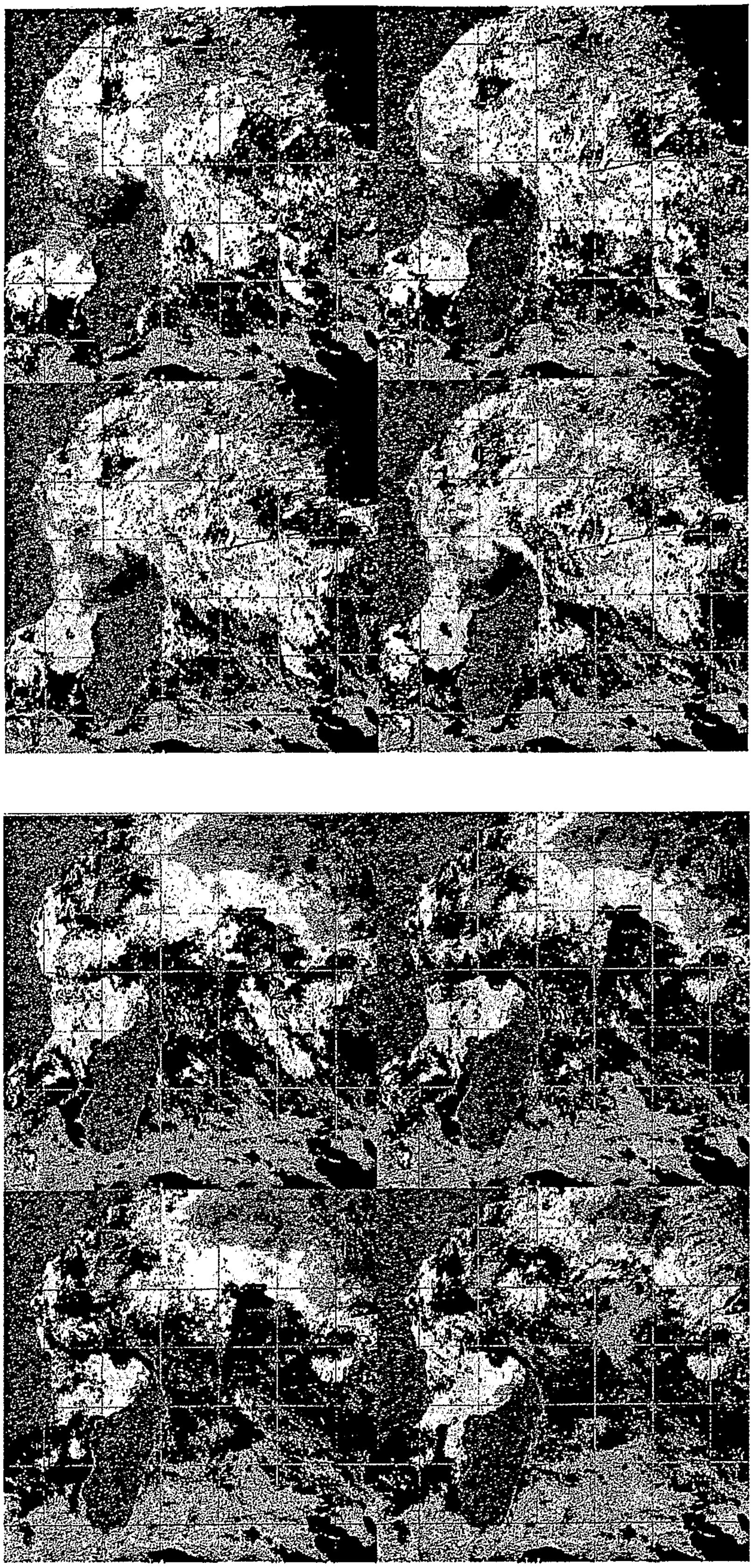

Figure 3 – Pseudo-animation with a temporal series of quick looks (one pixel for five in line and column). The thermal scale is the same as in the figure 2.
Série temporelle d'imagettes dégradées d'un facteur 5 en ligne et colonne pour donner une idée de ce qu'est l'animation des cartes de températures. Echelle des températures identique à celle de la figure 2.

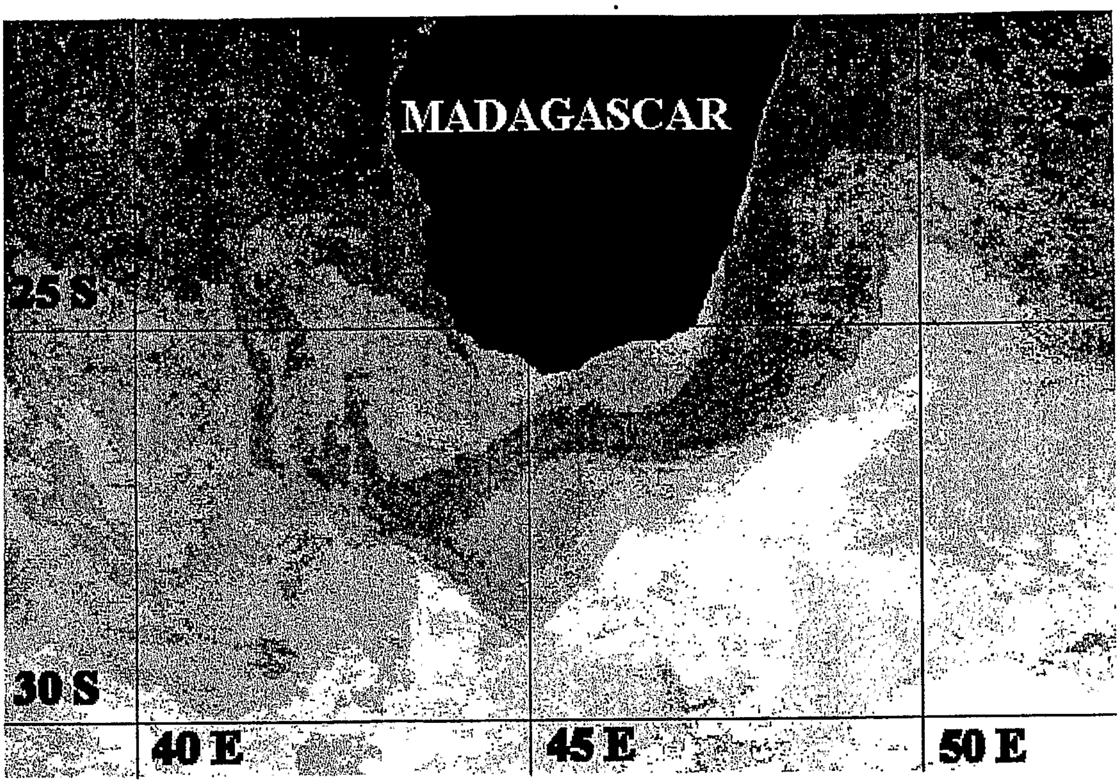

Figure 4 – A SST's chart zoom in the South of Madagascar shows some vortices which are enhanced by an fitted palette.
Avec une palette des couleurs adaptée, un agrandissement de la carte des températures de la mer dans le sud de Madagascar met bien en évidence les structures de vortex.

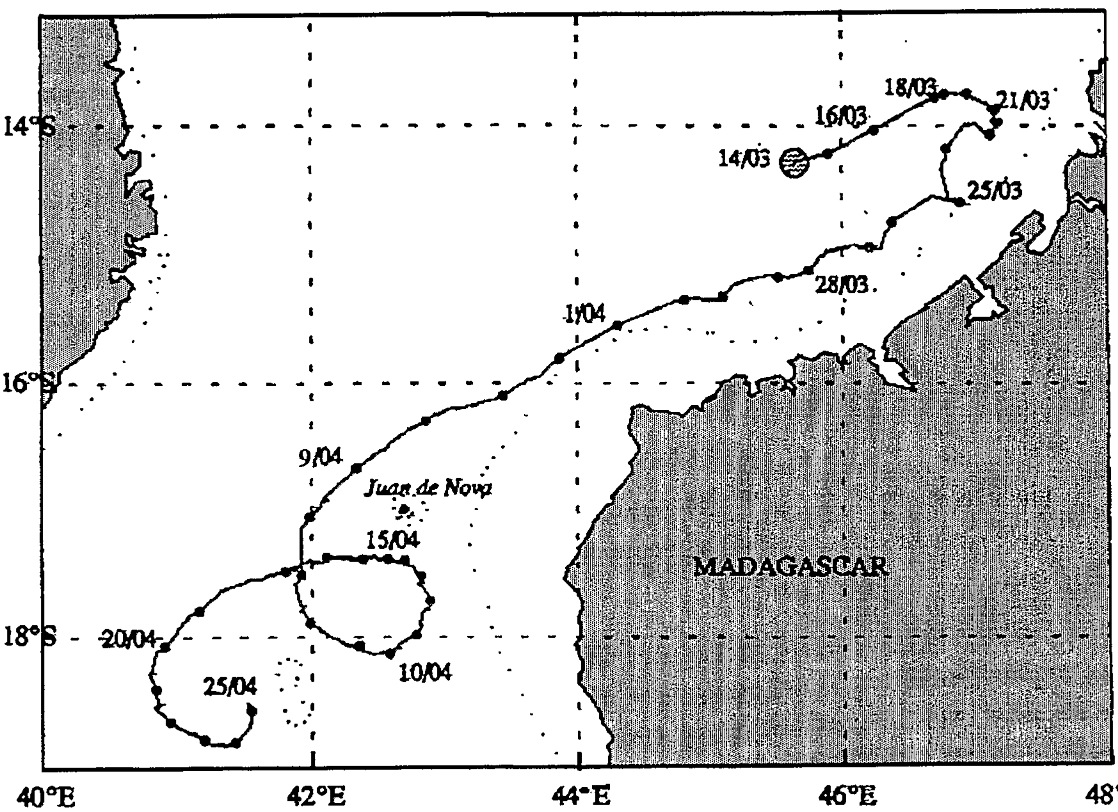

Figure 5 – The moving of ARGOS buoy which indicates surface currents and temperature confirms the mesoscale eddy structure of current in the Mozambique Channel (Buoy n° 6530, 14-25 April 1994 ; Marsac, pers. com.).
Déplacement d'une bouée ARGOS, indicatrice du courant et des températures de surface dans le canal du Mozambique confirme la structure tourbillonnaire du courant à mésoéchelle (Bouée n°6530, 14 au 25 avril 1994 ; Marsac, com. pers.).

The Artificial Life is a new A.I. field in gathering together ethologists and roboticians. They have been creating algorithms that allow artificial creatures to learn how to achieve goals, without any preprogrammed knowledge. We apply some of these tools – an artificial neural network managed by the genetic algorithm – to mimic tuna movements. Artificial neural network and genetic algorithm are probably the two tools the most common in A.I. (PARISI *et al.*, 1992). Neural network is often used to copy individual learning while genetic algorithm is a technique for optimizing following evolution concept. Tuna environment is described in a model which integrates the **alone** sea surface temperature. Through thermal sensors, the artificial adaptative tuna school learns by levels neural network to go from a departure geographic position at day D0 to arrival position at day DN. Then, we select the best network by genetic algorithm method. Our study area is the southwest Indian Ocean. We use daily sea surface temperature data processed from NOAA satellites data and daily French purse seine catches. In May, purse seiners leave the Mozambique Channel to go to Seychelles Islands. With a learning algorithm that responds to SST alone, we create artificial tuna schools able to pass from Mozambique Channel to Seychelles zone at the appropriate time.

The restricting hypothesis is that we make the catch set similar to school itself. Indeed, this model would be more realistic applied to tagging data or lengthy tracking data.

The results is shown on the **figure 8** (DAGORN, 1994): the algorithm has converged and the learning has been quick since soon the seventh generation the best network gave a final position around ten nautical miles from the arrival position. We noted that a classical analytical model based only on the detection of thermal gradient and absolute value of SST never gave the good final position and failed. Of course, even if we own a good artificial behaviour which allows to move artificial tuna school

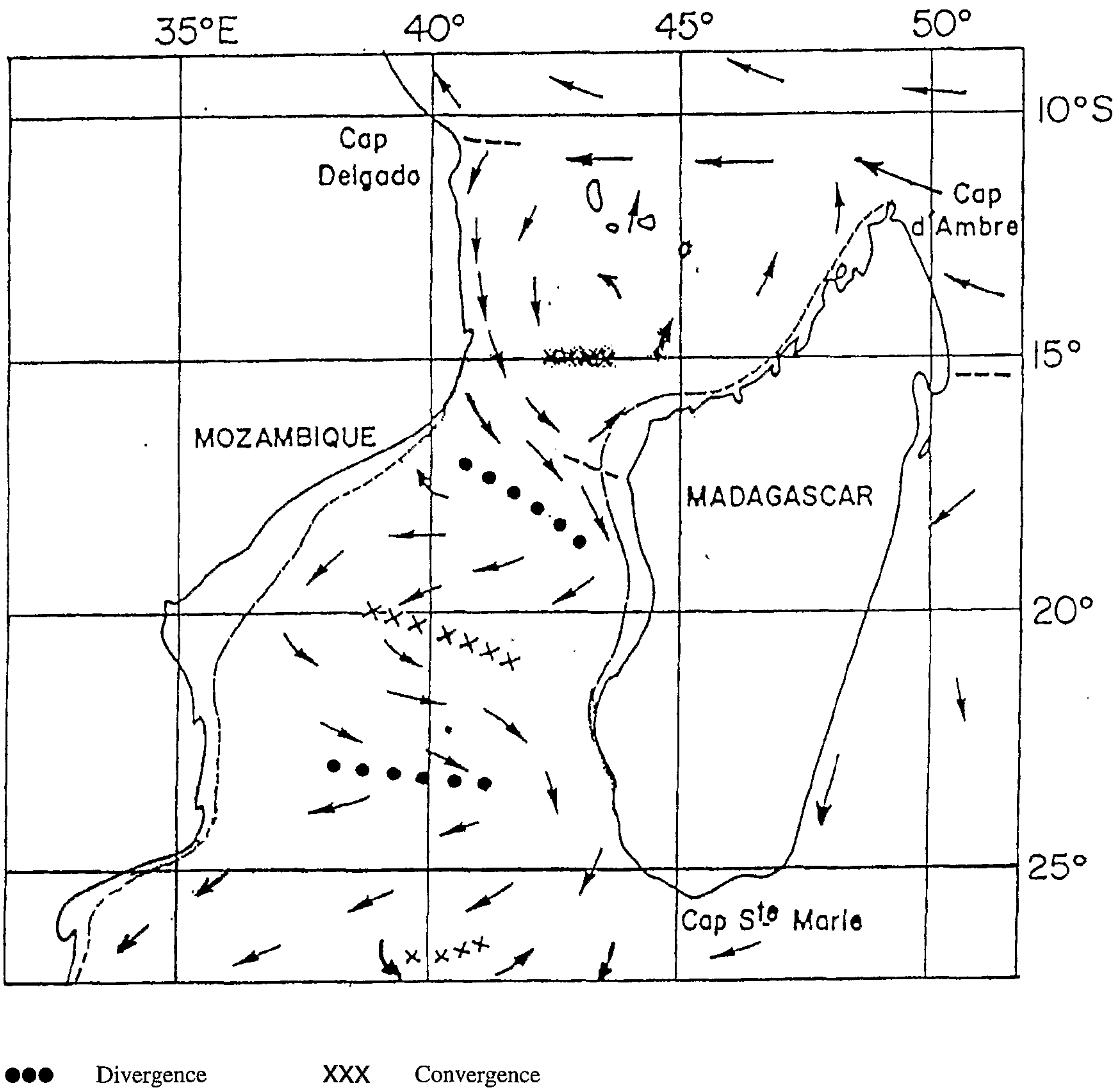

Figure 6 – Classical view of current in Mozambique Channel (from PITON, 1989 cited by MARSAC, 1992).
Description classique du courant dans le canal du Mozambique. D'après PITON, 1989 cité par MARSAC, 1992.

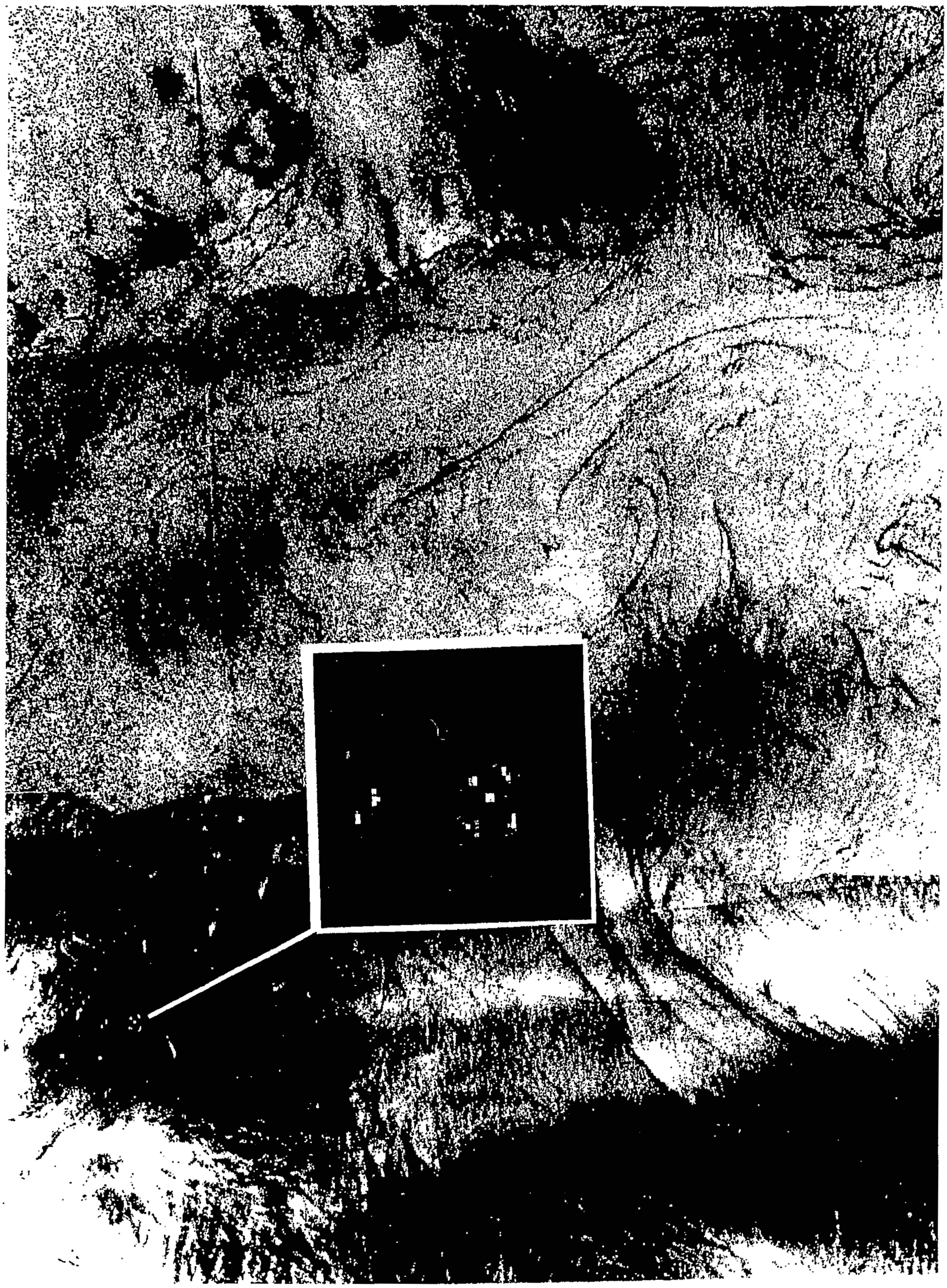

Figure 7 – This example of SAR/ERS-1 image in occidental Mediterranean sea shows the complexity of internal waves and vortices system. These data have been caught in July 1992 on the tuna French seiners (see boats in the zoom) area for the pilot project ESA/ORSTOM PPF-11.
Cet exemple d'image SAR/ERS-1 en Méditerranée occidentale met en évidence la complexité du système des vortex et des ondes internes. Ces données ont été acquises pour le projet pilote ESA/ORSTOM sur les lieux d'action de pêche des senneurs français.

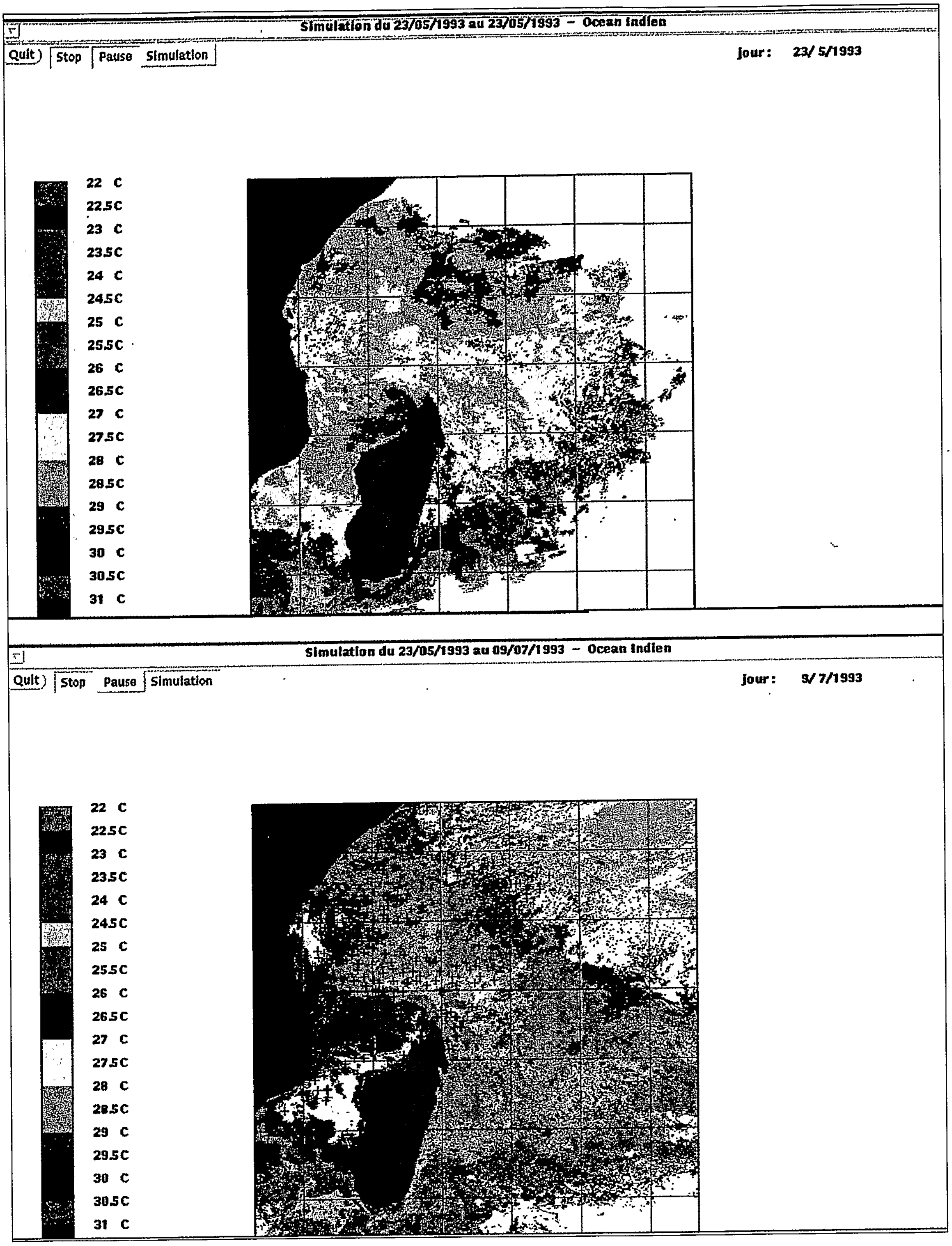

Figure 8 – Genetic algorithm chooses the best Neuronal Network which moves the artificial tuna on a track very close to reality. The artificial school is positioned in the North of Mozambique Channel at the end of May 1993. In July, each black crosses are potential positions for this artificial tuna school. A lot of them are near Seychelles Island. From DAGORN, 1994. (Display hard copy).

L'algorithme génétique a convergé et sélectionné un réseau de neurones qui donne un trajet du banc de thons artificiel conforme à la réalité. Ce banc est positionné fin mai 1993 au nord du canal du Mozambique. Sur la carte de juillet 1993, les croix noires indiquent les positions potentielles du banc, beaucoup d'entre elles sont près des Seychelles. D'après DAGORN, 1994. (Copies d'écran).

following true track, the rules of this behaviour are extremely difficult to interpret and the network corresponds more to a "black box" able to integrate the space and time SST's fronts effect on the school moving and gathering. This study prove that the SST's parameter can be sufficient to find the tuna moving if it is used dynamically in time and space. More available remote sensing data (sea colour from Seastar, winds from ERS-1, etc.) and accurate synchronous boat data would also improve the results of this kind of model.

In this order of thinking, in SEAS station, we conducted an experiment to get oceanic vorticity fields index using the wind module and direction data processed from ERS-1 scatterometer. It covers a period between January and July 1993. The aim of the processing was to get an algorithm of relative geostrophic component of vorticity as a new parameter for tuna fishing. The vertical vorticity of current is directly proportional to the normal geostrophic vorticity of the wind field near the ocean surface. Because of ERS-1 scatterometer cover, we have had to consider the week as time scale unit. So, it means that meso- and submeso-scale features of tuna environment stay filtered and masked. In spite of it, the preliminary results show that more than seventy five percents of total catches are into high vorticity zone (more than +1.5). At present time the hypothesis we are testing on a wide scale is that the high vorticity nucleus could generate thermocline pumping and, by this way, an "anomaly" (PETIT, 1991) able to gather tuna schools if they are present in the considered area.

2. Seamounts satellite inventory for fisheries in SEAS station

It is well known as well by fishermen as by scientists that fish school trend to gather near or upper seamounts zone even if the linked enrichment mechanisms are not really explained (KLIMLEY & BUTLER, 1988). In the framework of "Projet Thonier Régional, Phase 2", SEAS station team has had to do the inventory of seamounts in several part of West Indian Ocean by processing the altimetric data which were coming from SEASAT, ERS-1 and TOPEX/POSEIDON (BAUDRY *et al.*, 1994). In particular, for a zone in the South of 30°S, we were able to use the recently unclassified data of GEOSAT Geodesic Mission. The excellent geographical cover of these last data makes superfluous the using of the other satellite data and classical charts (**figure 9**) even on a zone where the morphology is complex. Twenty two seamounts have been detected in this area.

3. Where to next ?

In prospective, rather than in conclusion, we would want to note the experiments of exchange data we have with fishing boats, purse seiners and longliners. This two ways environmental data delivery is experimented through INMARSAT telecommunication system and with microcomputer inboard. The information collected by the fisherman is quite richer than a simple SST isolines classical chart, considering just only the potential of the colour animation of SST. Furthermore, with the electronic mail associated to this exchange, the information quantity will be increasing by exponential way.

On the other hand the in-situ marine biotic and abiotic observations of surface and sub-surface ocean conditions are essential for all the basis for ocean monitoring, not only for fisheries management but also for physical oceanography and climate change studies.

IV. CONCLUSION

As well for the physical as for the biological oceanography, fundamental concepts are changing and evolving: for example, the coupled Ocean-Atmosphere process begins to be considered under the Chaos angle (CHANG *et al.*, 1994; MCWILLIAMS *et al.*, 1994) and not only through analytical and predictive models; the artificial life is coming to understand interrelationship inside the fish schools ecology and their movements are not just considered as determinate migrations but as emergent functions of a complicated net of interactions.

For a part, all this changing in the way to outlook oceanic system come from the new vision brought by remote sensing performances and, vice versa, they need of remote sensing data to perform the new corresponding model. About that, applied sciences and Operational Fisheries Oceanography are not at all back and are ready to integrate the results of this quite accurate describing of oceanic landscape.

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REFERENCES

BARTON, 1989. — Comparison and optimisation of AVHRR Sea Surface Temperature Algorithms. — *Journal of atmospheric and oceanic technology*, **6**.

BAUDRY N., PETIT M., DAGORN L., 1994. — Halieutique et inventaire satellitaire des hauts-fonds. Océan Indien occidental. — Rapport scientifique du Projet thonier Régional Phase II, La Réunion 1994, 171 p.

BERNARDET X., 1994. — Logiciel d'animation d'images satellitaires NOAA. — station SEAS, ORSTOM BP 172, 97492 Ste Clotilde Cedex, France-Dom.

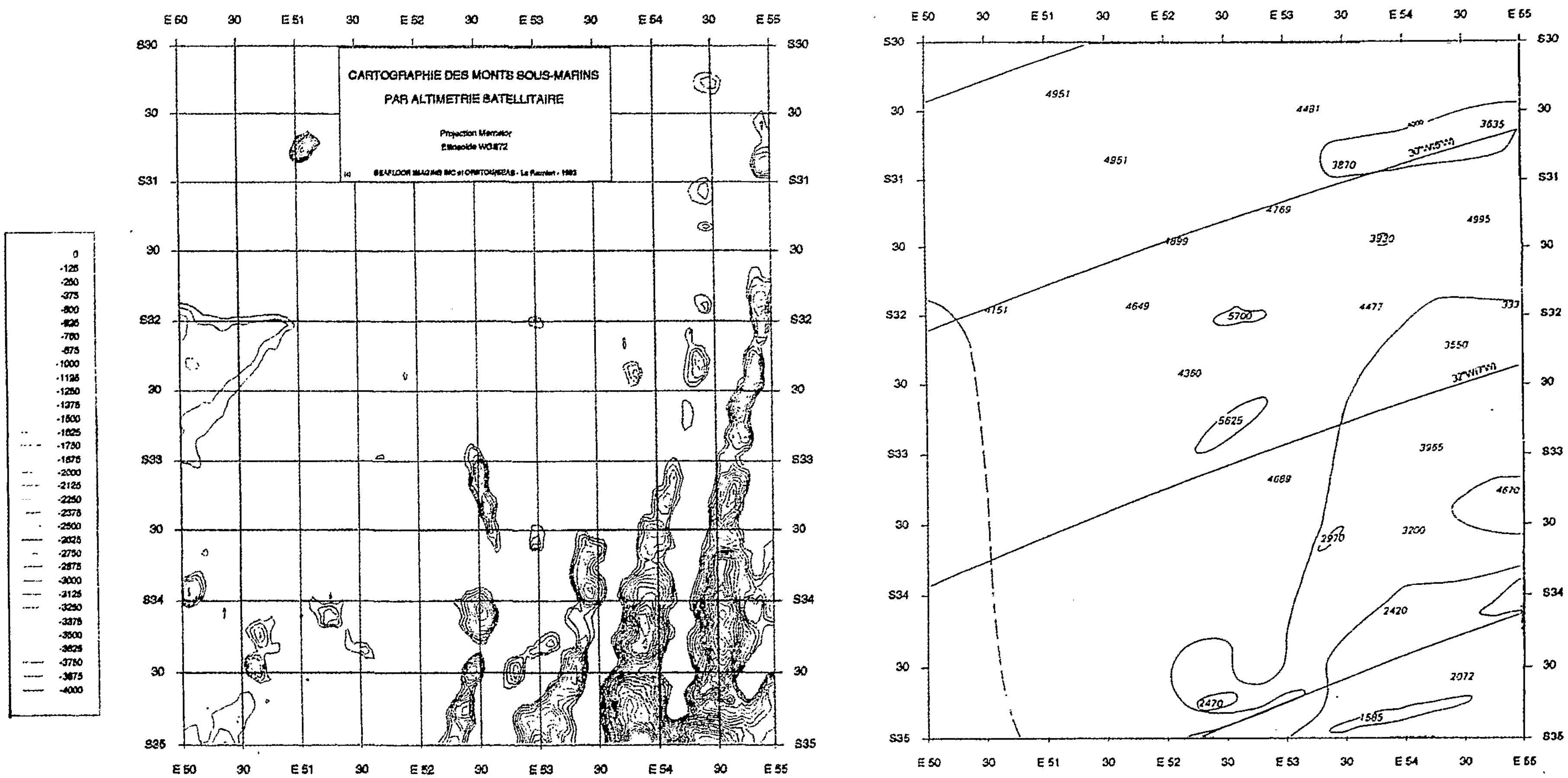

Figure 9 – Sea mounts inventory in the Indian Ocean South West from GEOSAT data (Geodesic mission). The right part of the figure is the chart from Service Hydrographique et Océanographique de la Marine (from BAUDRY *et al.*, 1994).
Inventaire des monts sous-marins dans l'océan Indien Sud-Ouest à partir des données GEOSAT – mission géodésique. La partie droite de la figure est la carte du SHOM. D'après BAUDRY *et al., 1994.*

CHANG P., WANG B. LI T., JI L., 1994. — Interactions between the seasonal cycles and ENSO. Frequency entrainment and Chaos in a coupled Ocean Atmosphere model. — *Nature*, in press.

DAGORN L., 1994. — Le comportement des thons tropicaux modélisé selon les principes de la Vie Artificielle. — Thèse de Doctorat, mention Halieutique, ENSAR, Rennes, 250 p.

FUSCO L., MUIRHEAD K. TOBISS G., 1989. — Earthnet's coordination scheme for AVHRR data. — *International Journal of Remote Sensing*, **10**, n° 4 and 5: 625-636.

KLIMLEY A.P., BUTLER S.B., 1988. — Immigration and emigration of a pelagic fish assemblage to seamounts in the gulf of California related to water mass movements using satellite imagery. — *Mar. Ecol. Prog. Ser.*, vol. **49**: 11-20.

LAEVASTU T., 1989. — Perspectives of services to fisheries: a review of the objectives and needs of fisheries analysis/forecasting. — Proceedings of International Symposium on operational fisheries oceanography, Newfounlands, Canada, october 23-27: 125-128.

LENA P., PETIT M., RAKOTO-RAVALONTSALAMA M., SLEPOUKHA M., 1993. — Significance of the Satellite Zenith Angles on AVHRR-Derived Sea Surface Temperature. — *In*: Some Marine Applications of Satellite and Airborne Remote Sensing, fourth computer-based learning module, Marinf/90, published by UNESCO (Paris).

MARSAC F., 1992. — Etudes des relations entre l'hydroclimat et la pêche thonière hauturière tropicale dans l'océan Indien occidental. — Thèse de doctorat de l'Université de Bretagne occidentale, Brest (France).

MOLINARI R.L., OLSON D., REVERDIN G., 1990. — Surface current distributions in the tropical ocean derived from compilations of surface buoy trajectories. — *Journal of Geophysic Research*, vol. **95**, C5: 7217-7238.

PARISI D., S. NOLFI and F. CECCONI, 1992. — Learning, behaviour, and evolution. — *In:* Toward a practice of autonomous systems. Proceedings of the first European conference on Artificial Life (Varela and Bourgine ed.): 207-216.

PETIT M. et A.WADSWORTH, 1990. — La télédétection aérospatiale comme l'un des déterminants du développement de l'halieutique opérationnelle. — *In:* Océanographie, halieutique et télédétection (M. Petit et J.M. Stretta eds.). *Bulletin de l'Institut océanographique, Monaco*, n° spécial **6**: 27-57.

PETIT M., 1991. — Contribution de la télédétection aérospatiale à l'élaboration des bases de l'halieutique opérationnelle : l'exemple des pêcheries thonières tropicales de surface (Aspect évaluatif). — Thèse de Doctorat, spécialité Océanologie biologique, Université Paris VI, 130 p. plus 5 annexes.

PITON B., 1989. — Quelques aspects nouveaux sur la circulation superficielle dans le canal du Mozambique (océan Indien). — *Cahier ORSTOM* (série océanographie), **14** (4) : 289-299.

RAMOS G.A., 1992. — Bioecologia del listado en aguas del archipiélago Canario : Modelo de gestion y explotacion mediante el uso de la teledeteccion. — Tesis doctoral presentada Universidad de Las Palmas de Gran Canaria, Departemendo de Biologia, 196 p.

SAUNDERS, 1988. — An Improved method for detecting clear sky and cloudy radiances from AVHRR data. — *Int. journal of remote sensing*, 1988, vol **9**, n° 1: 123-150.

STRETTA J.M., 1991. — Contribution de la télédétection aérospatiale à l'élaboration des bases de l'halieutique opérationnelle : l'exemple des pêcheries thonières tropicales de surface (aspect prédictif). — Thèse de Doctorat, spécialité Océanologie biologique, Université Paris VI, 145 p., annexes.

LE VOURCH J., MILLOT C., CASTAGNE N., LE BORGNE P., OLRY J.P., 1992. — Atlas des fronts thermiques en Mer Méditerranée d'après l'imagerie satellitaire. — *Mémoires de l'Institut océanographique, Monaco*, n°**16**,VI-152 p., 160 fig.n., 24 fig. coul.

MCWILLIAMS J.C., WEISS J.B., YAVNEH I., 1994. — Anisotropy and coherent vortex structures in planetary turbulence. — *Science*, vol. **264**, 15 April: 410-413.

ZÀVODY A.M., GORMAN M.R., LEE D.J., ECCLES D., MUTLOW C.T., LLEWELLYN-JONES D.T., 1994. — The ATSR data processing scheme developed for the EODC. — *International Journal Of Remote Sensing*, vol. **15**, n°4: 827-843.